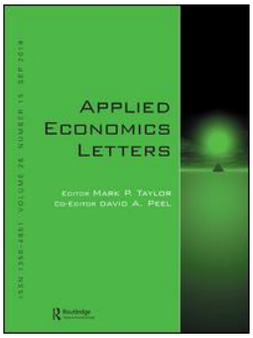

Applied Economics Letters

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rael20

Water scarcity reduces the efficiency of the manufacturing industry in the valley of Mexico Basin: DEA-based two-stage efficiency analysis

Daniel Alfredo Revollo-Fernández & Lilia Rodríguez-Tapia

To cite this article: Daniel Alfredo Revollo-Fernández & Lilia Rodríguez-Tapia (2021): Water scarcity reduces the efficiency of the manufacturing industry in the valley of Mexico Basin: DEA-based two-stage efficiency analysis, Applied Economics Letters, DOI: 10.1080/13504851.2021.1918623

To link to this article: https://doi.org/10.1080/13504851.2021.1918623

Published online: 03 May 2021.

APPLIED ECONOMICS LETTERS
https://doi.org/10.1080/13504851.2021.1918623

Routledge
Taylor & Francis Group

Water scarcity reduces the efficiency of the manufacturing industry in the valley of Mexico Basin: DEA-based two-stage efficiency analysis

Daniel Alfredo Revollo-Fernández[a] and Lilia Rodríguez-Tapia[b]

[a]CONACYT-UAM, Área de Crecimiento y Medio Ambiente, Departamento de Economía, Universidad Autónoma Metropolitana, Unidad Azcapotzalco, Ciudad de México, México; [b]Departamento de Economía, Universidad Autónoma Metropolitana, Unidad Azcapotzalco, Ciudad de México, México

ABSTRACT
This study analysed the impact of a series of socioeconomic variables on the efficiency of production processes used by different economic units belonging to the manufacturing industry in a hydrological basin with water scarcity problems. The main finding is that the economic units that used water from overexploited aquifers had lower efficiency scores than those that used water from non-exploited aquifers. Thus, the design of public policies for this sector, which is highly dependent on this natural resource, should take into account that actions to conserve water supply sources greatly affect the efficiency of the manufacturing industry.

KEYWORDS
Manufacturing industry; efficiency; water; shortage

JEL codes
L6; L25; Q25; Q55

I. Introduction

While Mexico's water supply is considered to be abundant in absolute terms, the country faces a serious problem with relative water scarcity (Conagua 2012). This problem is demonstrated by the inability to meet water demand in some of the country's basins, especially where populations and economic activity have experienced more growth over the years (Conagua 2016). While the Valley of Mexico Basin (VMB) occupies less than 1% of the nation's territory, it is home to 20% of the country's population and produces roughly 31.3% of the national Gross National Product (GNP) (Conagua 2012; Consejo de Cuenca Valle de México 2014). Meanwhile, the Relative Water Stress Index (ratio of total water volume use to mean freshwater availability) in the VMB is 140.4%, making it one of the regions in the world with the highest water stress (Conagua 2016). Currently, the main sectors in the VMB that consume water are public urban-domestic, agriculture, and industry. The manufacturing industry plays a key role in the dynamics of economic activity in the VMB, since it represents one-fifth of the total GNP, generating employment and goods and services (Conagua 2012). Given the production processes that are used by the manufacturing industry, this sector extracts the majority of the water from the aquifers, whose current overexploitation is so high that they have been declared closed (Conagua 2012).

Therefore, it is important to study whether variables related to water scarcity are among the determinants that affect the efficiency of the manufacturing sector (Gumus et al. 2016). While many studies have investigated the determinants of efficiency for various sectors of the economy using different models (Soni, Mittal, and Kapshe 2017; Hu et al. 2018; Guarani et al. 2018; Yao et al. 2018; Lombardi et al. 2019; Liu, Yang, and Yang 2020; Walheer and He 2020), virtually no studies have included water used in production in the context of scarcity or problems with overexploitation in hydrographic basins (Korattukudy-Varghese et al. 2013; Long and Pijanowski 2017). As indicated by Korattukudy-Varghese et al. (2013), investigators have not reached consensus as to the influence of water scarcity and efficiency on the use of water from groundwater sources. Some suggest that scarcity leads to prudent use while others suggest that it will cause the overexploitation of resources.

