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ORIGINAL ARTICLE

Price elasticity of the demand for water in the Brazilian states: a panel data analysis, 2011–2017

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Abstract
This study estimates the price elasticity of the demand for water using a panel data model for 5570 Brazilian municipalities in the period 2011–2017. Given the country's environmental and socioeconomic heterogeneity, regional demand elasticities are also estimated for each unit of the Federation. The results suggest demand for water is inelastic to the price. Since water is essential to life, it is reasonable to assume that the demand for water is relatively inelastic to the price level. However, for Brazil as a whole, the parameter associated to real tariff variations was significant at the 1%. The estimates effects also suggest that users tend, to some extent, to change water consumption levels. This may occur mainly, where consumption levels are relatively higher compared to the minimum required for survival. This relationship was significant in 25 of the 27 Brazilian states. It is concluded, therefore, that tariff policy could be an effective instrument in reducing water consumption.

Keywords Water management policies · Price elasticity · Water demand · Panel data

JEL Classification D12 · Q21 · Q01

Introduction

For decades, it has been known and widely disseminated that the planet's water resources are gradually depleting and that, in addition to the pollution of rivers and springs, irresponsible consumption with no sustainable basis in economic development is a relevant factor in reducing the availability of water. Concern regarding the scarcity of this resource has reached the most diverse segments of the social, political and economic spheres, as environmental problems have demanded greater consideration in all countries, whether developed or developing (Célia 2007).

An aggravating factor is the fact, that among the natural resources, water is very unequally distributed geographically, with abundance in some regions and great scarcity in others. It is an increasingly limited natural resource and, as such, has a recognized economic value. Its price measurement takes into account the cost of conservation, recovery and better distribution, the costs of monitoring quantity (as well as quality) of the water that is available to users, and the resources that should be allocated to other management actions (Albuquerque and Maia 2008).

In Brazil, for example, between 2014 and 2016, the capital of São Paulo state, the country's economic and financial center, experienced one of the most acute water crises in its history. That crisis occurred due to a series of climatic factors, with long periods of drought, which, combined with the lack of adequate planning, producing shortages that seriously affected the population (Neto 2016).

In the 1960s, the National Sanitation Plan (Planasa), which constituted the first attempt at establishing national basic sanitation standards (including for water supply) was introduced by the National Habitation Bank (Banco Nacional da Habitação—BNH). The BNH included the

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Sanitation Financial System (FSS) and was the body responsible for granting finance, and regulating the sector until the mid-1980s (Marques 2005). Based on this prevailing model, with Decree 82.587, which regulated Law No. 6528, dated May 11, 1978, clearer guidelines were established for charging basic sanitation services.

In 1997, Law No. 9433, which instituted the National Water Resources Policy (PNRH), stipulated that charging for the use of water resources has the following objectives: (1) to recognize water as an economic good and (2) to give the user an indication of its real value, (3) to encourage the rationalization of water use, and (4) to obtain financial resources to fund programs and interventions foreseen in plans for water resources (Article 19). Therefore, with the introduction of that mentioned law, one of the main objectives of charging for the use of water in Brazil was to stimulate responsible consumption and reducing the water wasting. Thus, this law brings a significant advance in terms of the guidelines for conducting tariff policy, namely, the use of water charges as a tool for managing demand.

In this perspective, on January 5, 2007, the Federal Basic Sanitation Law (LSB) No. 11,445 was created in Brazil, which established national guidelines for basic sanitation, which was regulated by Decree No. 7217 of June 21, 2010. In article 20 of this Law, which describes the economic and social aspects in the provision of services in the sector, Paragraph 1 establishes that the establishment of tariffs, public prices and fees for basic sanitation services must, together with several other guidelines, inhibit superfluous consumption and the waste of resources.

However, the effectiveness of using tariff policy as an instrument for managing water demand can depend on numerous factors that influence the relationship between the prices charged and the volume of water consumed, such as: (1) if (and how much) the level of consumption is above that which could be considered the minimum necessary for survival (which is a subjective measure, since it varies for each individual and due to the socioeconomic and environmental heterogeneity in Brazil itself); (2) the availability of water in a given region, given its unequal distribution in the national territory; (3) the weight of agriculture and some segments of industry (for example, food and beverages) in the local economy, since they are sectors that use water widely as an input in the production process, and can be more sensitive to prices; among other aspects.

In other words, the analysis of the efficiency and effectiveness of the tariff policy as an instrument for the management of water consumption depends mainly on the price elasticity of demand for this good, that is, on how sensitive its consumption is, given its price variation (Varian 1990). Being an essential resource, the demand for water is expected to be relatively inelastic to price. However, that relationship may not be perfectly inelastic (price elasticity equal to zero). The analysis of the sensitivity of water consumption in relation to its price is fundamental in guiding public policies that aim to encourage the rational use of this essential good, especially against a background of scarcity of water resources, as is the case in several Brazilian states, particularly in the Northeast region of the country.

Furthermore, serving as an instrument for the internal management of the providers' pricing policy, the analysis of the significance and magnitude of this relationship is central to the decision-making process regarding the conduct of the tariff policy itself, since according to Decree No. 7217, Article 27, item IV, the prices charged must consider the tariff modality, but, at the same time, ensure the economic–financial balance of the companies, to guarantee universal access of the population to basic sanitation services.

Empirically, in regional terms, in the early 1970s, Wong (1972) sought to analyze the relationship between tariff policy and water consumption in the municipalities in Northeastern Illinois. As a main conclusion, the study found municipal price elasticities of demand for water that ranged from − 0.02 to − 0.82, with statistically significant results in most municipalities. Adopting a similar approach, Young (1973) tested the significance of the relationship between demand and water tariffs in the case of Tucson, Southwest Arizona, and estimated the price elasticity of water consumption to be − 0.42. Foster and Beattie (1979), studied this same relation regarding consumption in predominantly urban municipalities of the USA, and reported estimates that reached between − 0.30 and − 0.69. Schneider and Whitlach (1991), adopting the same approach, but focusing specifically on residential water consumption, estimated this parameter to be in the range of − 0.26 for the municipality of Columbus, Ohio.

In Brazil, of the few studies that have adopted this approach, the majority have estimated the price elasticity of demand for a specific region, which may, due to various factors, present significant differences. For example, Rosa et al. (2006) estimate this parameter for the case of the State of Ceará. The authors, using cross-sectional data for the municipalities in the State, estimate a negative coefficient of − 0.355, considering urban residential water consumption. On the other hand, Amaral (2000), based on a time-series model, concludes that the water consumption in Piracicaba can be explained mainly by past consumption, observing components of persistence and seasonality of the variable over time. Another point to be considered is that the present study uses a panel data model, which as yet has been rarely explored for this topic in the Brazil.

