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Article

Value of water in irrigated agricultural production in Mexico

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Abstract

The objective of the research was to quantify the contribution that water made to the value of agricultural production under the irrigation modality in Mexico during the period 1980-2017. For this purpose, based on the econometric methodology, a hyperbolic logarithmic or logarithmic reciprocal model was estimated, relevant for a production function when only one input is considered while the others remain constant. The variable explained was the natural logarithm of the value of irrigated agricultural production at the national level in constant pesos of 2013, the explanatory variable was the inverse of the water supplied for irrigation in cubic hectometers; both variables were I(0). It was found that the hydrological-administrative regions I, II, III, IV, VI, VII, and VIII -northern and Bajío states of the country- concentrate 89.4% of the total national irrigated area, hydrological-administrative regions that were highly benefited with federal investments in the irrigation districts and units. During the period analyzed, two structural changes were detected: 1) from 1980 to 1987; and 2) from 2009 to 2017. It was concluded that the contribution of water to the value of irrigated production registered a positive trend, it was \$0.39 m^{-3} in 1980, \$1.92 m^{-3} in 2017, \$0.39 m^{-3} for the period 1980-1987, \$1.11 m^{-3} for 1988-2008, \$1.74 m^{-3} for 2009-2017. Finally, during the period considered, the average contribution of water to the value of irrigated production in Mexico was \$1.11 m^{-3}.

Palabras clave:

cointegration, districts, irrigation units, valuation..

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Introduction

Irrigated agriculture is the largest consumer of water in Mexico and the world. According to the Center for Public Finance Studies of the Chamber of Deputies. LXIV Legislature of Mexico (CEFP, 2019), at the global level, agriculture consumes 70% of the total water used in all consumptive uses, in Mexico, 76%.

Figure 1 shows the distribution of climate in Mexico, and Figure 2 shows the hydrological-administrative regions (HARs) into which the country has been divided for water administration and the degree of pressure on the water in each region. By relating both illustrations, it is possible to deduce that the HARs with high degrees of pressure on water are I, II, III, IV, VI, VII, and VIII, in which the climate is very arid, arid, and semi-arid.

Figure 1. Climate distribution in Mexico (A-BAK, 2014).

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Figure 2. Degrees of pressure on water in the hydrological-administrative regions (HARs) of Mexico (CONAGUA, 2018).

Due to Mexico’s climate, among other reasons, federal investments have been concentrated in HARs I, II, III, IV, VI, VII, and VIII, which have been highly benefited. Thus, of the 3 291 476 ha sown in the Irrigation Districts (IDs) during the 2015-2016 agricultural year, 2 770 038 ha corresponded to these HARs, which represent 84.16% of the total hectares sown in the IDs, as can be seen in Table 1.

Table 1. Area sown in the IDs and IUs, agricultural year 2015-2016.

No. of HAR	Hectares sown in the IDs	Hectares sown in the IUs	Total IDs+IUs
I	245 693	55 087	300 780
II	466 855	244 245	711 100
III	862 295	347 202	1 209 497
IV	199 390	356 327	555 717
V	71 914	87 203	159 117
VI	467 397	824 337	1 291 734
VII	71 964	295 723	367 687
VIII	456 446	1 005 828	1 462 274
IX	230 569	329 326	559 895
X	41 830	113 098	154 928
XI	37 158	42 763	79 921
XII	17 785	95 264	113 049
XIII	122 180	93 537	215 717
Total	3 291 476	3 889 940	7 181 416

Statistics on water in Mexico.

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For its part, the number of hectares sown during the 2015-2016 agricultural year in the irrigation units (IUs) in HARs I, II, III, IV, VI, VII, and VIII amounted to 3 128 749, which represent 80.43%of the total. The IDs and IUs of HARs I, II, III, IV, VI, VII, and VIII in the 2015-2016 agricultural year recorded 6 420 225 ha sown, this is 89.4% of the area sown under irrigation in the country.