This article includes four more sections, in addition to the introduction. The next section describes the

CONTACT Daniel Alfredo Revollo-Fernández darevollof@conacyt.mx; drevollofer@gmail.com CONACYT-UAM, Área de Crecimiento y Medio Ambiente, Departamento de Economía, Universidad Autónoma Metropolitana, Unidad Azcapotzalco, Av. San Pablo No. 180, Col. Reynosa Tamaulipas, Del. Azcapotzalco, Ciudad de México 02200, México

study area (VMB), which is followed by a presentation of the methodology and the results obtained. Lastly, the fifth section presents the conclusions.

II. Valley of Mexico Basin (VMB)

Location of the VMB

The VMB is located in central Mexico and is roughly 135 km wide and 180 km long (Conagua 2012; Consejo de Cuenca Valle de México 2014) (Figure 1). In hydrological terms, the basin contains 85 municipalities, which belong to the State of Mexico, Mexico City, Hidalgo and Tlaxcala. The VMB is the most densely populated region in Mexico and one of the densest areas in the world, with 22 million residents and roughly 2,234 residents per km^2 (Revollo-Fernández, Rodríguez-Tapia, and Morales-Novelo 2020). The majority of the economic activities taking place in its municipalities use water from seven aquifers, most of which already present overexploitation problems (Conagua 2012).

The manufacturing industry in the VMB

There are 69,984 economic units (EU) in the VMB's manufacturing sector, with a production value of 59,462 USD million USD (2013). This accounts for 35% of the basin's total product and generates employment for 751,178 people. The economic importance and dynamism of the VMB's manufacturing industry suggest a need to investigate the impact of its demand for water as a production input, given the region's absolute water scarcity, which may affect the sector's efficiency (Revollo-Fernández, Rodríguez-Tapia, and Morales-Novelo 2020). Since the water that the sector incorporates in its processes is for consumptive use, the water that is taken from water bodies does not return to them (Conagua 2016). The entire sector has an annual water volume demand of 127 hm3 for first use, most of which is extracted from wells located in the basin (85%) and the rest from public urban water supplies (15%) (Consejo de Cuenca Valle de México 2014).

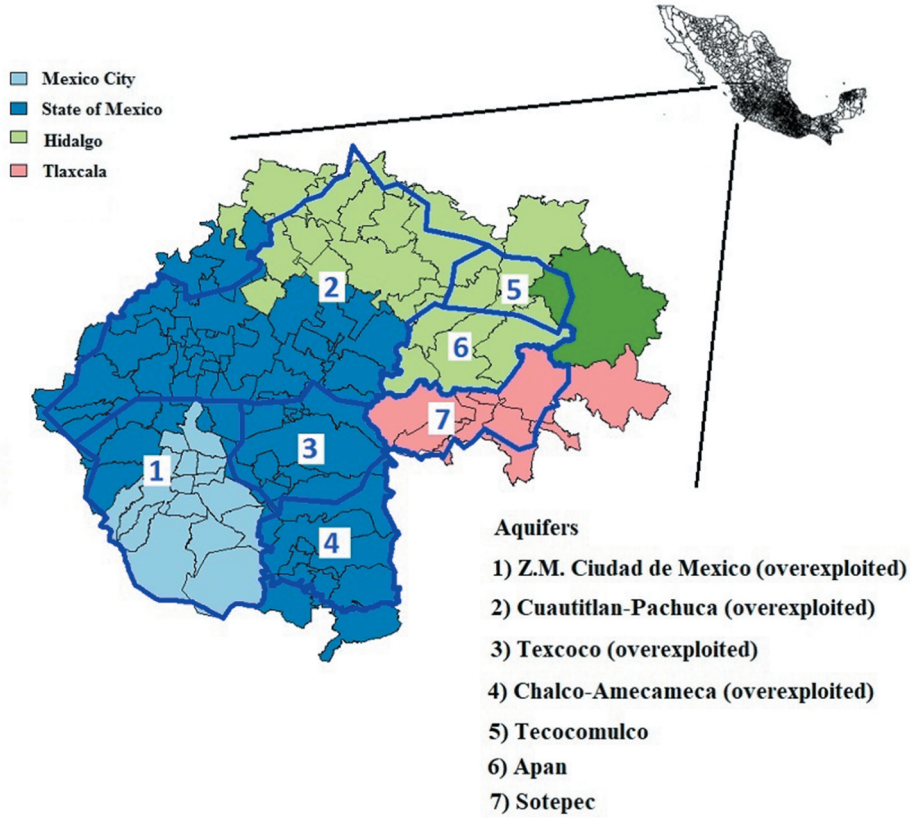

Figure 1. Hydrological delimitation of the VMB.

