The Bullwhip Effect in the Northern States of Mexico: an Econometric and Sustainable Analysis in the Transport and Logistics Sector

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Abstract

Today, pollution and sustainability are two important aspects of the global agenda; however, economic growth is also an important but challenging factor that helps to minimize climate change and maximize society's progress. This article analyses the behavior of the Bullwhip Effect specifically in Mexico's transport and logistics sector during the period 2004 – 2017 as well as in the Northern States of Mexico and several OECD countries, taking into account the economic contractions that have happened as well as the existence of the sustainable phenomenon, applying a proposed model based on the Cobb-Douglas function and using the Time Series and Data Panel techniques using the stochastic frontier model (SFA). The objective of this article is to detect the sustainable inventory limits of Mexico's Transport and Logistics Sectors when the Bullwhip Effect arises, representing the above in useful applications for temporary measures obtaining economic and sustainable benefits. The results show that the maximum sustainable Bullwhip Effect limit for the logistics & transport sector in the northern states of Mexico is 23.1% and in several OECD countries is 40.0%.

Keywords
Bullwhip Effect, Northern states of Mexico, OECD countries, Transportation, Sustainability.

1. Introduction

The phenomenon of the Bullwhip Effect arises when the high trend of orders is presented to suppliers and higher than the sales themselves, in other words, the demand initiated by the customer is progressively amplified through the links of the supply chain (Lee et al. 2014). Its implications are varied as it relates directly to supply, demand, inventories, business cycles, and consequently with affectation to all links in the supply chain. This study phenomenon was analyzed in 1958 by Forrester, who has been regarded as the father of this study phenomenon, which by the way before being coined as "Bullwhip Effect", until the 1990s this had been known as the "Forrester effect" (Udenio 2014).

However, within the classic contexts in which the bullwhip effect relates such as demand signal processing, reasoning games, batch order, price fluctuations (Lee et al. 1997), there is a context in which it has gained remarkable relevance in recent decades and which has inserted uncertainty not only to companies but also to human existence itself: climate change and sustainability (Turrisi and Bruccoleru 2012), (Dahl et al. 2007). Several fields of study have inserted the sustainability variable as an active participant within the Economy (Labandeira et al. 2007), (Van den Bergh and Nijkamp 1997), Finance, Engineering, Medicine, Politics Science, Regional Science (Bell and Morse 2008), (Levin et al. 2018), (Grazi et al. 2007), Spatial Economics (Poirson and Weber 2011) and therefore this cannot be alien to the bullwhip effect. As the Bullwhip Effect occurs at any given time, companies alter their inventory levels from those that are not consistent with their demand levels, and as a result, is generating high storage costs (also resulting in unnecessary levels of contamination due to the production of unnecessary products for sale); otherwise, if the bullwhip effect is reverse, not having sufficient levels of products to meet demand also results not only in sourcing costs but also in unnecessary contamination due to increased emerging transport use to achieve such provisioning.

Today, where economic crises and fierce international competition between corporations is virtually the context of every day, it means that companies are pressured to reduce their inventories, their costs and even their assets; and when facing a temporary increase in demand while the company was in the previous context, it would not be able to respond nimbly to meet that demand which would diminish its competitiveness and thus jeopardize the company's very existence (Udenio 2014). This gives even more importance to the phenomenon of study of the bullwhip effect in the logistics field. Many researchers have been devoted to analyzing the Bullwhip Effect and sustainability from the Green Supply Chain (GSC) phenomenon where sustainable actions are meant to be carried out in a normative manner within the links of the supply chain itself. Our research is different in the sense that the basis of our analysis is constructed on the relationship between the macroeconomic behavior of the regional structure of economic growth, sustainability and the Bullwhip effect. The relevance of our research is that in Mexico, much of the supply chains are not entirely sustainable (especially those of the Transport Sector), so analyzing the external behavior of sustainability would be a relevant piece to drive it over supply chains, especially Mexico's second most polluting sector: the transport sector.

1.1 Objectives

The useful strategy for studying this aforementioned terna (bullwhip effect-economics-sustainability), is by understanding the behavior of each of its components over time and therefore these measurements can be obtained to control inventory levels, representing the above an alternative control for both public and private sectors. That is why this article figures out the following research question: What is the maximum sustainable level of inventory for the transport sector, given a bullwhip effect in a region? It is therefore that our overall objective is to empirically determine the maximum limits of inventory stock for the most polluting sectors of northern Mexico during the existence of the bullwhip effect phenomenon, applying both multivariate regression models as well as sustainable principles.

2. Literature Review

With research obtained from the Bullwhip Effect in recent decades, the causes of the effect have been detected by several authors, among which are: demand signal processing, reasoning games, batch order, price fluctuations (Lee et al. 1997). Other authors resemble the causes of this phenomenon in conjunction with the Beer Game phenomenon (Sterman 1989); note, then, that the main causes of this phenomenon are operational and behavioral in type. However, it appears that high levels of aggregation and seasonal data adjustments limit the empirical statistical reliability of this phenomenon.

However, despite various research on the Bullwhip effect on its causes as well as approaches to mitigate it, there are few proposals in this regard when it comes to inserting the Sustainability variable into that phenomenon. This is possible because the sustainable phenomenon is a one of new study since its concept was first formalized in the 1990s by UN decree (Dahl et al. 2007), compared to the study of the same bullwhip effect which its study began in the late 1950s. Another factor that has most likely impacted the scant investigation of this relationship is to believe that economic growth represents the antithesis of sustainable growth, which has already been proven that this approach is wrong. Economic growth is a tool like any other for making decisions, so it is very up to the decision-maker to end up having such growth. There are many interests at stake when carrying out the sustainability process within a society: industrial interests, financial interests, political interests, scientific interests, cultural interests, etc.; however, even though a sustainable culture is great in a region, it is an ethical and social duty to defend and strengthen the productive fabric to achieve sustainable processes for current and future generations.