In summary, the present study seeks to investigate the relationship between the water supply tariff policy in Brazil and the behavior of the demand for water, by estimating how sensitive consumption has been as a function of variations in the price level. That is, we propose to measure the

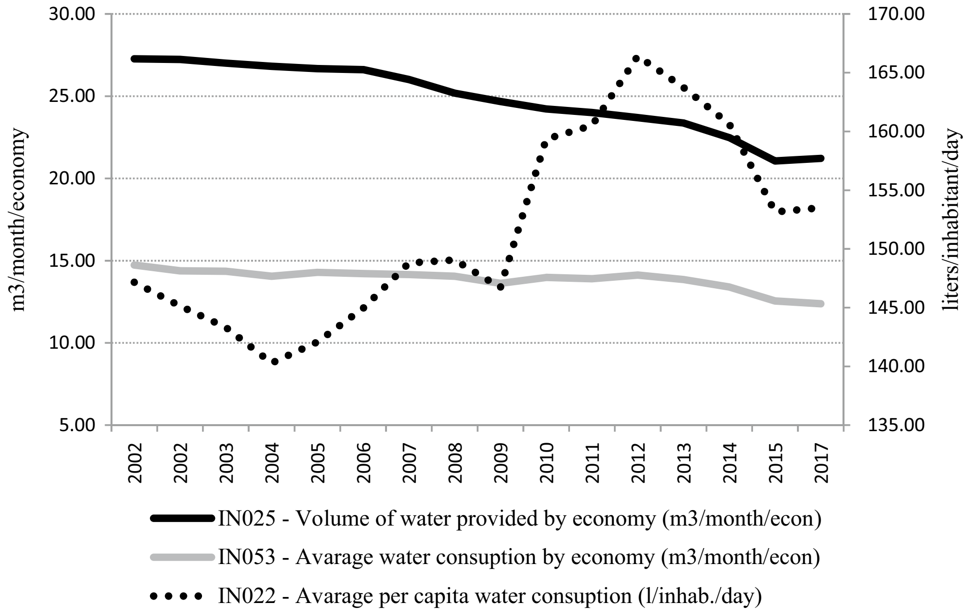

Fig. 1 Water consumption and availability indicators in Brazil—2002–2017 Source: National Sanitation Information System (SNIS)

price elasticity of the demand for water in Brazil. In addition, given the heterogeneity of the country's regions with regards to several factors that influence this relationship, we seek to estimate the regional elasticities of water demand in the Brazilian states. For this purpose, the National Sanitation Information System (SNIS) database for all municipalities and states in the period 2011–2017 is used. Estimates are then made based on a model using panel data.

This paper is divided in three sections. The first section seeks to analyze some characteristics of water consumption in the states, capitals and other Brazilian municipalities. In the second section, the methodology and specification of the variables to be estimated in the panel data model are presented. The main results of the parameters estimated in Brazil and by federal unit are shown in the third section. At the end, some final remarks are offered.

Characterization of the demand for water in the national territory

Compared to developed countries, Brazil as a whole has always been characterized by the abundance of natural resources. However, over the years, the unsustainable growth of economic activities involving production technologies that failed to anticipate the optimization of water consumption and the minimization of the emission of potential pollutants. The population growth in the Brazilian state capitals without a corresponding reduction in per capita consumption based on responsible consumption (on the contrary, according to SNIS data from 2002 to 2017, there was a significant increase in the volume consumed per inhabitant in several regions of the country over the years); the expansion of civil construction, accelerating the number of occupied homes and the urbanization process itself, especially in the context of reduced interest rates and expanding credit. These, among other factors, have contributed to reducing water availability and quality throughout the country, including the large capitals.

Analyzing the evolution of supply, measured by the average volume of water produced by the economy, and the demand, measured by the volume of water consumed per economy (residence) and per inhabitant in Brazil (Fig. 1), it is seen that, in fact, the volume of water (m^3/month/economy) has registered successive declines over the years 2002–2017, more precisely − 22.2% over the whole period. These decreases have been accompanied, although to a lesser extent, by the demand behavior, with a decrease of − 15.9% in the average volume consumed by the economy in the same years. By contrast, analysis of the demand trend for average per capita water consumption shows an increase of 13.1% up to 2012, compared to the base year of 2001, although this has stabilized in recent years. However, over the 16-year period contemplated in this study, the registered growth is 4.3%.

The behavior of water consumption was heterogeneous throughout the Brazilian states. Comparing the per capita consumption in 2017 that of 2002 per Federal unit (Fig. 2), the most worrying fact is that those regions predominantly characterized by the scarcity of water resources, in the cases of North and Northeast states, were those that showed the highest rates of consumption growth (such as the states of Pará, Acre, Piauí, Amazonas and Rondônia). The exceptions to these cases were Alagoas, with a significant drop in demand of − 18.5%, and Rio Grande do Norte, which maintained practically the same level of consumption in the

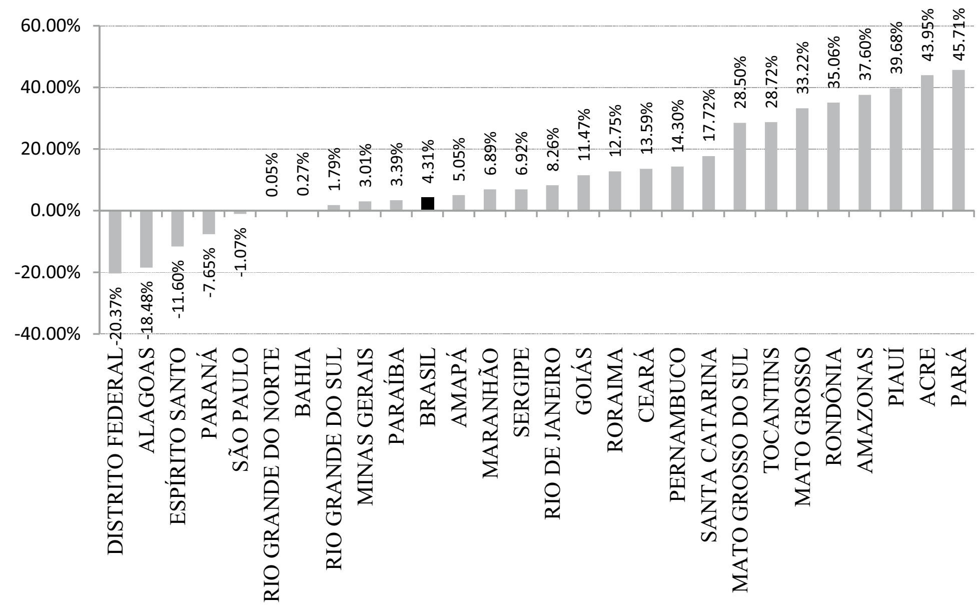

Fig. 2 Variation in average per capita water consumption in the Brazilian States (%) 2002/2017 Source: National Sanitation Information System (SNIS)