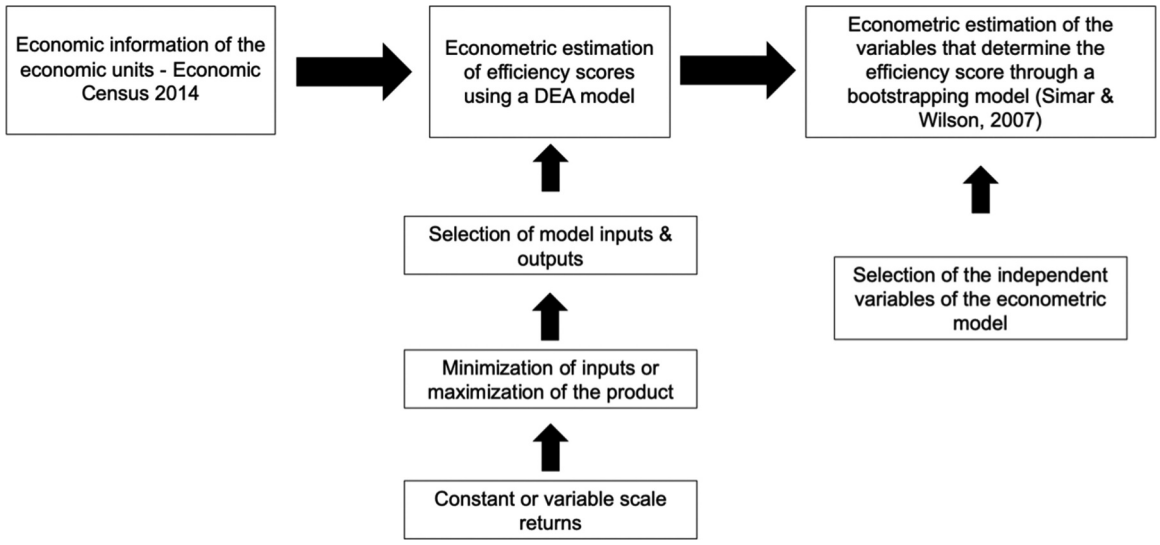

Figure 2. Methodological process for determinants of the efficiency of the manufacturing industry: DEA based two-step efficiency analysis.

III. Methodology

The methodology consisted of three phases (Figure 2). First, economic information was obtained about the different economic units in the manufacturing sector located in the VMB. Second, an econometric estimation was applied by using a DEA model to estimate efficiency scores. And third, a bootstrapping econometric model was generated.

Data

Data were obtained from the 2014 Economic Census (EC). Every five years, the National Institute of Statistics and Geography (INEGI in Spanish) administers the EC to the economic units (EUs) that perform various industrial activities in Mexico. The year 2014 was used for this research since INEGI offers free access to that information without restrictions. STATA 16 software was used to process the data that corresponded to the EUs belonging to the manufacturing sector located in the VMB's municipalities. Information was included from a total of 69,984 EUs. The variables that were used included: a) value of the manufactured products (Q), which quantifies the monetary value of all goods and services produced; b) total labour force (L), which includes the monetary value of all the people who work; c) raw materials and materials used in production (M), which is the monetary value of the cost of acquiring raw and secondary materials that are used in production processes; d) water used in production (W), which is the monetary expenditure on water reported by the census; and e) total fixed assets (K), total fixed assets (K), the updated monetary value of all those goods, owned by the EU assets, that had the capacity to produce goods and services. Lastly, it is important to mention that the EUs in the different VMB municipalities were the decision-making units (DMU) in this study, and their input and output units were considered to be homogeneous.