Lee et al. (2014) adjust the customer's environmental needs within the bullwhip effect for three supply chains. As a methodology, they apply the Case Method. Although their contributions are important, those are normative – qualitative type focusing on standards that must be met for each link in the supply chain, leaving an area of opportunity in the quantitative aspect. Turrisi & Bruccoleri (2012), propose a model of optimizing the structure of reverse logistics, to avoid variability in production and therefore achieve polluting mitigation in favor of sustainability. However, while its proposals are important, sustainability is taken not as a direct variable but as a third effect as a result of the main effect, which is a limitation. Trivellas et al. (2020) detect keys to shaping the so-called "Green Logistics" through field research on several agricultural companies, including the transport network and transparent information between the links. Although they do not directly study the bullwhip effect, their empirical detections are qualitatively important. But they have an area of opportunity to quantitatively settle the variables of the bullwhip effect and sustainability. Shaban et al. (2020) analyze the bullwhip effect quantitatively using a production ratio and a regressive demand analysis. Sustainability is analyzed as a purely economic matter, without any environmental characteristic. While the contributions of the study of the bullwhip effect in this research are interesting, it has an area of opportunity to relate to environmental sustainability within the supply chain. Song (2018) analyses the phenomenon of spillover (externalities) of vertical and horizontal business interaction about greenhouse gas reduction, using a data panel. His contributions are interesting, however, he does not study directly the bullwhip effect and sustainability within supply chains. Roman et al. (s.f.) study the institutional regulatory effect to promote a "green" bullwhip effect within Brazilian supply chains. Through the case method, they detect that it is cooperation, regulation, audits, clauses and embargoes that support this form of mitigation to the bullwhip effect. However, although the keys detected are important, they are qualitative and normative in type. Klumpp (2011) proposes a brief and descriptive analysis of the implications of the "green" bullwhip effect within supply chains as well as general proposals for its study. Although his proposals are interesting, such proposals do not land on a mathematical model. Haque (2015) proposes a model to reduce the bullwhip effect with a focus on inventory management. Despite the proposal being interesting to mitigate this effect at the inventory level taking into account the supply chain, it does not take into account the sustainable effect. Jena (2012) studies the bullwhip effect for mitigation using a fuzzy logic model based on ANOVA. Although the results are very interesting, it does not apply sustainability variables as well as economic type variables.

3. Methods

For this research, it is proposed to build a macroeconomic model to represent aggregate behavior at the National and State level where the Bullwhip Effect, Economic Growth and Sustainability are also integrated and take place. Subsequently, we disaggregate the participation of the transport and logistics sector from the full sectors bullwhip effect that occurred in a given period, and once the significance of this model has been established, the efficiency of sustainability and spatial dependence concerning the bullwhip effect occurring in the transport and logistics sector is analyzed.

In this research, due to the statistical nature of the data obtained (see Results and Discussion section), the Stochastic Frontier Model is applied as it conforms to the type of drawing presented for the subject matter of study. The Stochastic Frontier Model (SFM) was proposed in 1977 by Aigner et al. and Meeusen & van den Broeck (Statacorp 2019): In this model, the reality is represented by the existence of failure and efficiency, therefore any production function [a] is accompanied by a level of efficiency (ξ_{it}) going from the value from 0 to 1, where 1 means the optimum point of efficiency; when less than 1, it means that the inputs of that function are not fully absorbed by the production function (Statacorp 2019): $q_{it} = f\ (z_{it}, \beta)\xi_{it}$; in this equations can be observed that the function of production quantities per time is represented by q_{it}; the matrix of the main characteristics of inputs is represented by z_{it}; the vector of estimated parameters is represented by β. One of the recent last decades' most efficient economic growth representative functions on GDP, is Cobb-Douglas's function. Based on this function, our proposed model is as follows:

$$Y = K^{\alpha_1} L^{\alpha_2} C^{\alpha_3} (w * T)_{t-1}^{\alpha_4} D_a^{\propto_5} D_b^{\propto_6} e^{\lambda}$$

$$\text{with } \sum_{i=1}^{n} \alpha_n > 0$$

Where Y = Aggregated production (PIB); K = Capital stock; L = Labor force; C = Pollution index; T = Transport & Logistics Sector Bullwhip Effect Index; w = Aggregated compensation parameter for the added bullwhip effect; D_a = Sustainability existence (dummy variable); D_b = Economic contraction (dummy variable); λ = Technological shock; α_n= variable regressor. With our proposed model, by leaving the sum of the parameters greater than zero and without restricting for to be greater than or less than 1, we thus give to our model the flexibility so that the most significant representation of the model itself is dictated by the nature of its variables, in other words, that the model detects in its final and significance results whether it is of a decreasing returns nature, consistent returns or increasing returns. It should also be noted that variable C (pollution index), we give nature as another input of production because it has had such behavior and importance in different models of various researches, and in this way we manage to relate sustainable behavior to our study. As part of our proposal, we represent the added bullwhip effect (effect resulting from all productive sectors) by $w * T$, in this way we can analyze the disaggregated bullwhip effect of the transport & logistics (T) sector without altering the total bullwhip effect of all production sectors. That is why w is represented by the reason of the total Bullwhip Effect concerning to one of the transport & logistics sectors. This representation needs to be made because our model has a dependent and aggregated nature variable. In addition, because the data worked are annual and taking into account the possibility that in the last months of the year a bullwhip effect could have arisen that with its overproduction could affect not only the current year but also the following one, that is why we propose to insert the AR(1) nature into the $w * T$ product.