period under analysis. On the other hand, in states such as the Distrito Federal, Espírito Santo, Paraná and São Paulo, the shift was in the opposite direction, with decreases of − 20.4%, − 11.6%, − 7.7% and − 1.1%, respectively. In the latter case, the decline was less expressive, but fundamental, since the Metropolitan Region of São Paulo experienced one of the biggest water crises in its recent history, beginning in 2014, combined with the planning deficit, which led to a drastic reduction in the Cantareira System, a reservoir managed by the São Paulo State Basic Sanitation Company (SABESP) which is responsible for supplying water to approximately 8.8 million people. In addition, other states such as Bahia, Rio Grande do Sul and Minas Gerais showed a slight growth in per capita consumption, although still below the national average.

Analyzing other indicators from the NHIS ("Appendix 1: Indicators selected from the SNIS by Federal Unit-2017"), it can be seen that in the majority of the states with the highest growth in water demand, the hydrometric index (the number of micro-measured water connections in relation to the total active connections) was relatively low in 2017. The lowest are from Pará, Acre and Amazonas, with rates of 35.5%, 63.1% and 67.4%, respectively. While in relation to the volume of water made available (volume of micro-measured water compared to the volume of water produced), the indicators of these states were even worse: 17.4%, 29.3% and 19.1%. By contrast opposition, in the Federal units, where demand decreased substantially, such as the Federal District, Alagoas, Espírito Santo, Paraná and São Paulo, the hydrometric indexes were over 88%.

In 2017, the states with the highest per capita water consumption were Rio de Janeiro, Amapá and Rondônia, with averages that exceeded 170 l per inhabitant per day. Although São Paulo had recorded a drop over the years, average consumption was still above the national average, namely 164.9 against 153.5 l/inhabitant/day. This was aggravated by the fact that in the same year São Paulo was the Federal unit with the lowest available water volume per economy, with 23.8 cubic meters per month per economy, thus having the highest consumption rate compared to the volume of water available, at 52.3%. An attenuating factor in the case of São Paulo was the level of losses of distributed water, which were below the Brazilian average (volume of water consumed in relation to that available). On the other hand, states such as Rio Grande do Sul, Santa Catarina, Pará, Goiás, among others, had per capita consumption below the national average. Pernambuco was the state with the lowest average: 91.1 l/inhabitant/day ("Appendix 1: Indicators selected from the SNIS by Federal Unit-2017"). In addition, in 2017, the states with the lowest rates of distributed water loss were Tocantins, Goiás, Rio de Janeiro, Mato Grosso do Sul and Santa Catarina.

Hence, another aspect to consider regarding the Northern and, to a greater extent, Northeastern regions is that, even with the considerable growth in demand in some states, on average, per capita consumption in the recent period fell far short of that in other Brazilian states, highlighting the scarcity of water resources, which was even lower in 2001. Specifically, the average per capita consumption in these regions was 133.54 l/inhabitant/day in 2017, while in the Central-West, South and South-East regions the average was approximately 160.72 l/inhabitant/day (a difference of 20.35%, comparing the latter with the former).

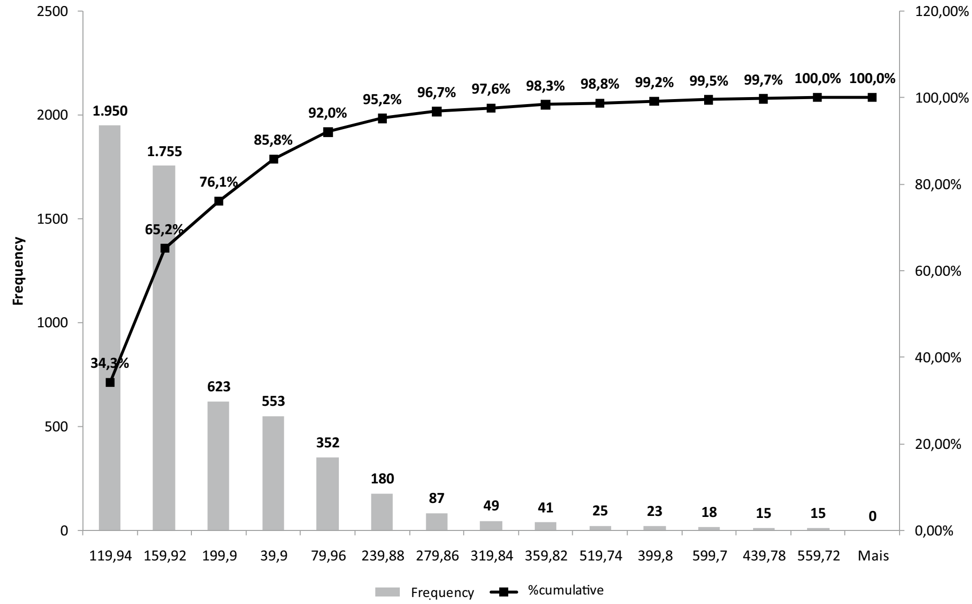

Fig. 3 Histogram of per capita water consumption in Brazilian municipalities—2017 Source: National Sanitation Information System (SNIS)

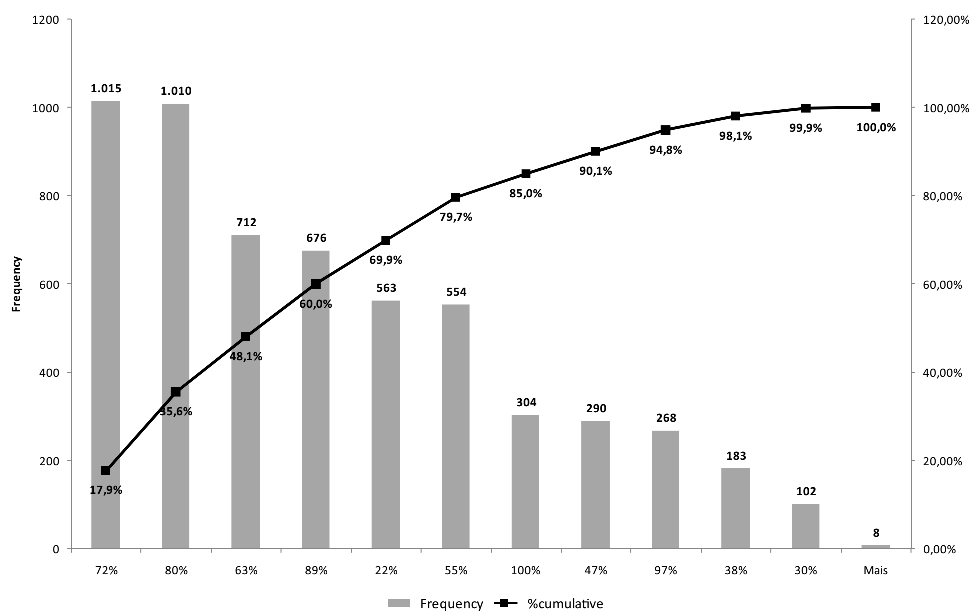

Fig. 4 Histogram of consumption in relation to the availability of treated water in Brazilian municipalities—2017 Source: National Sanitation Information System (SNIS)