Although the mentioned HRs have been highly benefited by federal investments in infrastructure for irrigation, it is necessary to bear in mind that the construction of irrigation works was carried out mainly by the landowners since the beginning of the twentieth century, it was not until after '1924 that the use of federal waters is regulated, in 1926 the Irrigation Law and the National Irrigation Commission were created, which promoted the construction of large irrigation works'.

This investment was, and has been, of such magnitude that it has led to the 'formation or development of important population centers based on the attraction represented by the various economic activities that have developed around them, which has led to a strong growth of rural and urban areas located in the irrigation districts'. On the other hand, it has also generated 'conditions of inequality and poverty, which coexist with a spectacular development of agricultural exports in the last 20 years' (Flores, 2018).

On the other hand, as is known, agricultural production in Mexico is carried out in the IDs, IUs, technified rainfed districts, and rainfed districts. According to the Agrifood Information Consultation System (SIACON, 2019) of the Secretariat of Agriculture and Rural Development (SAGARPA, 2019), in 2019, 20 664 554.08 ha were sown under the irrigation and rainfed modalities, and it includes crops in the agricultural year and perennial plants.

Of the 20 664 554.08 ha under the irrigation and rainfed modalities sown during the 2019 agricultural year and perennial plants, 14 627 813.1 ha corresponded to the modalities of technified rainfed and rainfed. Of the total hectares sown in 2019, 6 036 740.98 ha corresponded to the modality under irrigation -IDs and IUs or UNDERALES-.

However, according to the National Water Commission (CONAGUA, for its acronym in Spanish), 'the area with infrastructure that allows irrigation is approximately 6.5 million ha, of which 3.3 million correspond to 86 irrigation districts (IDs) and the remaining 3.2 million to more than 40 thousand irrigation units (IUs)' (CONAGUA, 2018) and their water consumption represents about 80% of that allocated for all consumptive uses in the country, as in developing countries, as can be seen in Table 2.

Table 2. Water consumption in irrigated agriculture in some developing countries selected for illustrati ve purposes only, 2017.

Country	Total water withdrawal (billion m^3 $year^{-1}$)	Agricultural use (%)	Industrial use (%)	Public supply use (%)
India	761	90.4	2.2	7.4
Pakistan	183.5	94	0.8	5.3
China	598.1	64.4	22.3	13.3
Mexico	87.84	76	9.6	14.4
Brazil	74.83	60	17	23
Argentina	37.78	73.9	10.6	15.5
Spain	37.35	68.2	17.1	14.2
Chile	35.43	83	13.4	3.6

Statistics on water in Mexico (CONAGUA, 2018).

Thus, for example, in 2017, of the total water concessioned, irrigated agriculture consumed 76.04% (CONAGUA, 2018), equivalent to 66.8 km^3 of a total concession of 87.84 km^3 (CONAGUA, 2018).

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According to the Food and Agriculture Organization of the United Nations (FAO, 2020), Mexico has an irrigation potential of 13.5 million hectares. Nevertheless, due to the availability of water, such potential decreases to only 9.8 million hectares.

The restriction imposed on the availability of water to reach the irrigation potential in Mexico is due, in part, to the fact that IDs and IUs were built mainly in arid and semi-arid (north and Bajío) areas of the country in HRs I, II, III, IV, VI, VII and VIII, as noted above. It should be remembered that 60% of the Mexican territory is arid and that 63% of the area allocated to cultivation requires irrigation (Soto, 2003).

Since arid and semi-arid climates predominate (51.7%) in Mexico, mainly because the north of the country is in the world desert strip -deserts of the Sahara in Africa, Nefud and Rub al-Khali in the Arabian peninsula and Thar in India- (A-BAK', 2014). Mexico great variety of climates.

On the other hand, according to SIACON (2019), the value of irrigated production in 2019 amounted to 433 383 684.36 thousand current pesos; that of rainfed production to 241 984 111.71. When dividing these values by the number of hectares sown, respectively, it is obtained that 71.79 thousand current pesos were obtained per irrigated hectare and only 16.54 thousand current pesos per rainfed hectare. From this, the superiority of the yield of irrigated agriculture is concluded.