Continuing with the accentuation of the representativeness of economic reality in our model, we apply two dummy variables to capture the existence over time of two phenomena of interest: sustainability and prevailing economic contraction. To determine the existence of sustainability during the study period, we apply the principle of the Finite State represented by Gallopín (2003): $\boldsymbol{V}(\boldsymbol{O}_{t+1}) \geq \boldsymbol{V}(\boldsymbol{O}_t)$; where $\boldsymbol{O}$ = output variable vector (existing inputs) and $\boldsymbol{V} =$ function of output variables. In our research, for practical purposes, the vector of output and input variables is represented by the independent variables consisting only of the variable $\boldsymbol{C}$ and $\boldsymbol{Y}$, therefore, we decide that sustainability exists when the production of the following year is greater than the current one but with a decrease in its contamination. For our research, the years in which the function applied by Gallopín is fulfilled is represented with value 1 in our variable dummy $\boldsymbol{D_a}$. Concerning the dichotomous variable representing economic contraction $\boldsymbol{D_b}$, it is represented by values of 1 for 2008 and 2009 years; in this way, we properly represent years when economic growth was affected by the last major mortgage depression of 2008. Therefore, by representing in a logarithmic way to our model we get the following equation:

$$lnY_t = \lambda + \alpha_1 lnK + \alpha_2 lnL + \alpha_3 lnC + \alpha_4 ln(w * T)_{t-1} + \alpha_5 D_a + \alpha_6 D_b + \varepsilon$$

Where ε is the error of the regression and λ is the technological change that represents the interception of the model and which at the same time also represents the "historical accident" of the study phenomenon (Krugman, 1998). To determine the Bullwhip Effect over a given period, we apply the approach described by Chacón et al. (2006) where it states that the bullwhip effect appears when the variance of a sector's production is greater than the variance of its demand, as long as its reason is greater than 1:

$$\textbf{Bullwhip effect} = \frac{\boldsymbol{Varaiance\ (Production)}}{\boldsymbol{Variance\ (Demand)}} > \mathbf{1}$$

4. Data Collection

The data used for our research were obtained from the following databases: a) National and state GDP: INEGI time series (2019) were taken. This database is located in the sections of GDP and national accounts, economic activity (national and state), detailed series, constant values at constant prices of 2013; b) Capital stock: INEGI time series (2021) were taken, specifically in the database of State and municipal finances, interactive tabulations, state public finances, entry chapter. For the determination of capital stock, the applied methodology was taken from Gutierrez (2017) based on perpetual inventories, with a depreciation rate of 9.7%, applied at constant prices in 2013; c) Labor: The statistical databases of the labor insured persons registered annually were used from both the IMSS portal as well as the ISSSTE subpage of the Government of Mexico. Data on the economically active population (PEA) in order to calculate informal labour were: PEA's (2000-2008) were taken from UNAM's Historical Statistics database of Mexico; and the rest of the years was taken from the National Occupation and Employment Survey (INEGI 2021); d) Sustainability: For national analysis, data for net Gg emissions in CO2e were taken from the National Institute of Ecology and Climate Change (INECC 2021) database; for state-level analysis, the Human Settlement and Environmental Health Indicators database was used (INEGI 2021), specifically motorization rates by federative entity; the above due to the lack of sustainable data available at the state level; e) Total annual production and total annual sales amount of the transport and logistics sectors: The time series of the INEGI interactive database, specifically the Automated Census Information System (INEGI 2021) were used; f) OECD countries data: Time series for OECD variables were taken from fred.stlouisfed.org such as GDP (Real GDP at Constant National Prices), Capital of Stock (Capital Stock at Constant National Prices), Force Labor (Number of Persons Engaged). Pollution Index (CO2 emissions embodied in domestic final demand, by source country and industry, from stats.oecd.org). To disaggregate the bullwhip effect, the next variables (taken from fred.stlouisfed.org and stats.oecd.org) were: Production of Total Industry (index 2015=100), Nominal Private Sector Final Consumption Expenditure (domestic currency), Total Manufacturing Production (index 2015=100), Production transport equipment (gross output, current prices).

The software used for the analysis of the above data in this investigation was STATA 15.0., SPSS 25, Eviews 12.0 and ArcGIS 10.3.

5. Results and Discussion

5.1 Numerical Results

Applying the Stochastic Frontier Model, we obtain the following parametric results for both the national and the state level (Table 1 and 2):

Table 1. Parametric results of the time series model (National level, Mexico)

Variable	Stochastic Frontier Model
Constant	2.602403*** (0.0001974)
ln$K$	0.0934029*** (2.28e-06)
ln$L$	0.6651004*** (0.0000136)
ln$C$	0.0663335*** (4.30e-06)
$\ln(w * T)_{t-1}$	-0.0289378*** (1.19e-06)
D_a	-0.0105106*** (7.84e-07)
D_b	-0.0728706*** (1.98e-06)
R-squared	Wald chi2(6) = 3.20e+11 Prob > chi2 = 0.0000

Own elaboration with STATA 15.0. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 2. Technical efficiency (National level, Mexico, by year)

year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
TE	1	0.978	0.967	1	0.985	1	0.989	1	0.948	0.994	0.979	1	0.934	0.983	1	0.989	1

Own elaboration with STATA 15.0. (TE: Technical Efficiency)

The obtained results are highly significant at 1% as can be seen, and with 95% with confidence. These results indicate to us that at the national level, Mexico posed moderately robust infrastructure to such an extent that when all its production factors were non-existent, an intercept of 2.6024 (constant parameter) would be obtained as natural urban support which is an output generated in decades. Subsequently, it was also found that for each 1 % of capital stock, aggregate production increases by 0.0934 %, a result that is quite acceptable according to economic research, in addition to showing that the investment made in the country during the study period is low. It is also found that for each 1% of the workforce, aggregate production increases by 0.6651%, which means that Mexico has a moderate level of employability. It is also found that for each 1% of the effect of the last great depression (the year 2008) it has hurt subsequent years of aggregate production by 0.0728 %, which is acceptable and consistent with economic theory.