DEA model

The concept of efficiency is related with the economy of resources (Charnes, Cooper, and Rhodes 1978; Asid 2010; You and Yan 2011). This work used the DEA non-parametric method to estimate efficiency, with which the production function is constructed based on observations of outputs versus inputs (Zhu 2002; Coelli et al. 2005; Mukwate Ngui-Muchai and Muchai-Muniu 2012). Since this work used a product-based approach, the interpretations of the results indicate the increases in production that can be obtained when holding input amounts constant.

Two basic DEA models are used to measure efficiency: those that assume a Constant Return to Scale (CRS) and those that assume a Variable

Return to Scale (VRS) (Adeoti 2013). It is appropriate to use the CRS assumption when all of the companies operate at an optimal scale. Nevertheless, in some circumstances this does not occur, for example, when there is imperfect competition or financial limitations, such as in the case of the VMB. Therefore, the following variables were used by the DEA model for the VMB, with a product-oriented approach and considering the VRS: i) Q (output), ii) L (input), iii) M (input), iv) W (input), and v) K (input).

Bootstrapping model (BM)

The BM proposed by Simar and Wilson (2007) was used in order to identify the determinants of the manufacturing sector's efficiency. This step used the efficiency scores that were estimated in the previous stage as the dependent variable, in addition to the independent variables, which were divided into three groups: i) agglomeration economies, in order to identify whether the formation of clusters or industrial specialization impacted efficiency (Porter 1998), which included both the Gini Index and Specialization Index for the production value; ii) water scarcity in the production process, which included whether the EUs used water from overexploited aquifers and the Gini Index for water consumption; and iii) the socioeconomic group, which was defined by the size of the economic unit based on the production value per worker and the percentage of the total labour force that was economically active. Unlike the censured or truncated models that are typically reported in the literature, the main advantage of the bootstrapping model is a lower risk of analysis bias, that is, it estimates the variance based on a random resampling of the initial sample rather than on the population, thereby obtaining more reliable and robust results (Simar and Wilson 2007).

IV. Results

Table 1 presents an efficiency score of 0.812 for the entire manufacturing industry. When comparing the efficiency scores of companies that used water from aquifers that were not overexploited versus those that used water from overexploited aquifers, we found the former score to be 10% higher (0.841 and 0.808, respectively), which was a statistically significant difference (ANOVA test) That is, the EUs that used water as an input in their production process from aquifers that were not overexploited reported higher efficiency than companies that used water from overexploited aquifers. This result was confirmed by applying the proposed econometric model in order to analyse the determinants of the efficiency score (Table 2).

When analysing those determinants, we found that greater geographic concentration of the production value of the manufacturing industry increased the efficiency score by roughly 0.2 points, while greater specialization in the sector reduced the score. In the case of water-related variables, the efficiency score decreased by 0.1 points for EUs that used water from overexploited aquifers, and it decreased by 0.14 when water usage was concentrated in a fewer number of EUs. Lastly, the production value per worker, which was used as a proxy for the size of the EUs, showed that the larger the size the greater the efficiency. A higher

Table 1. Efficiency score for the different aquifers that make up the VMB.

Aquifer VMB	Situation	Efficiency	
Apan	ANO	0.893	
Tecocomulco	ANO	0.805	
Cuautitlan	ANO	0.795	
Soltepec	ANO	0.736	
Chalco Amecameca	AO	0.837	
Texcoco	AO	0.791	
Z Metropolitana Ciudad de Mexico	AO	0.824	
Condition of the aquifers		Efficiency	ANOVA
Aquifer not overexploited (ANO)		0.891	0.005
Aquifer overexploited (AO)		0.808	
TOTAL		0.812	

Table 2. Determinants of efficiency in the manufacturing industry of the VMB.

Number of obs		85	
Number of efficient DMUs		16	
Number of bootstr. Reps		1000	
Wald chi2 (6)		22.26	
Prob > chi2 (6)		0.0023	
efficiency: 0 < EF < 1	Coef.	Std. Err.	P>|Z|
Agglomeration economies			
Gini Index for the production value	0.19	0.099	0.052
Specialization Index for the production value	−0.02	0.008	0.004
Water scarcity			
Overexploited aquifers	−0.09	0.038	0.021
Gini Index for water consumption	−0.14	0.085	0.090
socioeconomic			
Size of the economic unit	0.06	0.025	0.026
Percentage of the total labour force	0.41	0.735	0.075
Constant	0.83	0.082	0.000

score was also found when there were more economically active people in the total labour market.