However, it is wrongly concluded that the yield of irrigated agriculture is higher than that obtained under rainfed conditions because they are non-comparable production processes, for this, I refer to (Montesillo-Cedillo, 2017). Water is essential for irrigated agricultural production in Mexico. Nonetheless, to date, there are few studies on the contribution that water makes to the value of irrigated agricultural production in the national context. With this, a perception of non-scarcity is generated, and it can lead to a 'lack of social awareness about the real value of water'.

The first problem faced by hydraulic policy in Mexico is the lack of social awareness about the real value of water both by the authority and by agricultural and urban users, which is manifested in an inefficient, often neglected, use of this resource (Palacios-Vélez *et al*., 2016). In addition, 'valuing water means recognizing the values that society assigns to water and its uses, considering them in political and commercial decisions, including those on the appropriate pricing of water and sanitation services' (Banco Mundial, 2020).

Ignorance of the value of water, as well as ignorance of its real costs of extraction -in the case of underground sources- in the short term can lead to 'false profitability of certain crops; in the medium term, absence of incentives to make technological improvements and in the long term, loss of competitiveness of the sector'.

Although it is necessary to know the value of water in irrigated agriculture in Mexico for the above, there are works in this direction but focused on IDs, states, or dams. Thus Zetina-Espinosa *et al*. (2013) calculate the marginal value of irrigation water in ID 044, Jilotepec, State of Mexico, Flores Lozano *et al*. (2017) estimate the value of water in strawberry production in the Duero basin, Michoacán, Mexico, Ríos-Flores *et al*. (2017) calculate the price of water for bean production in Rural Development District 189, Zacatecas, Ramírez Barraza *et al*. (2019) estimate the shadow price or opportunity cost of water applied in irrigation for the Lagunera Region, Coahuila and Durango, Mexico and Trujillo-Murillo (2020) calculate the economic value of the water from the Solís dam, Acámbaro, Guanajuato, Mexico. The present research work aimed to calculate the contribution that the water supplied makes to the value of irrigated agriculture production in Mexico.

Materials and methods

The data used to estimate the contribution of water to the value of agricultural production under the irrigation modality in Mexico, as well as the source from which they were obtained, are presented in Table 3.

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Table 3. Volume of irrigated agricultural production in pesos of 2013 and water supplied to said production in Mexico, 1980-2017.

Year	Water supplied for irrigation (hm^3)	Value of production (thousand constant pesos, 2013=100)	Year	Water supplied for irrigation (hm^3)	Value of production (thousand constant pesos, 2013= 100)
1980	54 638.14	10 9751 649.54	1999	64 800	178 121 902.24
1981	57 891.64	117 702 286.83	2000	56 210	174 436 978.81
1982	62 506.52	132 430 078.08	2001	56 386	178 411 000.66
1983	54 439.4	121 504 272.33	2002	56 100	175 574 139.07
1984	55 271.86	127 772 137.89	2003	56 900	186 120 774.11
1985	64 109.25	147 355 293.97	2004	57 500	198 176 486.07
1986	64 439.23	140 670 452.76	2005	58 700	198 553 900.71
1987	64 534.54	157 631 739.05	2006	59 400.2	198 603 430.53
1988	54 745.79	120 734 655.11	2007	60 571.93	205 689 283.32
1989	65 913.31	125 684 208.01	2008	61 215.1	213 499 321.53
1990	56 057.96	119 940 877.24	2009	61 793.04	206 940 917.26
1991	58 633.4	132 901 997.14	2010	61 490	208 644 560.98
1992	56 306.72	132 812 105.49	2011	62 090	200 603 483.81
1993	56 426.67	133 277 025.47	2012	63 349.4	223 852 740.71
1994	63 353.33	140 790 345.81	2013	61 822.5	234 061 947.15
1995	53 940.16	152 311 730.44	2014	65 154.5	248 476 797.93
1996	52 505.47	164 189 417.84	2015	65 359.3	260 140 862.67
1997	55 658.9	173 536 162.57	2016	66 800	268 152 904.95
1998	60 500	174 384 961.14	2017	66 798.9	286 050 982.14

Water National Commission. Statistics on water in Mexico (2000-2018); from 1987 to 1997 (INEGI, 2000).