Now, we go on to analyze the most connotation variables for our research, the bullwhip effect of the transport & logistics sector has negative behavior, that is, for each 1% of that bullwhip effect specifically in that sector, aggregate production decreases by 0.02893%, a result perfectly consistent with logistical theory because that effect causes that production factors are going to scarce resources unnecessarily because it meets an overestimated demand for the following links in the supply chain. An interesting detection of our results is that, despite the great efforts that both the public and private sectors have made in favor of sustainable culture and related actions, it has not been enough for Mexico during the study period which that is extremely worrying: the pollution rate increase by 0.0663% to increase aggregate production by 1%, a fact that is also confirmed by the result of our first variable dummy $\boldsymbol{D_a}$, wherein the years that the phenomenon of sustainability appears (years 2010, 2012 and 2017) resulted in a negative effect for domestic production in general by 0.01051 % on the 1% of aggregate production. This result is worrying. The sustainable efforts are found to need to multiply otherwise only a sustainable culture is being fostered in a way that is not advancing to a multiplicative one rather than just individual phase of results. Now, as part of our methodology to detect the maximum and most efficient factor levels, we develop the following proposal: through restrictions and with a *Ceteris Paribus* approach, different percentages of increase to this bullwhip effect are applied in our model until the first fall of technical deficiency observed in the stochastic frontier model is detected; subsequently, obtaining the following results (Table 3):

Table 3. Proposed methodological proposal for the determination of sustainable inventory, based on the technical efficiency of the stochastic frontier model.

year	α_4 -0.0289	α_4 Δ 45%	α_4 Δ 46%	α_4 Δ 47%	α_4 Δ 48%	α_4 Δ 48.10%	α_4 Δ 48.20%	α_4 Δ 48.30%	α_4 Δ 48.40%
2001	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2002	0.978	0.9762	0.9762	0.9761	0.9761	0.9761	0.9761	0.9761	0.9761
2003	0.967	0.9588	0.9586	0.9584	0.9582	0.9582	0.9582	0.9581	0.9581
2004	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2005	0.985	0.9763	0.9761	0.9759	0.9758	0.9757	0.9757	0.9757	0.9757
2006	1.000	0.9897	0.9895	0.9893	0.9890	0.9890	0.9890	0.9890	0.9889
2007	0.989	0.9783	0.9780	0.9778	0.9776	0.9775	0.9775	0.9775	0.9775
2008	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2009	0.949	0.9578	0.9580	0.9582	0.9584	0.9584	0.9585	0.9585	0.9585
2010	0.994	0.9996	0.9997	0.9998	1.0000	1.0000	1.0000	1.0000	1.0000
2011	0.980	0.9877	0.9879	0.9881	0.9882	0.9883	0.9883	0.9883	0.9883
2012	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2013	0.935	0.9174	0.9171	0.9167	0.9163	0.9163	0.9162	0.9162	0.9161
2014	0.983	0.9789	0.9788	0.9787	0.9786	0.9786	0.9786	0.9786	0.9786
2015	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2016	0.989	0.9969	0.9970	0.9972	0.9974	0.9974	0.9974	0.9974	0.9975
2017	1.000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Variance	0.0003678 1	0.0004950	0.0004982	0.0005025	0.0005068	0.0005070 5	0.0005075 8	0.0005078 9
	% Δ TE		34.5995%	0.6502%	0.8613%	0.8430%	0.0449%	0.1040%	0.0618%

Own elaboration with STATA 15.0. (α_4: regressor Bullwhip Effect; TE: Technical Efficiency).

Continuing with the same proposed methodology, we do the corresponding to the Northern States of Mexico, obtaining the following results (Table 4):

Table 4. Parametric results of the data pane model (Northern States of Mexico level)

Variable	Stochastic Frontier Model
Constant	5.72412***
	(0.7058376)
ln$K$	0.1575601***
	(0.0280943)
ln$L$	0.4069433***
	(0.0627793)
ln$C$	0.0467859 ***
	(0.0215913)
$\ln(w*T)_{t-1}$	-0.0044484***
	(0.0023492)
D_a	0.0200576 ***
	(0.0101139)
D_b	-0.045442***
	(0.0142248)
R-squared	Wald chi2(6) = 956.02 Prob > chi2 = 0.0000

Own elaboration with STATA 15.0. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The obtained results are highly significant at 1% as can be seen, and with 95% reliability. We can see that the parametric differences concerning the obtained data at the national level are not so pronounced, but if there are differences in their interpretation: we can see that the intercept, or the "historical accident" (Krugman, 1998), is higher than the national average because the northern region of the country has always been characterized by having a more agile infrastructure and culture in terms of productivity mainly because is located with the border with the United States and having another type of work idiosyncrasy in its inhabitants. The level of fixed investment (capital stock) is a parametric value of 0.1575, which although is higher than the national average, is still low if we contrast it with other global regional references. It is also noteworthy that, unlike the national parameter, the obtained value is lower for the slope labor (0.4069), indicating that the generated production in the northern states of Mexico is almost balanced between labor and industrial automation, which is congruent due to the industrial turns that exist in these entities. Note also that the negative effect on the 2008 economic downturn is slightly less than the rest of the national, which is consistent with the different economic infrastructure of this northern region.