In this sense, the results show that water scarcity problems and the importance of this resource for production are factors that lead to inefficiencies in production. This is of crucial importance since various economic sectors in many of the world's hydrographic basins that are important in socio-economic terms are already experiencing significant problems with access to water and its quality. Therefore, from the public policy perspective, more and better conservation measures need to be considered for aquifer recharge zones, including the implementation of conservation measures for scarce production inputs and raising awareness among all economic sectors of the importance of the value of water.

V. Discussion and further reflections

The present econometric analysis used a two-stage DEA-based efficiency analysis. While this type of analysis has recently been used in the literature, it has not been widely applied to the manufacturing sector. This analysis made it possible to determine that agglomeration variables positively affected efficiency scores while specialization variables negatively affected it. In addition, the score was negatively affected by water scarcity, measured as accessing water from an overexploited aquifer. And lastly, the size of the economic units and the number of people available to be employed by the market positively affected efficiency. The new contribution provided by this study is the inclusion of the water scarcity variable as one of the main production inputs for one of the most important economic sectors in the VMB, the manufacturing sector, and for a sector located in a very densely populated zone with problems involving the overexploitation of aquifers. The literature reports very few studies on DEA that include this variable, especially for this sector. Consequently, the design of future public policies, particularly for hydrographic basins with water scarcity problems, should focus on good management of the conservation of aquifers so as to affect both the environment as well as adverse economic factors that reduce the efficiency and competitiveness of economic sectors that are important to the economy, as in the case of the manufacturing industry in the VMB. Lastly, it is recommended that more DEA studies be conducted that include socio-environmental variables such as water scarcity or quality for economies where those variables already present problems involving overexploitation, or where there is competition for their use and consumption among different sectors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This article was prepared with the financial support of the Valley of Mexico Basin's Water and Economic Model Project, as part of the "Programa de Cátedras CONACYT" [Nº 1812].

References

Adeoti, J. 2013. "Explaining the Characteristic and Efficiency of Manufacturing Firms in Lagos." *European Journal of Social Sciences* 37 (1): 121–138.

Asid, R. 2010. "The Technical Efficiency Analysis of Manufacturing Sector in Malaysia: Evidence from the First Industrial Master Plan (1986–1995)." *Asian Social Science* 6 (2): 99–120. doi:10.5539/ass.v6n2p99.

Charnes, A., W. W. Cooper, and E. Rhodes. 1978. "Measuring the Efficiency of Decision Making Units." *European Journal of Operational Research* 2 (6): 429–444. doi:10.1016/0377-2217(78)90138-8.

Coelli, T. J., D. S. P. Rao, C. J. O´Donnell, and G. E. Battesse. 2005. *An Introduction to Efficiency and Productivity Analysis*. USA: Springer. doi:10.1007/b136381

Conagua. 2012. "Programa Hídrico Regional, Región Hidrológico-administrativa XIII Aguas del Valle de México, México". Accessed 04 October 2019. http://www.pronacose.gob.mx/pronacose14/contenido/documentos/XIII%20PHOCAVM.pdf

Conagua. 2016. "Estadísticas del Agua en México, edición 2016". *CDMX, México*. Accessed 25 October 2019. http://201.116.60.25/publicaciones/EAM_2016.pdf

Consejo de Cuenca Valle de México. 2014. "Programa de Medidas Preventivas y de Mitigación de la sequía, México". Accessed 01 October 2019. http://www.gob.mx/cms/uploads/attachment/file/99971/PMPMS_CC_Valle_de_M_xico_Acta_aprobaci_n.pdf

Guarani, D. S., I. Pacheco-Lacerda, D. Riehs-Camargo, L. F. Dresch, and A. And Sartori-Piran. 2018. "Do the Improvement Programs Really Matter? An Analysis Using Data Envelopment Analysis." *BRQ Business Research Quarterly* 21: 225–237. doi:10.1016/j.brq.2018.08.002.