Among the Brazilian state capitals, of particular note are the average per capita consumption rates estimated in 2017 in Rio de Janeiro, Porto Alegre, Palmas, Vitória, Macapá, Florianópolis and Cuiabá, which are substantially above the national average (Annex 2). However, most of these cities are among the capitals with the lowest rates of losses of distributed water (for example, Porto Alegre had a 25% loss, compared to an average of 38.2% in Brazil). In the municipalities of Maceió, Boa Vista, Recife, Belém, São Luiz and Salvador, the consumption behavior was significantly below the national average. In this regard, the capital of São Paulo registered consumption almost identical to per capita consumption in Brazil.

As can be seen in Fig. 3, in general terms, the highest concentrations of Brazilian municipalities presented per capita water consumption between 79.9 and 119.9 l/inhabitant/day (1950 municipalities, corresponding to 34.3% of cities), and between 120 and 159.9 l/inhabitant/day (1755 municipalities, accumulating, in these two bands, 65.2% of all cities). Compared to the volume of water available, the consumption of Brazilian municipalities in relation to the supply of treated water tended to be less concentrated (Fig. 4). In this case, 1015 cities (approximately 17.8% of the total) had consumption between 63.1% and 72% of the total volume of water available and 1010 (35.6% of the total) municipalities registered a percentage between 72.1 and 80%.

Table 1 Sources used in the model Source: Elaborated by the authors

Data	Source	Available at	Accessed on
D_A	National Sanitation Information System (SNIS)	http://www.snis.gov.br/aplicacao-web-serie-historica	18/12/2018
P	National Sanitation Information System (SNIS)	http://www.snis.gov.br/aplicacao-web-serie-historica	18/12/2018
DOM(*)	IBGE/PNAD (National Household Sample Survey)	https://www.ibge.gov.br/estatisticas-novoportal/downloads-estatisticas.html	18/12/2018
POP	IBGE/Demographic census (2010) and Population estimates	https://www.ibge.gov.br/estatisticas-novoportal/downloads-estatisticas.html	18/12/2018
T	Ministry of Agriculture, Livestock and Food Supply/ Meteorological Database for Teaching and Research (BDMEP)	http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep	23/12/2018
IND	IBGE/System of National Accounts	http://downloads.ibge.gov.br/downloads_estatisticas.htmPIB	23/12/2018
AGRO	IBGE/System of National Accounts	http://downloads.ibge.gov.br/downloads_estatisticas.htmPIB	23/12/2018
ESC1, ESC2 e ESC3	IBGE/Demographic census (2010) and Population estimates; and Ministry of Labor and Employment/RAIS	https://www.ibge.gov.br/estatisticas-novoportal/downloads-estatisticas.html http://www.rais.gov.br/sitio/index.jsf	23/12/2018
REM	IBGE/System of National Accounts	http://downloads.ibge.gov.br/downloads_estatisticas.htmPIB	23/12/2018
Deflator	IBGE/Consumer Price Index (IPCA).	https://www.ibge.gov.br/estatisticas-novoportal/downloads-estatisticas.html	18/12/2018

(*) In relation to the number of households, the PNAD only provides data for Brazil's Metropolitan Regions. To complement the information, the number of active economies with water supply was used as a proxy variable. Since the providers report all the forms of supply (not only those via distribution networks) to the SNIS, the correlation between the number of households and these economies tends to be high

Methodology

Given the vital importance of water and the increasing global concern about the availability of water resources, several studies have sought to study the empirical relationship between prices and demand for water.

Worthington and Hoffman (2008) compiled these empirical studies applied in the previous 25 years by various researchers in the United States of America (USA). The authors concluded the variables used in the models were mostly related to prices and tariff structure, income levels, climatic and environmental conditions that determined seasonal components of consumption, population growth and the number of households, levels of education and other non-monetary variables that impact the cultural patterns of demand. In general, the studies concluded that the price elasticity of demand in the USA as a whole has been estimated with negative coefficients around 0.5, that is, tariff increases of 1% may have led to falls in consumption of around 0.5%.

These and other similar studies highlight the importance of studying this relationship, due to the regional heterogeneity of the estimated results. Despite the evidence of being an inelastic relationship, in the vast majority of cases it is different from zero, resulting in another instrument for policies to encourage responsible consumption.

Therefore, theoretically, and as some studies have proven, it is expected that the increase in price can generate a decrease in water consumption. In relation to the other variables, it is expected that population growth and the number of households will tend to generate an increase in water consumption, as well as increases in the average temperature. As a significant part of the demand for water is due to agriculture and some segments of the industry (mainly beverages), water consumption can also be directly related to these variables. In addition, given the educational awareness, the higher the level of education of individuals, it is expected that less water consumption tends to be, and a similar relationship can occur with respect to income levels (Worthington and Hoffman 2008).

In this paper, we propose applying a panel data model with these variables in which all the Brazilian municipalities with information declared in the SNIS are observed during the period 2011–2017. Specifically, panel data models combine time-series and cross-sectional data, with the advantage, in general, of a large number of degrees of freedom when estimating parameters (Gujarati 2006). The data sources are presented in Table 1.

Among the most widely used panel data models are the seemingly unrelated regressions (SUR) model, the fixed effects model and the random effects model (Asteriou and Hall 2007). The SUR model assumes the intercept and response parameters to be estimated differ between individuals, but are constant over time, which, therefore, constitutes a limitation. When the number of individuals is very large, the number of parameters to be estimated will also be large, restricting the degrees of freedom when estimating the parameters and may lead the model in question to produce unreliable estimates (Asteriou and Hall 2007).

The Fixed Effects Model seeks to control the effects of omitted variables that vary among individuals and remain constant over time. Thus, it assumes the intercept varies from one individual to another, but it is constant over time, whereas the response parameters to be estimated are constant for all individuals and at all time periods (Hill et al. 1999). It is the best option for modeling panel data when the intercept is correlated with the explanatory variables, regardless of the time period (Wooldridge 2002).