Agrifood and Fisheries Information System-Secretariat of Agriculture and Rural Development (SADR-SIAP, 2021). It was proposed to estimate a hyperbolic logarithmic or logarithmic reciprocal model:

$$\ln(vp)=\beta_1-\beta_2\left(\frac{1}{A}\right)+u$$

1)

Where: ln(vp)= the natural logarithm of the value of agricultural production obtained under irrigation in thousands of pesos at constant prices of 2013, (1/A)= the reciprocal of the water supplied for irrigation in cubic hectometers, both at the national level; β_i= the parameters and u= the error term.

The described model was proposed because, from the perspective of economic theory, it represents a short-term production function when modeled with a single input, ceteris paribus, while the rest remains constant (Varian, 1999), in this case, only the input water supplied for irrigation at the national level was used.

The water supplied-value of irrigated agricultural production elasticity (ε) was determined according to the estimated model. That is: ε= β_i (1/A), this elasticity is not constant. Therefore, it was calculated for each year considered in the present research work and for the average of that period, as is customary in the literature on the subject. The proposed model included the variable t (chronological time) because when performing the augmented Dicky-Fuller unit root test, the included variables turned out to be I(0) with a deterministic trend and a drift (intercept).

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The unit root tests performed on the variables ln(vp) and 1/A and the estimation of the proposed econometric model were performed with the Eviews 11 program. In turn, the proposed model registered two structural changes, consequently, the estimated model was:

$$\ln(vp) = \beta_1 - \beta_2\left(\frac{1}{A}\right) - cD1\left(\frac{1}{A}\right) - dD2\left(\frac{1}{A}\right) + t + u$$

2). In which D1 and D2 represent binary or dichotomous variables. D1= 1 during the period 1980-1987 and D2= 1 from 2008 to 2017. Consequently, the models obtained were: for the period 1980-1987.

E[ln(vp)/D1= 1, D2= 0, ln(vp)]=

$$\beta_1 - \beta_2\left(\frac{1}{A}\right) - cD1\left(\frac{1}{A}\right) + t + u$$

E[ln(vp)/D1= 1, D2= 0, ln(vp)]=

$$\beta_1 - (\beta_2 + c)\left(\frac{1}{A}\right) + t + u$$

3). For the period 1988-2008. E[ln(vp)/D1= 0, D2= 0, ln(vp)]=

$$\beta_1 - \beta_2\left(\frac{1}{A}\right) + t + u$$

4). For the period 2009-2017. E[ln(vp)/D1= 0, D2= 1, ln(vp)]=

$$\beta_1 - \beta_2\left(\frac{1}{A}\right) - dD2\left(\frac{1}{A}\right) + t + u$$

E[ln(vp)/D1= 0, D2= 1, ln(vp)]=

$$\beta_1 - (\beta_2 + d)\left(\frac{1}{A}\right) + t + u$$

5).

Results and discussion

The augmented Dicky-Fuller unit root test with a trend and a drift of ln(vp) provided a probabilistic value -*p* value- of 0.004, that of (1/A), a value of 0.0039. Therefore, both variables had stationary processes in trend and a drift. The estimated model provided the following results: ln(vp)= 18.83 -22561.74(1/A) + 11947.39D1 - 7383.07D2 + 0.029t t 108.22 -2.28 6.88 -3.98 20.57.