Gumus, S., G. Egilmez, M. Kucukvar, and Y. Shin Park. 2016. "Integrating Expert Weighting and Multi-criteria Decision Making into Eco-efficiency Analysis: The Case of US Manufacturing." *Journal of the Operational Research Society* 67 (4): 616–628. doi:10.1057/jors.2015.88.

Hu, Z., S. Yan, L. Yao, and M. Moudi. 2018. "Efficiency Evaluation with Feedback for Regional Water Use and Wastewater Treatment." *Journal of Hydrology* 562: 703–711. doi:10.1016/j.jhydrol.2018.05.032.

Korattukudy-Varghese, S., P. Chellattan-Veettil, S. Speelman, J. Buysee, and G. Van Huylenbroeck. 2013. "Estimating the Causal Effect of Water Scarcity on the Groundwater Use Efficiency of Rice Farming in South India." *Ecological Economics* 86: 55–64. doi:10.1016/j.ecolecon.2012.10.005.

Liu, K., G. Yang, and D. Yang. 2020. "Investigating Industrial Water-use Efficiency in Mainland China: An Improved SBM-DEA Model." *Journal of Environmental Management* 270: 110859. doi:10.1016/j.jenvman.2020.110859.

Lombardi, G. V., G. Stefani, A. Paci, C. Becagli, M. Miliacca, M. Gastaldi, B. F. Gianeetti, and C. M. V. B. Ameida. 2019. "The Sustainability of the Italian Water Sector: An Empirical Analysis by DEA." *Journal of Cleaner Production* 227: 1035–1043. doi:10.1016/j.jclepro.2019.04.283.

Long, K., and B. C. Pijanowski. 2017. "Is There A Relationship between Water Scarcity and Water Use Efficiency in China? A National Decadal Assessment across Spatial Scales." *Land Use Policy* 69: 502–511. doi:10.1016/j.landusepol.2017.09.055.

Mukwate Ngui-Muchai, D., and J. Muchai-Muniu. 2012. "Firm Efficiency Differences and Distribution in the Kenyan Manufacturing Sector." *African Development Review* 24 (1): 52–66. doi:10.1111/j.1467-8268.2011.00309.x.

Porter, M. E. 1998. *Clusters and the New Economics of Competition*. Harvard Business Review 76, no. 6 (November–December 1998): 77–90. https://www.hbs.edu/faculty/Pages/item.aspx?num=46852

Revollo-Fernández, D., L. Rodríguez-Tapia, and J. A. Morales-Novelo. 2020. "Economic Value of Water in the Manufacturing Industry in the Valley of México Basin, Mexico." *Water Resources and Economics* 30: 100138. (https://www.sciencedirect.com/science/article/pii/S2212428418300598 .

Simar, L., and P. W. Wilson. 2007. "Estimation and Inference in Two-stage, Semi-parametric Models of Production Processes." *Journal of Econometrics* 136 (1): 31–64. doi:10.1016/j.jeconom.2005.07.009.

Soni, A., A. Mittal, and M. Kapshe. 2017. "Energy Intensity Analysis of Indian Manufacturing Industries." *Resource-Efficient Technologies* 3: 353–357. doi:10.1016/j.reffit.2017.04.009.

Walheer, B., and M. He. 2020. "Technical Efficiency and Technology Gap of the Manufacturing Industry in China: Does Firm Ownership Matter?" *World Development* 127: 104769. doi:10.1016/j.worlddev.2019.104769.

Yao, X., W. Feng, X. Zhang, W. Wang, C. Zhang, and S. You. 2018. "Measurement and Decomposition of Industrial Green Total Factor Water Efficiency in China." *Journal of Cleaner Production* 198: 1144–1156. doi:10.1016/j.jclepro.2018.07.138.

You, S., and H. Yan. 2011. "A New Approach in Modelling Undesirable Output in DEA Model." *Journal of the Operational Research Society* 62 (12): 2146–2156. doi:10.1057/jors.2011.1.

Zhu, J. 2002. *Quantitative Models for Performance Evaluation and Benchmarking: Data Envelopment Analysis with Spreadsheets and DEA Excel Solver*. Boston: Kluwer Academic Publishers.