Turning to the connotating results for our research, also noticed that the parametric level of contamination of these entities (0.04678) is slightly lower than the rest of the national, which is congruent because of the technology and work idiosyncrasy that prevails in these entities are affecting the sustainable aspect. An interesting result is that the parametric value of the bullwhip effect of the transport and logistics sector is -0.004448, that is, for each 1% share of this bullwhip effect specifically in that sector, the aggregate production of the northern states decreases by -

0.004448 %. This result represents only 15.37% of the ratio between the bullwhip effect at the national level, which tells us that in the northern states the optimization and storage and production activities of the transport and logistics sector are well-performing compared to the rest of the national level. Another obtained result with a notable difference is the parametric value of the sustainable existence dummy variable (0.02005), which means that for each 1% when the sustainability effect arises, aggregate production in the northern states increased by 0.02005%, which is contrary to the behavior obtained from the data at the national level. This means that when sustainability exists in those Mexican states, in one or more of them, its effect is a multiplier on its production in all the entities of the north thanks to the originated sustainability. This is an encouraging step forward in the sustainable development of this region, however, this achievement is absorbed by the rest of the country as can be seen in the value of the same dichotomous variable at the national level (-.02893). However, while sustainable achievement by the northern states of the country is small, it is a hopeful step for the multiplier effect of sustainable culture required by the country.

The technical efficiency of the stochastic frontier model applied to state-level analysis tells us which federal entity efficiently used its resources and production factors in a better way during the 2004 – 20017 study period. We can see that the most deficient federal entity is Baja California Sur, so it has a considerable area of opportunity to be used and accelerates its available resources as well as in the transportation and logistics sector; on the other hand, the federal entity that had a very high level of efficiency is Nuevo León. Nuevo León, has generally been characterized by being not only the 2nd metropolis of the country (generally the 1st. has been considered the capital of the country, Mexico City), but also has the enormous advantage that is positioned in a strategic location where the routes of transport and logistics of the country about the United States are the shortest one, and that represents a natural competitive advantage for that federative entity, which is checked against the obtained results. Applying our methodology through a Ceteris Paribus approach, the results of technical efficiencies were as follows (Table 5):

Table 5. Proposed methodological proposal for the determination of sustainable inventory, based on the technical efficiency of the stoic border (Northern States of Mexico level).

	TE	Δ 20%	Δ 21%	Δ 22%	Δ 23.2%	Δ 24%
α_4	-0.0044484	-0.00533808	-0.00538256	-0.00542705	-0.00548042	-0.00551602
Da	0.02006	0.019850	0.019840	0.019829	.0198167	0.019079
Baja California	0.5768081	0.5763216	0.5762973	0.5762731	0.5762439	0.5762244
Baja California Sur	0.2814029	0.2815942	0.2816042	0.2816142	0.2816262	0.2816342
Coahuila	0.6509864	0.6510287	0.6510309	0.6510331	0.6510355	0.6510373
Chihuahua	0.5124201	0.5126654	0.5126776	0.5126898	0.5127043	0.512714
Durango	0.3026584	0.3027118	0.3027147	0.3027176	0.302721	0.3027234
Nuevo León	0.9776021	0.9775894	0.9775882	0.9775871	0.9775853	0.9775841
Sinaloa	0.4338944	0.4339204	0.4339218	0.4339232	0.4339248	0.4339259
Sonora	0.6220657	0.6221931	0.6221997	0.6222063	0.6222141	0.6222193
Tamaulipas	0.5564063	0.5569046	0.5569295	0.5569544	0.5569841	0.557004
Variance	0.0433835	0.04336458	0.04336354	0.04336251	0.04336122	0.04336036
Δ TE		-0.04360%	-0.00240%	-0.00237%	-0.00297%	-0.00199%
Δ Da		-1.04686%	-0.05038%	-0.05544%	-0.06203%	-3.72262%

Own elaboration with STATA 15.0. ($\boldsymbol{\alpha_4}$: regressor Bullwhip Effect; Da: Sustainability, dummy; TE: Technical Efficiency)

With the above results, we can see that negative variance increases almost double when the coefficient of the state bullwhip effect is increased to 23.2%. Therefore, the maximum limit of the sustainable bullwhip effect at the state level is 23.2%, specifically for the northern part of the country.

Concerning the behavior of the percentage change regressors on the rest of the variables (K, L, C, D_a, D_b, constant) for states of northern states of Mexico data panel, when the Δ of Bullwhip Effect reaches 23.2% (-0.00548042), under Ceteris Paribus approach applying the same model with a significance level of 5%, the results were -0.168%, 0.164%, -0.365%, -1.201%, -1.17% and -0.179%, respectively. As can be seen, in all the regressors it has a negative impact (except for variable L), which is inferred that the existence of sustainability in these northern states deteriorates by 1.20%; this sustainability variable being the one that presented the most negative effect of the rest of the other productive factors. We can also observe that a 23.2% increase in the Bullwhip effect in these northern states, leads to a deterioration in their capital stock (-0.168%) thus representing a decrease in long-term investment, and further increases environmental pollution causing it to negatively impact aggregate production by -0.365%; on the other hand, and this same environmental damage consequently decreases the homeostasis of these regions (represented by interception) by -.179%. This scenario, also represents a decrease of 1.17% concerning the conjunctural economic advantage that this northern region obtained from the global economic contraction of 2008. Another interesting fact is that in this scenario the only increase is observed in the labor variable (L) with 0.164%, which represents an increase in employment and use of labor in the face of this adverse scenario.