The of random effects model (variables) makes the same assumptions as the fixed effects model. However, the difference between the two models lies in the treatment of the intercept. While the fixed effect model treats the intercept as fixed parameters, the Random Effects Model treats the intercept as random variables (considering the unobserved effect of the differentiation). That is, it considers the individuals on whom data are available are random samples from a larger population of individuals (Hill et al. 1999).

According to Wooldridge (2002) and Asteriou and Hall (2007), the main determinant for choosing the model to be used is the unobserved effect the differentiation of the intercept among the individuals. When it is not correlated with the explanatory variables, the Random Effects Model is the most appropriate. By contrast, when it is correlated with some explanatory variables, the fixed effects model should be used. To test any such correlation, according to the authors, the Hausman Test should be used. In the present study, the results of that test pointed to the fixed effects model ("Appendix 3: Hausman Test"). Therefore, based on studies like Worthington and Hoffman (2008), the equation to be estimated was defined as

Table 2 Result of the estimated model (dependent variable or explained = D_A) Source: Research results

Variables	Coefficient	Standard error	*T* ratio	*P* value
Constant	− 1.7095	0.0497	− 34.4221	0.0000
P	**− 0.2768**	**0.0097**	**− 28.4388**	**0.0000**
DOM	0.7652	0.0024	318.2625	0.0000
POP	0.0189	0.0068	2.7694	0.0056
T	0.0085	0.0011	7.7369	0.0000
IND	0.0358	0.0039	9.0779	0.0000
AGRO	0.0353	0.0068	5.2056	0.0000
ESC1	0.0486	0.0056	8.6516	0.0000
ESC2	− 0.0082	0.0043	− 1.9085	0.0564
ESC3	− 0.0124	0.0046	− 2.6786	0.0074
REM	0.0550	0.0044	12.4877	0.0000
F-statistic				94.5550
P value				0.0000
R-squared				0.7332
Durbin–Watson				1.9410

The results for the Hausman test, at 1% level of significance, indicated that the random effects model estimators are not consistent, thus the fixed effects method was chosen

Bold values indicate the main results of interest

$$\ln(D_{Ait}) = C_i + \beta_1 \ln(P_{it}) + \beta_2 \ln(\mathrm{DOM}_{it}) + \beta_3 \ln(\mathrm{POP}_{it}) + \beta_4 \ln(T_{it}) + \ln(\mathrm{IND}_{it}) + \beta_5 \ln(\mathrm{AGRO}_{it}) + \beta_6 \ln(\mathrm{ESC1}_{it}) + \beta_7 \ln(\mathrm{ESC2}_{it}) + \beta_8 \ln(\mathrm{ESC3}_{it}) + \beta_9 \ln(\mathrm{REM}_{it}) + \mu_{it}$$

where D_A = volume of water consumed, in cubic meters; C = estimated coefficient of intercept (or constant) for the municipalities; P = average water tariff charged by the service providers, in Reais per cubic meter billed, at constant prices from 2017 (using the IPCA)[1]; DOM = number of households; POP = population growth rate; T = annual mean temperature; IND = real growth rates of production of industrial sectors[2]; AGRO = real growth rates of production in the agricultural sector[3]; ESC_1 = Proportion of economically active population, measured from formal employment, classified as illiterate; ESC_2 = Proportion of the EAP, as measured by formal employment, which completed the primary education; ESC_3 = Proportion of the EAP with at least incomplete secondary education; REM = Municipal GDP Per Capita, at constant prices from 2017 (using the IPCA); μ = random error term that captures the influence of other variables not specified in the model; ln = natural logarithm[4]; i and t = indicate that the observations refer to municipality "i"(cross section) and period "t" (annual temporal section). As a main result, the estimated coefficient β_1 will give the direction (direct relation, positive case, or inverse, negative

[1] The IPCA is the index of water tariffs most used by the 30 largest providers of this service in Brazil.

[2] This variable was chosen because a significant proportion of water is consumed by the industrial sector.

[3] In several predominantly rural municipalities in Brazil, water consumption is mainly determined by the pace of expansion of agricultural activities.

[4] In this functional specification, the variance of the data is minimized and the coefficients can be interpreted as relations of percentage variations (that is, elasticities).

case, and, as expected, the increase in the price of a normal good tends to reduce its consumption) and the magnitude of effects of price variations on percentage changes in demand for service.

Results

Table 2 shows the results of the estimated model. We used 38,968 observations to estimate the parameters. The R-squared value indicates about 73% of the variability of the demand for water can be explained by combining variations of the indicators used, which empirically represents the specified model has high explanatory power. The *F*-statistic indicates the joint significance of the variables. The Durbin–Watson statistic is close to 2, which indicates the lack of autocorrelation of the residues.

However, the model showed evidence of heteroscedasticity (non-constant variance and non-normality of residuals), so that the variance of the residues was not constant in relation to consumption levels. In this case, although not biased, the estimators will not be the most efficient under the ordinary least squares (OLS) method and, in general, the inference can be impaired, since the tests of significance of the parameters tend to have values smaller or equal to the estimates under homoscedasticity. Hence, the estimators cease to be BLUE (Best Linear Unbiased Estimator), and the results for the significance tests become inaccurate. Therefore, heteroscedasticity does not destroy the non-biased properties and consistency of the OLS estimators, but rather they become inefficient (Gujarati 2006). The model was estimated with the White correction for robust standard errors. As the cross section is relatively larger than the time units, unit root tests have concluded for the stationarity of the series ("Appendix 4: Unit root tests").

As a result, it can be noted that all the estimated parameters were significant, most at the 1% level of significance (Table 2). In summary, it can be inferred that, for every 1% change in the number of households and population growth, demand for water was related to increases of 0.76% and 0.02%, respectively. Water consumption was also influenced by the average temperature of the municipalities. Also, the greater the weight of agriculture and industry in local productive structures, the greater the demand tends to be. Consumption behavior was also associated with the educational level of the economically active population (EAP), thus, it was possible to infer that lower consumption was related to higher education levels. More precisely, on average, it is estimated that, when the proportion of users with a lower level of education (illiterate) increases by 1%, consumption tends to increase by 0.05%. Whereas, when the relative weight of consumers with complete primary and incomplete secondary education increases by 1%, the volumes consumed tend to decrease by 0.01% and 0.012%, respectively. Demand was also directly related to income level, as with the behavior of a normal good. When real income (as measured by per capita GDP at constant prices of 2017—IPCA) is raised 1%, consumption may increase by 0.05%.