With an R^2 of 0.97, an adjusted R^2 of 0.96, and a Durbin-Watson of 1.71. To corroborate the possible existence of serial correlation, the Breusch-Godfrey test was also applied with two and three lags, which allowed us to confirm the possible existence of such serial correlation. The non-existence of heteroskedasticity was confirmed based on the tests of Breusch-Pagan-Godfgrey, Harvey and White.

The serial correlation was 'corrected' with the method proposed by Huber-White-Hinkley (HC1). The normality test of the residuals of the estimated model was performed based on the Jarque-Bera test (J-B) and a *p*-value of 0.49 was obtained, with a skewness coefficient of 0.46 and a kurtosis coefficient of 2.75, its histogram (Figure 3).

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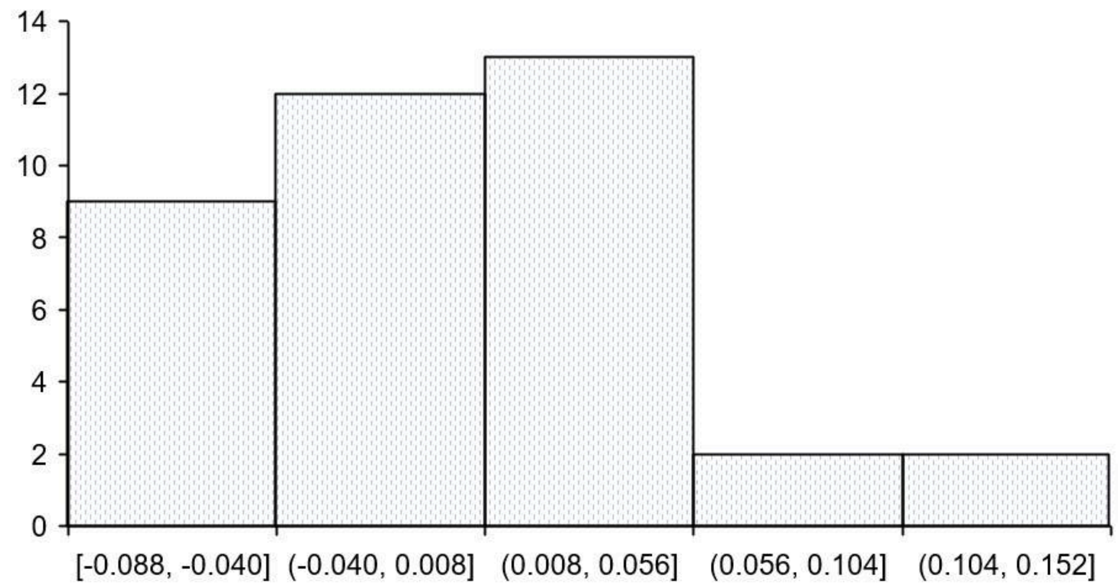
Figure 3. Test of normality of the residuals of the estimated model.



The above allowed us to indicate that these residues are approximately normally distributed because for the distribution to be normal, the skewness must be zero and the kurtosis (kurtosis) three. The J-B test was designed for large samples, and 38 observations can be considered a non-large sample (Orizont, 2012).

The possible bias of model specification was tested with the augmented White test (with crossed terms), which, with a *p*-value of 0.53, confirmed the correct specification. On the other hand, the Ramsey regression specification error test -RESET- was applied, which, with a *p*-value of 0.59, allowed us to rule out this possibility. Parametric stability was checked with the Cusum and Cusum of squares tests, which can be seen in Figures 4 and 5, respectively.

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Figure 4. Cusum parametric stability test.