To determine a comparison with the rest of the countries, the same proposed methodology was applied for most of the OECD member countries such as the United Kingdom, Germany, United States, Sweden, Spain, Portugal, Poland, Netherlands, South Korea, Japan, Italy, France, Finland, Czechoslovakia, Canada, Belgium, Austria, India and Turkey (these countries were selected by availability data). The obtained results (Table 6 and 7) indicate that in this world representative region, the existence of sustainability (D_a) has a positive impact on aggregate economic production. However, the bullwhip effect begins to generate its negative effect on production until it increases by up to 40.0 % so that the technical efficiency of the factors in these countries begins to stagnate.

Table 6. Parametric results of the data pane model (OECD Countries level)

Variable	Stochastic Frontier Model
ln$K$	0. 6963105***
	(0. 0206762)
ln$L$	0. 2669311***
	(0. 0526119)
ln$C$	0. 1423757 ***
	(0. 0169373)
$\ln(w * T)_{t-1}$	-0. 0020082***
	(0. 0005992)
D_a	0. 0193882 ***
	(0. 0035323)
R-squared	Wald chi2(6) = 2873.79 Prob > chi2 = 0.0000

Own elaboration with STATA 15.0. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7. Proposed methodological proposal for the determination of sustainable inventory, based on the technical efficiency of the stochastic frontier model (OECD countries level).

	TE	Δ 20%	Δ 25%	Δ 30%	Δ 35%	Δ 36%	Δ 37%	Δ 38%	Δ 39%	Δ 40%	Δ 45%	Δ 50%
α_4	-0.002	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
D_a	0.0193	0.01921	0.01917	0.01913	0.01909	0.01908	0.01907	0.01906	0.01905	0.02011	0.01901	0.01897
United Kingdom	0.114	0.119	0.120	0.122	0.123	0.124	0.124	0.124	0.124	0.142	0.126	0.128
Germany	0.115	0.120	0.122	0.123	0.125	0.125	0.126	0.126	0.126	0.144	0.128	0.130
United States	0.125	0.130	0.132	0.134	0.136	0.136	0.136	0.137	0.137	0.156	0.140	0.142
Sweden	0.140	0.145	0.147	0.149	0.150	0.151	0.151	0.151	0.152	0.173	0.154	0.156
Spain	0.108	0.113	0.114	0.116	0.117	0.117	0.118	0.118	0.118	0.135	0.120	0.122
Portugal	0.089	0.092	0.093	0.094	0.095	0.096	0.096	0.096	0.096	0.110	0.098	0.099
Poland	0.172	0.179	0.181	0.183	0.185	0.186	0.186	0.187	0.187	0.213	0.190	0.193
Netherlands	0.137	0.143	0.144	0.146	0.148	0.148	0.148	0.149	0.149	0.169	0.151	0.153
South Korea	0.109	0.114	0.115	0.116	0.118	0.118	0.119	0.119	0.119	0.136	0.121	0.123
Japan	0.096	0.100	0.102	0.103	0.104	0.105	0.105	0.105	0.105	0.120	0.107	0.109
Italy	0.094	0.098	0.099	0.100	0.102	0.102	0.102	0.103	0.103	0.117	0.105	0.106
France	0.108	0.113	0.114	0.116	0.117	0.118	0.118	0.118	0.118	0.135	0.120	0.122
Finland	0.153	0.158	0.160	0.162	0.164	0.164	0.164	0.165	0.165	0.187	0.167	0.170
Czech	0.101	0.105	0.106	0.108	0.109	0.109	0.109	0.110	0.110	0.125	0.112	0.113
Canada	0.128	0.134	0.135	0.137	0.138	0.139	0.139	0.139	0.140	0.159	0.142	0.144
Belgium	0.120	0.125	0.126	0.128	0.129	0.129	0.130	0.130	0.130	0.148	0.132	0.134
Austria	0.130	0.135	0.137	0.138	0.140	0.140	0.141	0.141	0.141	0.161	0.143	0.145
India	0.066	0.068	0.068	0.069	0.069	0.070	0.070	0.070	0.070	0.085	0.071	0.071
Turkey	0.246	0.256	0.259	0.262	0.265	0.265	0.266	0.267	0.267	0.300	0.271	0.274
Variance :	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Δ TE		8.18%	2.15%	2.21%	2.28%	0.46%	0.46%	0.47%	0.47%	22.18%	-15.79%	2.48%
Δ D_a		-0.90%	-0.22%	-0.22%	-0.22%	-0.04%	-0.04%	-0.04%	-0.04%	5.53%	-5.48%	-0.21%

Own elaboration with STATA 15.0. (α_4: regressor Bullwhip Effect; D_a: Sustainability existence dummy variable; TE: Technical Efficiency)

It stands out given the above results, that Turkey is the country with the highest level of technical efficiency in its production factors (0.246398); oppositely, the country with the lowest level of its production factor is India (0.066199). It also highlights something worrying: if we make a proportional ratio of the resulting parameters regarding the level of pollution (variable C) concerning the regional capital stock, it is obtained that for the region of the northern states of Mexico obtains 29.69%, while in the region of the OECD countries the same ratio is 20.44%, that is, that the northern states of Mexico have a very important area of opportunity in the sustainable aspect concerning their economic growth, if we compare it with the results obtained from the OECD countries analyzed.