As a main conclusion, the estimated parameter β_1 of P was significant and, as expected, inversely related to the volume of water consumed. More precisely, the estimated model suggests that in Brazil, with every 1% real increase in the average water tariff, demand tends to fall by 0.28%, at a 1% level of significance. It should be emphasized that, as is well known, water is an essential commodity/good, without perfect substitutes and, thus, the expectation was that the estimated parameter would be smaller than the unit. However, despite the relation between consumption and prices being inelastic, it can be inferred that the tariff policy of the sanitation sector is effective to some degree as an instrument for managing demand, especially in the context of water crisis. For example, on average, a 10% increase in the tariffs charged may lead to reductions in the level of consumption of around 2.77%, all else being constant. A fall in demand of this ratio might be an important tool for momentarily attenuating a water crisis.[5]

In addition, according to the conclusions of the studies mentioned in Sect. 3, this effect can vary significantly among localities. Thus, given the heterogeneity of the environmental and socioeconomic conditions in Brazil, this model was estimated and replicated for each state in the same period, with data from the municipalities within each Federal unit. Figure 5 shows the estimated parameters for the price elasticity of demand for each state. It can be seen that the effects of tariff policy have been heterogeneous in the different regions of the country, varying from − 0.44 in the case of the state of Tocantins to − 0.0003 in Roraima, where the coefficient was found not to be significant. In summary, the parameters estimated in 21 Federal units were significant even at 1% level of significance; in 3 states they were significant at the 5% level; and in the Federal District and Roraima alone, the results indicate price policy as a tool for managing demand tends to be innocuous (it should be remembered that the former presented the biggest fall in per capita water consumption during the 2000s, as shown in Chart 2, in addition per capita consumption below the national average in 2017).

Roughly speaking, with some exceptions, it can be seen that, in those states with consumption higher than the

[5] Due to the crisis in the state of São Paulo in 2015, SABESP adopted an emergency measure to increase rates by 15.24%. This measure was supported by the regulator, ARSESP. Considering the period under study, in the 2 years prior to the increase, the average per capita consumption for the capital of São Paulo stood at 13.34 l/inhabitant/day, while, with the rationing policies, together with the real increase in tariffs, consumption dropped to 11.29 l/inhabitant/day in 2017, corresponding to a decrease of 13.9% (SNIS 2010–2017).

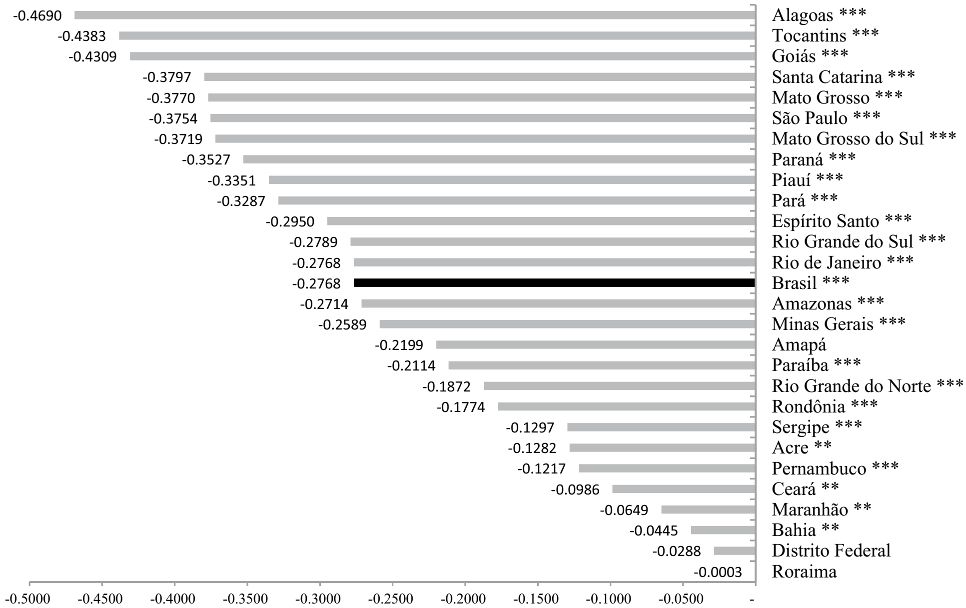

Fig. 5 Estimates of the regional price elasticity of water demand in the Brazilian states Source: Research results

national average, the estimated parameters were also higher than those in Brazil as a whole. In other words, the higher the level of consumption, the higher the price elasticity of demand for water, indicating that users can adapt and change consumption behavior significantly. And the reverse occurred in those regions, where consumption, as well as the availability of water, already tends to be lower.

Therefore, the results from the model indicated greater efficiency, considering the highest estimated impacts, in the states of Tocantins, Goiás, Santa Catarina, Mato Grosso, São Paulo, Mato Grosso do Sul,Paraná, Piauí, Pará, Espírito Santo, Rio Grande do Sul and Rio de Janeiro. In these cases, the estimated parameter was higher than that found for Brazil. These parameters indicate that the tariff policy can, in fact, be an effective instrument for the management of consumption levels.

By contrast, in the states of the North and, mainly, Northeast, where there is historical evidence of scarcity of water resources and consumption indicators were lower than in the other regions of Brazil the results from the model show the demand for water tends to be even more inelastic in relation to prices. Nevertheless, given the environmental specificities of these regions, namely scarce supply and demand pressure due to elevated temperatures, the model showed the elasticities range from coefficients very close to those estimated for Brazil (for example, − 2.27% in the case of Amazonas), to smaller but significant parameters of − 0.045% (in Bahia). Thus, it can be inferred that, although less efficiently, tariff policy tends to have significant effects on consumption, and is, therefore, fundamental in this context.

Last but not least, from the point of view of the economic–financial balance of basic sanitation providers, it is important to point out that in Brazil and especially in the federal units whose results indicate greater sensitivity regarding the relation studied here: when price increases are used to raise investments, it should be taken into account that not all tariff increases are converted into higher revenues from services, since demand tends to be more elastic (or less inelastic) at the level of prices, and users change their consumption behavior.

Final remarks

Managing the demand for water resources is increasingly important in both developing and developed countries. In mid-2014, the state of São Paulo experienced one of the biggest water crises in its history. This event alerted the Brazilian authorities to the importance of planning and of using demand management instruments in situations of water scarcity.

Any analysis of the effectiveness of tariff policy as an instrument of demand management depends, mainly, on the price elasticity of the demand for water, that is, on the variation of consumption given a variation in prices. Since water is essential resource, it is reasonable to assume that the demand for water is relatively inelastic to the price level. However, such a relationship may not be perfectly inelastic (price elasticity equal to zero).