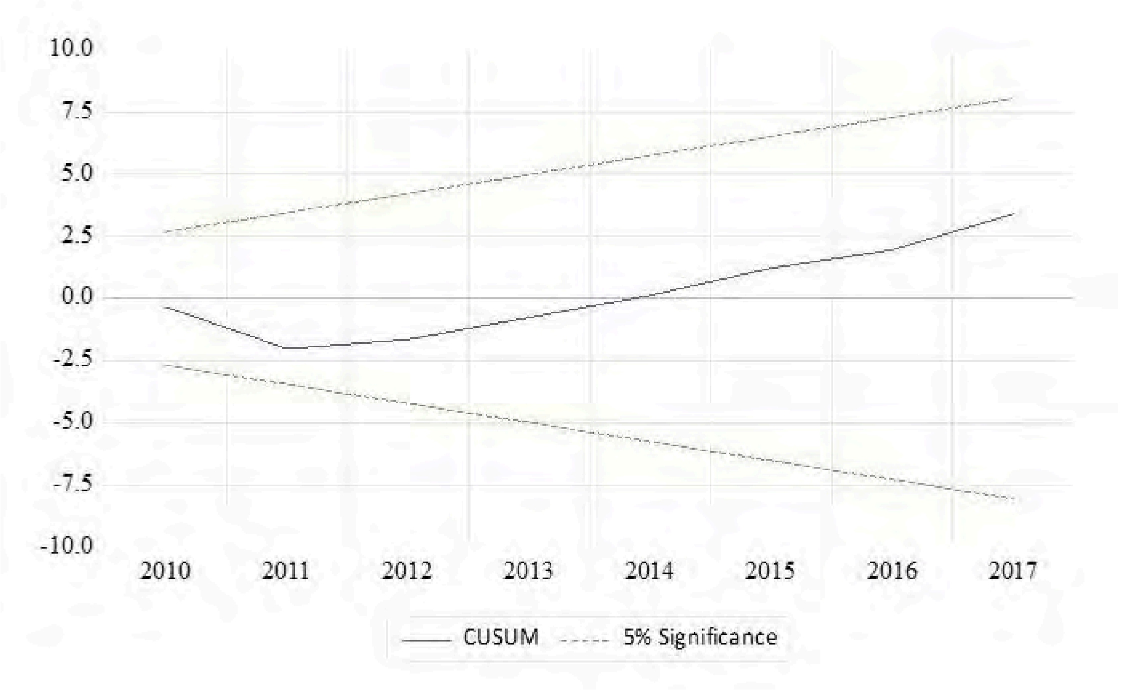
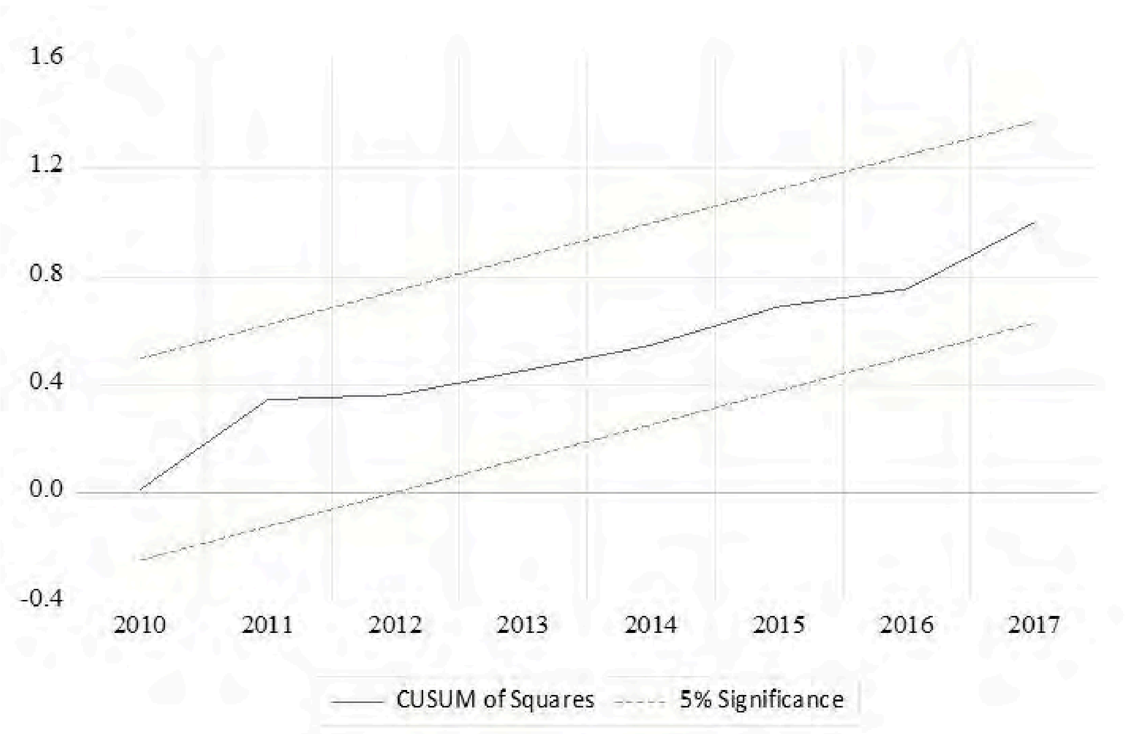