5.2 Graphical Results

The technical efficiency data obtained from the proposed data panel was applied to the Morans I spatial autocorrelation model, under the reverse distance relationship on Euclidean method, with the following results obtained (Figure 1 and 2): the northern states of Mexico have a random spatial type on its technical efficiency, meaning that the efficiency spillovers related to the bullwhip effect on this region are not enough to support the resilience between the terna Bullwhip effect-Economics-Sustainability; probably due to its cosmopolitan and globalizing commercial features. This is an additional reason why this northern region must take action on this resilence issue and an excellent opportunity to take advantage of the technical efficiency index obtained from every northern state and sustainable capacity limit for its bullwhip effect (Figure 3). Previous results resulting from the Morans I model indicate that during the 2004-2017 study period, the northern features of the country did not have a different spatial economic scenario than random. This also tells us that the economic agglomerations that took place within these federative entities did not have a significant influence in achieving the obtained technical efficiencies. This also means that the northern states of Mexico do not behave predominantly as a conglomerate that protects it to achieve its productivity about its geographical position, but behaves like a region where its strengths are strongly concentrated with the foreign market. This result is consistent because this area of the country borders the United States of America.

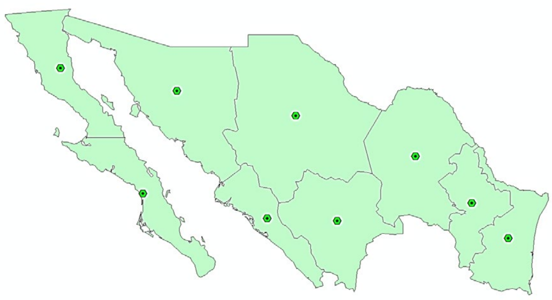

Figure 1. Medium centres of the study regions
Own elaboration with software AcGIS 10.3

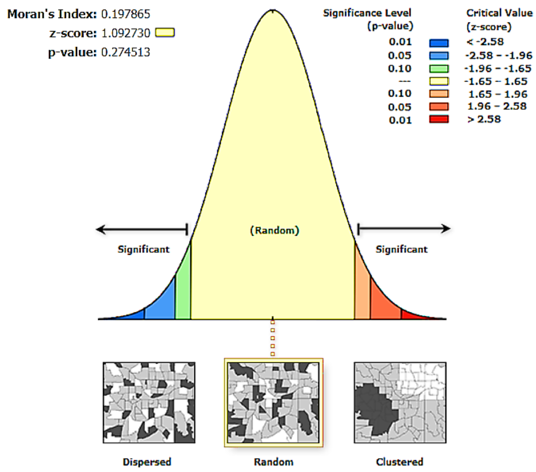

Figure 2. Moran Index (I) results on the technical efficiency indices of the Northern states of Mexico.
Own elaboration with software AcGIS 10.3

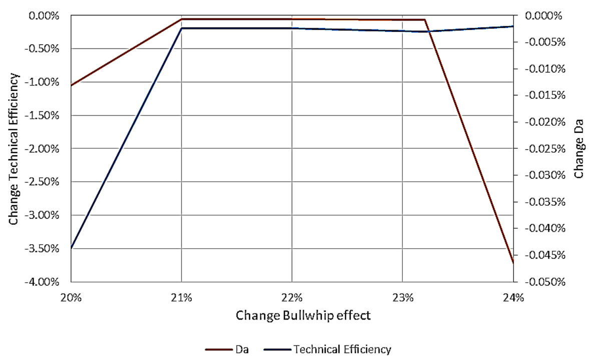

Figure 3. Sustainable capacity limit for Northern states of Mexico´s bullwhip effect.

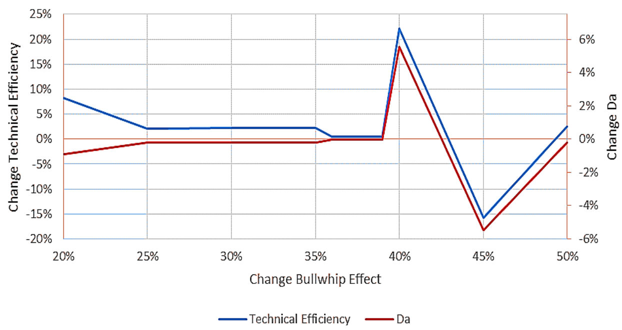

Figure 4. Sustainable capacity limit for OECD Countries´ bullwhip effect.

On the other hand, contrasting the same results of the changes in percentages applied in the parameter of the Bullwhip Effect and analyzing the results between the variable of the technical efficiency of each analyzed OECD country as well as the variable of Pollution (*C*), but converting them into a regression and rectangle graphs, we get the following results: in Figure 4, the obtained results show that in the resilence of sustainability existence takes place until the technical efficiency reaches almost 40 % on change, meaning that the sustainable capacity limit for its bullwhip effect for the transport sector supply chains. This result must to bee seen as if these countries were running as a common region.

5.3 Proposed Improvements

Based on the results obtained in our research, it is proposed that in the case of Mexico, specifically in its northern states, is essential that the transport supply chains that prevail in these regions re-evaluate their storage capacities related to the transport sector so that they do not exceed 23.1 % of their current capacity, and in this way avoid structural damage, both economic and environmental one. Urgency must be taken in this aspect, since this region presents two alarming aspects obtained: that this region has a random spatial behavior (which makes it even more difficult to apply sustainable resilience policies in the logistical aspect) and that in addition, its level of pollution is much higher than some of the most relevant member countries of the OECD.