In fact, the results of the panel data models estimated for all the Brazilian municipalities in the period 2011–2017, with data from the SNIS, indicated that real variations in the tariffs charged may have significantly influenced water consumption levels, despite it being inelastic in relation to prices. Specifically, in Brazil, with every 1% of real increase in the average water tariff, demand tends to fall by 0.28%, at a 1% level of significance.

These effects were heterogeneous in the Brazilian states, and of the 27 Federal units, it can be inferred that, in only two, the effects of price policies on the demand for water tend to be innocuous. However, some states presented greater sensitivity of water consumption in relation to the price level, namely: Tocantins, Goiás, Santa Catarina, Mato Grosso, São Paulo, Mato Grosso do Sul, Paraná, Piauí, Pará, Espírito Santo, Rio Grande do Sul and Rio de Janeiro. In summary, in the 25 Federal Units with significant estimated parameters, these ranged from − 0.44 to − 0.04%.

Therefore, it can be concluded that, in the country, although to a lesser extent, determining tariff levels can significantly influence the demand for water, and thus constitutes an effective instrument for the management of the use of water resources.

On the one hand, these results are fundamental from the point of view of their potential for public policies. On the other hand, it is important to remember that, from the point of view of the financial performance of the service providers, when the increase in the price level of services is aimed at expanding investments in the sector for a universal service, it is essential to consider that not all tariff increases lead to an increase in revenue, since service users tend to change consumption behavior.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Appendix 1: Indicators selected from the SNIS by Federal Unit-2017

State	IN005: average water tariff (R$/m^3)	IN026: expenditure on exploration per m^3 billed (R$/m^3)	IN009: hydrometricIndex (%)	IN010: micro-measured index for the volume made available (%)	IN014: micro-measured consumption by economy (m^3/month/eco)	IN022: average per capita consumption (l/inhab/day)	IN025: volume of water made available by economy (m^3/month/eco)	IN049: loss rate in distribution (%)	IN053: average water consumption by economy (m^3/month/eco)	Volume of water consumed/volume of water made available (%)
Acre	2.35	2.27	63.13	29.26	19.56	156.72	56.51	61.06	16.62	29.40
Alagoas	2.88	3.91	88.51	28.78	9.21	96.66	28.94	45.90	11.96	41.32
Amazonas	4.06	3.25	67.40	19.11	9.87	165.87	36.41	44.76	17.56	48.24
Amapá	2.34	2.49	20.86	4.11	12.17	172.20	69.60	70.49	19.73	28.35
Bahia	3.09	2.45	95.16	50.91	8.91	110.72	25.07	38.36	9.89	39.43
Ceará	2.60	2.02	97.53	56.12	9.37	124.67	25.48	40.55	9.70	38.07
Distrito Federal	4.71	3.90	99.51	59.83	12.09	148.87	32.22	35.21	13.02	40.39
Espírito Santo	2.98	1.94	95.59	60.74	12.80	164.35	32.94	36.28	12.96	39.33
Goiás	5.06	3.72	98.69	67.21	9.92	135.63	23.78	30.23	10.03	42.16
Maranhão	2.50	2.68	27.65	9.35	11.39	136.96	40.34	62.85	13.94	34.56
Minas Gerais	3.44	2.17	96.23	59.69	10.40	154.85	27.19	35.13	10.98	40.37
Mato Grosso do Sul	4.80	2.47	98.21	66.81	12.41	152.54	31.99	31.93	12.38	38.71
Mato Grosso	2.31	1.59	87.84	42.68	12.77	166.35	35.88	43.47	13.98	38.98
Pará	2.14	2.76	35.48	17.42	12.78	146.81	33.32	42.78	16.23	48.69
Paraíba	3.61	3.07	85.70	50.95	9.54	115.49	25.85	36.46	10.44	40.38
Pernambuco	3.50	2.99	87.34	42.69	8.86	91.11	28.19	52.64	8.70	30.88
Piauí	3.10	3.68	90.85	39.65	8.98	124.48	30.93	43.69	11.61	37.53
Paraná	3.81	2.34	99.85	64.82	10.84	136.98	27.41	34.33	10.90	39.75
Rio de Janeiro	3.44	1.93	68.40	38.68	16.21	247.28	42.82	31.39	20.53	47.93
Rio Grande do Norte	3.60	2.81	84.73	41.89	10.54	115.34	30.29	49.87	10.74	35.45
Rondônia	3.55	3.90	77.53	33.87	13.78	170.34	42.77	50.83	15.71	36.73

State	IN005: average water tariff (R$/m^3)	IN026: expenditure on exploration per m^3 billed (R$/m^3)	IN009: hydrometricIndex (%)	IN010: micro-measured index for the volume made available (%)	IN014: micro-measured consumption by economy (m^3/month/eco)	IN022: average per capita consumption (l/inhab/day)	IN025: volume of water made available by economy (m^3/month/eco)	IN049: loss rate in distribution (%)	IN053: average water consumption by economy (m^3/month/eco)	Volume of water consumed/volume of water made available (%)
Roraima	2.55	2.79	62.82	19.11	15.43	150.52	60.99	66.61	16.84	27.62
Rio Grande do Sul	4.16	3.91	97.39	55.17	10.09	148.30	27.12	36.97	10.67	39.35
Santa Catarina	2.52	2.45	98.76	55.74	10.77	147.90	25.72	32.23	11.53	44.84
Sergipe	3.96	3.92	98.00	50.03	10.76	116.08	31.66	47.69	11.04	34.86
São Paulo	2.96	1.97	99.44	59.62	11.94	164.91	23.77	37.66	12.43	52.31
Tocantins	3.73	3.39	96.61	58.61	10.48	142.74	27.72	29.47	11.84	42.72
Brazil	**3.30**	**2.37**	**92.14**	**50.91**	**11.23**	**153.50**	**28.45**	**38.24**	**12.38**	**43.51**

Source: NationalSanitationInformation System (Sistema Nacional de Informações sobre Saneamento—SNIS)