Figure 5. Cusum of squares parametric stability test.



The variables included in the model are I(0), as indicated above, and are cointegrated. The latter was confirmed based on the unit root test applied to the residuals of the estimated model, the

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augmented Dickey-Fuller τ statistic was -3.7, whose Davidson-McKinnon *p*-value was 0.0344. For its part, the Durbin-Watson statistic had a value of 1.86.

According to the results of the estimated model, it was obtained that the average elasticity of water supplied-value of irrigated agricultural production in Mexico for the period 1980-1987 was [(22561.74 + 11947.39) * (1/A)]= [(10614.35) * (2.99461E-06)]= (10614.35) (0.0000299461)= 0.18; for the period 1988-2008, it was [(22561.74) (1.72449E-05)]= 0.39, and for the period 2009-2017, it was [(22561.74+7383.07) (1.56779E-05)]= (29944.81)(1.56779E-05)= 0.45.

As the estimated model was hyperbolic logarithmic or logarithmic reciprocal, the elasticity of water supplied value of irrigated agricultural production in thousands of constant pesos of 2013 is not constant, Table 4 shows this elasticity for each year considered in the present research, as well as its average value for the three periods determined based on the structural changes detected and the average of the entire period considered in this research (Avilés, 2006).

Table 4. Elasticity of water supplied-value of irrigated agricultural production in constant pesos of 2013 in Mexico, 1980-2017.

Year	Elasticity of water supplied-value of irrigated agricultural production	Year	Elasticity of water supplied-value of irrigated agricultural production
1980	0.19	1999	0.35
1981	0.18	2000	0.4
1982	0.17	2001	0.4
1983	0.19	2002	0.4
1984	0.19	2003	0.4
1985	0.17	2004	0.39
1986	0.16	2005	0.38
1987	0.16	2006	0.38
1988	0.41	2007	0.37
1989	0.34	2008	0.37
1990	0.4	2009	0.48
1991	0.38	2010	0.49
1992	0.4	2011	0.48
1993	0.4	2012	0.47
1994	0.36	2013	0.48
1995	0.42	2014	0.46
1996	0.43	2015	0.46
1997	0.41	2016	0.45
1998	0.37	2017	0.45
1980-1987	0.18	2009-217	0.45
1988-2008	0.39	1987-2017	0.36

Based on the estimated model and data in Table 3.

The contribution of water supplied for irrigation to the value of agricultural production in constant pesos of 2013 at the national level was calculated based on the elasticities in Table 5. It should be noted that this value has a positive trend and ranges from \$0.39 m^{-3} in 1987 to 1.92 m^{-3} in 2017, with an average value of \$1.11 m^{-3} during the period considered. Results, in general terms, not very similar to those obtained by Flores Lozano *et al*. (2017), who, based on a production function, calculate the value of water for strawberry cultivation at \$3.67 m^{-3} in the Duero basin, Michoacán, Mexico (Inforural, 2020).

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Table 5. Contribution of water to the value of irrigated production in Mexico, pesos of 2013 per cubic meter of water, 1980-2017.