5.4 Validation

We detected the deviation of our data from the normal distribution: the level of skewness that although close to the value of zero in most variables, is not entirely symmetrical to its normal distribution curve because for the case of the National level series is predominantly and slightly elongated to the right; and as for the state-level series some lengthened to the left and others to the right. On the other hand, the values of kurtosis indicate that for most variables both National, State and Countries levels are less than 3 which represents a very flattened curve. So our residuals resulting from our model tend to non-normal distribution, predominantly. This underpins the need for both the use of a technique of a different type of statistical distribution as well as the application of dummy variables, which also justifies for our research the use of the Stochastic Frontier Model technique (with exponential distribution) as well as the two dummy variables of our macroeconomic model (D_a y D_b). In addition to performing these descriptive tests, we apply a unitary root test to our series data to verify that their level of integration is under economic theory and to ensure that our estimates are not spurious (Alviar et al. 2006): ln$Y$ I(1); ln$K$ I(2); ln$L$ I(1); ln$C$ I(1); ln$T$ I(1); ln$w$ I(0). Subsequently, we apply three types of Cointegration tests (Kao, Pedroni, Westerlund) for our data panel obtaining the following results shown in Table 8. In conclusion from these tests, we can affirm that our data are not spurious.

Table 8. Cointegration test for States & OECD data panels

Test	State level	State level		OECD level	
		Statistics	P-valor	Statistics	P-valor
Test Kao	Modified Dickey-Fullert t	-3.8311	0.0001	1.8409	0.0328
	Dickey-Fuller t	-3.4589	0.0003	1.4442	0.0743
	Augmented Dickey-Fuller t	-3.4313	0.0003	1.4060	0.0799
	Unadjusted modified Dickey-Fuller t	-3.9003	0.0000	1.8742	0.0304
	Unadjusted Dickey-Fuller t	-3.4792	0.0003	1.4820	0.0692
Test Pedroni	Modified Phillips-Perron t	3.6395	0.0001	4.7939	0.0000
	Phillips-Perron t	-1.1036	0.1349	-2.0466	0.0203
	Augmented Dickey-Fuller t	-0.3012	0.3816	-4.4978	0.0000
Westerlund	Variance ratio	2.4479	0.0072	5.7044	0.0000

Own elaboration with STATA 15.0.

In Table 9, the null hypothesis for all cointegration tests is that there is no cointegration. Therefore, as can be seen, the null hypothesis is rejected as prevalent. For most results, it is then accepted that in our data pane they cointegrate the study variables over time.

Table 9. Unit Root Tests for National level time series.

Variable	Difference	ADF		Phillips-Perron		KPSS	Order of Integration
		Intercept & Trend	P-values	Intercept & Trend	P-values	Intercept & Trend	
ln$Y$	1st	-3.8551	0.0407**	-4.205	0.0223**	0.08865	I(1)
ln$K$	2nd	-4.5564	0.0133**	-4.8274	0.0085***	0.124266*	I(2)
ln$L$	1st	-3.4734	0.0770*	-3.45932	0.0787*	0.151724**	I(1)
ln$C$	1st	-4.2504	0.0206**	-4.2504	0.0206**	0.09319	I(1)
w	level	-3.815	0.0417**	-3.8026	0.0426**	0.09098	I(0)
T	1st	-5.2504	0.0037***	-11.871	0.000***	0.5000***	I(1)

Own elaboration with Eviews 12.0. *** p<0.01, ** p<0.05, * p<0.1.

6. Conclusions

The Bullwhip effect is a phenomenon of study where information concerning market demand is distorted through the different links of supply chains in such a way that production and unnecessary storage costs and scarce resources are generated. This phenomenon of study, although since 1958 has been studied in depth, today there is very little research where its relationship and behavior with the sustainable effect in Mexico is analyzed. In this regard, this research provides a proposal for controlling and resiling the sustainable Bullwhip Effect in the transport & logistics sector in Mexico, by identifying the maximum sustainable levels of production of this sector (23.1% of the excess over the actual bullwhip effect they have) based on our methodology taking into account the levels of stochastic technical efficiency of northern states of Mexico based on the data 2004 – 20017.

The future lines for research, generated from this investigation, are among others: the application of the methodological proposal applied to the rest of the federal states of Mexico (center and south region states); the behaviour of the bullwhip effect of the transport & logistics sector and its sustainable levels of production in the face of economic convergence and divergence scenarios; inserting to the proposed model sustainability variables where human capital is included; analyze the spatial lapse behavior of the bullwhip effect in relation to the sustainable phenomenon within the transport & logistics sector for the central and southern sectors of Mexico; apply the methodology and the present model with respect to specific types of sustainability such as those related to the sustainability of water, agriculture or forestry in relation to the bullwhip effect that occurred in the transport & logistics sector; determine the geographical strategic areas of each state to develop commercial agglomerations in order to be favorable both for sustainable spillage and for the productivity of the logistics & transport sector; apply the methodology and model proposed in this research specifically on the behavior of the bullwhip effect but as panels of continental world regions (Europe, Asia, Africa, America, Oceania) as well as under an extrapolation of time series until 2021 to see how this bullwhip effect behaved during the COVID-19 pandemic.

Undoubtedly the field of study of the bullwhip effect is wide and interesting. Despite its extensive analysis, there are still several areas of opportunity that can be used thanks to the Big Data tools and therefore this same bullwhip effect can be analyzed with information from the more than 2400 municipalities that compose up Mexico, obtaining useful conclusions in favor of the progress of the Transport & Logistics Sector.

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