Bold values indicate the totals for Brazil and national averages

Appendix 2: Indicators selected from the SNIS for Brazilian State Capitals—2017

Capital	IN005: average water tariff (R$/m^3)	IN026: expenditure on exploration per m^3 billed (R$/m^3)	IN009: hydrometric Index (%)	IN010: micro-measured index for the volume made available (%)	IN014: micro-measured consumption by economy (m^3/month/eco)	IN022: average per capita consumption (l/inhab/day)	IN025: volume of water made available by economy (m^3/month/eco)	IN049: loss rate in distribution (%)	IN053: average water consumption by economy (m3/month/eco)	Volume of water consumed/volume of water made available (%)
Rio Branco	2.42	2.02	63.31	29.73	19.07	170.61	42.81	58.19	17.31	40.43
Manaus	5.28	3.80	84.09	23.56	9.81	171.46	42.22	44.15	19.39	45.93
Macapá	2.49	2.56	29.17	6.46	12.62	187.69	60.14	66.25	20.30	33.75
Belém	2.73	2.53	47.78	27.71	13.47	118.99	28.40	46.77	14.79	52.08
Porto Velho	5.02	8.23	82.67	24.02	15.98	153.13	56.40	70.88	16.43	29.13
Boa Vista	4.69	4.19	91.52	71.93	7.94	91.94	10.44	15.37	8.56	81.99
Palmas	5.07	1.69	100.00	61.50	12.08	214.01	20.50	13.05	17.08	83.32
Maceió	5.79	5.17	86.05	25.61	8.91	80.35	31.08	59.93	12.45	40.06
Salvador	4.33	2.25	94.61	42.22	10.51	121.62	25.27	53.07	10.77	42.62
Fortaleza	2.95	1.75	99.99	57.36	9.96	128.41	17.37	42.64	9.96	57.34
São Luiz	2.17	5.12	15.59	3.92	12.04	120.35	49.52	64.10	17.78	35.90
João Pessoa	3.91	2.85	92.86	51.93	11.97	148.90	23.51	40.28	13.34	56.74
Recife	4.26	4.82	85.24	36.24	10.41	109.16	28.67	61.16	9.93	34.64
Teresina	3.28	4.10	95.15	37.85	9.48	144.43	28.51	47.54	12.55	44.02
Natal	3.96	2.42	87.78	42.03	12.06	128.95	25.45	54.22	11.65	45.78
Aracaju	5.01	4.36	99.63	66.19	13.08	154.63	19.69	33.45	13.10	66.53
Goiânia	7.20	2.90	96.33	73.92	11.34	155.14	14.81	22.53	10.89	73.53
Campo Grande	5.41	1.90	99.91	77.72	13.23	163.93	21.47	19.42	13.71	63.86
Cuiabá	3.86	1.91	93.80	34.62	12.65	178.44	34.48	59.22	13.17	38.20
Vitória	4.00	1.79	90.19	63.99	14.90	206.92	22.19	33.21	14.80	66.70
Belo Horizonte	4.51	2.16	100.00	62.64	11.31	160.61	18.14	37.36	11.31	62.35
Rio de Janeiro	3.63	1.45	69.12	41.76	20.38	328.94	37.61	25.36	26.57	70.65

Capital	IN005: average water tariff (R$/m^3)	IN026: expenditure on exploration per m^3 billed (R$/m^3)	IN009: hydrometric Index (%)	IN010: micro-measured index for the volume made available (%)	IN014: micro-measured consumption by economy (m^3/month/eco)	IN022: average per capita consumption (l/inhab/day)	IN025: volume of water made available by economy (m^3/month/eco)	IN049: loss rate in distribution (%)	IN053: average water consumption by economy (m3/month/eco)	Volume of water consumed/volume of water made available (%)
São Paulo	3.60	1.89	99.96	63.28	11.48	151.80	19.72	36.69	11.48	58.22
Curitiba	4.06	2.04	100.00	60.54	11.58	156.15	19.17	39.46	11.58	60.41
Porto Alegre	4.03	2.54	95.17	67.06	13.21	220.30	23.61	24.98	14.42	61.08
Florianópolis	4.91	2.51	97.21	39.89	9.41	181.36	23.26	39.35	11.97	51.46
Brazil	**3.30**	**2.37**	**92.14**	**50.91**	**11.23**	**153.50**	**28.45**	**38.24**	**12.38**	**43.51**

Source: NationalSanitationInformation System (Sistema Nacional de Informações sobre Saneamento—SNIS)

Bold values indicate the totals for Brazil and national averages

Appendix 3: Hausman test

Estimated model with random effects (GLS)				
Dependent variable: *D*				
	Coefficient	Standard error	*z*	*P* value
const	− 1.8113	0.0363	− 49.8927	0.0000
P	− 0.2811	0.0049	− 57.0335	0.0000
DOM	0.7643	0.0012	618.9459	0.0000
POP	0.0058	0.0042	1.3938	0.1634
T	0.0077	0.0010	8.0555	0.0000
IND	0.0467	0.0034	13.7624	0.0000
AGRO	0.0361	0.0049	7.3951	0.0000
ESC1	0.0384	0.0050	7.6588	0.0000
ESC2	− 0.0147	0.0039	− 3.7554	0.0002
ESC3	− 0.0053	0.0039	− 1.3474	0.1779
REM	0.0662	0.0031	21.0792	0.0000
Hausman test				
Null hypothesis: GLS estimates are consistent				
Asymptotic test statistics: Chi square (10) = 156.927 with *P* value = 0.0000				
Test statistic	156.9273			
P value	0.0000			

The null hypothesis is rejected at a level of 1% significance. Therefore, the fixed effects model should be chosen

Appendix 4: Unit root tests

Increased Dickey–Fuller test								
Akaike criterion lags selection								
Null unit root hypothesis: $a=1$								
Variables	Order	Lags	Test without constant		Test with constant		Test with constant and trend	
			Test statistic: tau	Asymptotic *P* value	Test statistic: tau	Asymptotic *P* value	Test statistic: tau	Asymptotic *P* value
D	In level	1	− 5.2268	0.0000	− 13.6762	0.0000	− 13.8802	0.0000
P	In level	1	− 4.3557	0.0000	− 10.8893	0.0000	− 12.0424	0.0000
DOM	In level	1	− 5.7495	0.0000	− 13.6978	0.0000	− 13.9209	0.0000
POP	In level	1	− 5.2268	0.0000	− 12.4525	0.0000	− 12.6554	0.0000
T	In level	1	− 16.2294	0.0000	− 25.6129	0.0000	− 26.4698	0.0000
IND	In level	0	− 4.7913	0.0000	− 12.3289	0.0000	− 12.4429	0.0000
AGRO	In level	0	− 5.0308	0.0000	− 13.6653	0.0000	− 13.6791	0.0000
ESC1	In level	0	− 4.8843	0.0000	− 13.3496	0.0000	− 13.3513	0.0000
ESC2	In level	0	− 4.9331	0.0000	− 12.4323	0.0000	− 12.4327	0.0000
ESC3	In level	0	− 4.7434	0.0000	− 11.8376	0.0000	− 11.8421	0.0000
REM	In level	1	− 4.9779	0.0000	− 13.7978	0.0000	− 13.9209	0.0000

The null hypothesis is rejected at a level of 1% significance. Therefore, there is no evidence of a unit root process in the variables

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