Year	Value of water for irrigation ($ m^{-3})	Year	Value of water for irrigation ($ m^{-3})
1980	0.39	1999	0.96
1981	0.373	2000	1.25
1982	0.36	2001	1.27
1983	0.435	2002	1.26
1984	0.444	2003	1.3
1985	0.381	2004	1.35
1986	0.36	2005	1.3
1987	0.402	2006	1.27
1988	0.909	2007	1.26
1989	0.653	2008	1.29
1990	0.861	2009	1.62
1991	0.872	2010	1.65
1992	0.945	2011	1.56
1993	0.944	2012	1.67
1994	0.791	2013	1.83
1995	1.181	2014	1.75
1996	1.344	2015	1.82
1997	1.264	2016	1.8
1998	1.075	2017	1.92
1980-1987	0.39	2009-2017	1.74
1988-2008	1.11	1987-2017	1.11

Based on the data in columns 2 and 4 of Table 3 and the elasticity calculated in this research paper.

Based on a linear programming model, Zetina-Espinosa *et al*. (2013) calculate the marginal value of irrigation water in ID 044, Jilotepec, State of Mexico, between 0.96 and 5.72 pesos m^{-3} in the autumn-winter cycle and between 0.03 and 0.29 in the spring-summer cycle of the 2008-2009 cycle. For the cultivation of beans with pumped irrigation in Rural Development District 189, Zacatecas, Mexico, Ríos-Flores *et al*. (2017) estimate the price per cubic meter of water at $0.48.

For the Lagunera Region, Coahuila and Durango, Mexico, Ramírez-Barraza *et al*. (2019), based on a linear programming model, estimate the shadow price or opportunity cost of water applied in irrigation and conclude that it is $1.56 m^{-3} for pumped irrigation, and it is $0.91 m^{-3} for gravity irrigation, they argue that that of pumped irrigation is higher because it has higher productivity and its water loss rate is lower relative to gravity irrigation during the 2015-2016 agricultural year.

On the other hand, Trujillo-Murillo (2020), based on the contingent valuation, estimate the value of the water of the Solís dam, Acámbaro, Guanajuato, Mexico, at $1.00 m^{-3}. The contribution of water to the value of irrigated agricultural production estimated in this research, unlike the works cited, provides a vision of its evolution from 1980 to 2017 and reveals that the contribution of water has been growing and will probably continue like this.

The value of water used in irrigated agricultural production for specific crops and sites differs from that calculated in the present research, which represents the climatic, soil and other diversity of the country and highlights the urgent need for such estimates by state, ID, and crop type. As well as for the type or form of irrigation: by gravity, by pumping, by drip, etc. Finally, the average annual growth rate, obtained based on the estimated model, of the value of production in real terms -in pesos of 2013- of irrigated agriculture in Mexico from 1980 to 2017 has been 2.98%.

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Conclusions

The HARs I, II, III, IV, VI, VII, and VIII concentrate 84.16% ha of the IDs and 80.43% of the IUs. In total, these HARs concentrate 89.4% of the total irrigated area in Mexico, so we can say that the northern and bajío states have been highly benefited with federal investments in the construction of irrigation infrastructure.

Irrigated agriculture in Mexico, as in developing countries, is the largest consumer of water in Mexico, its consumptive use amounts to 66.8 km^3 in 2017, which represents 76.04% of total consumptive uses, which amount to 81.84 km^3. The average annual growth rate, obtained based on the estimated model, of irrigated agriculture in Mexico from 1980 to 2017 has been 2.98%.

The value of water or the contribution that water makes to the value of irrigated agricultural production has a positive trend during the period 1980-2017, ranging from \$0.38 to \$1.92 m^{-3}, and its average value during the period considered is \$1.11 m^{-3}. In order to increase the social valuation of water, it is necessary to know its value or price at the level of ID, IU, state, dam or basin and by system or type of irrigation.

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