A formulation for measuring the bullwhip effect with spreadsheets
Una formulación para medir el efecto bullwhip con hojas de cálculo

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Abstract: The bullwhip effect refers to the scenario in which orders to suppliers tend to present larger fluctuations than sales to buyers, and the resulting distortion increasingly amplifies upstream in a supply chain. We propose a transformation of the known formulation by Chen et al. (2000) to calculate the bullwhip effect in a supply chain for the purpose of being easily applied with spreadsheets without using VBA macros. We present this formulation modeled by Ms Excel® using a numerical example.

Key words: bullwhip effect, measuring, spreadsheet.

Resumen: El efecto bullwhip se refiere al escenario en el que los pedidos al proveedor tienden a presentar mayores fluctuaciones que las ventas a los compradores, y la distorsión resultante se amplifica crecientemente aguas arriba en una cadena de suministro. Se propone una modificación de la conocida fórmula de Chen et al. (2000) para calcular el efecto bullwhip en una cadena de suministro con el objetivo de que sea aplicada fácilmente a través de hojas de cálculo sin usar macros VBA. Se presenta esta formulación con Ms Excel© usando un ejemplo numérico.

Palabras clave: efecto bullwhip, medida, hoja de cálculo.

1. Introduction

An integrated supply chain includes purchasing raw materials, manufacturing with assembly, or sometimes also disassembly, and the distribution and re-packaging of produced goods sent to end customers. Various operating stages in the logistic chain (chain nodes) can be represented by a simple model of some material-transformations or location-changes processing cells and arcs. In each processing cell, a value is added and some costs are incurred. There is also supply and demand, and both are often stochastic in nature.

Inventories are an insurance against risk of shortage of goods in each cell of a logistic chain. They are limited by not only the given capacity of each processing node, but also by the transportation capability of the input and output flows.

The bullwhip effect, a well-known phenomenon, was already intensively studied by the mid-20th century, and was known previously under the name of demand amplification or the Forrester effect (Forrester, 1961). It is often considered to reduce uncertainty in demand, and also because of a lead time stochastic behavior.

The Forrester effect is also encompassed in Sterman's bounded rationality (Sterman, 1989). Such an approach is particularly welcome when mathematical tools are either not well developed or not well understood.

Most research works on demand amplification have focused on demonstrating its existence, identifying its possible causes, and developing methods for mitigating its negative effect. Lee et al. (1997a) identify four main causes of the bullwhip effect: wrong methods of demand forecasting, supply shortage anticipation, batch ordering and price variation. Demand amplification occurs mostly because of finite perturbations in final demand and in lead times throughout the supply chain, which is always anticipated and interacts with other causes. How the industry faces this phenomenon has been broadly studied by Lee et al. (1997b), where some considerations of the bullwhip effect in supply chains are presented in detail. For an extension of the

bullwhip effect concept in a supply chain, we refer readers to Campuzano and Mula (2011).

The main contribution of this paper is to propose a transformation of the formula by Chen et al. (2000) in order to measure the bullwhip effect in supply chains, for the purpose of using it easily with spreadsheets and without having to develop VBA macros.

The rest of the paper is organized as follows: Section 2 reviews the main alternatives to measure the bullwhip effect. Section 3 proposes a transformation of the formulation by Chen et al. (2000) to measure the bullwhip effect. Section 4 presents the application of our proposal to spreadsheets using a numerical example. Finally, Section 5 provides the conclusions and further research.

2.   Measuring the bullwhip effect

As mentioned above, the bullwhip effect refers to the scenario in which orders to suppliers tend to present larger fluctuations than sales to buyers, and distortion propagates up a supply chain in an amplified manner. As distortion creates additional costs, bullwhip indicators are assumed to be in contingency with costs or added value.

Ordering goods (input flow) in distribution centers can be studied as a multi-period dynamic problem. The demand during each period can be considered a stochastic variable. The distribution of this variable is often described with a certain probability function. It is identically distributed in our proposal, based on the production and inventory control results, especially on the variability trade off study as presented by Dejonckheere et al. (2003). It is also based on the study of the impact of information enrichment on the bullwhip effect in supply chains (Dejonckheere et al. 2004), where some measures have been introduced.

Amplification upstream of the supply chain can be measured through the variance of demand along the supply chain. Lee at al. (1997b) proposed changes to the variance in demand σ^2 upstream as a measure of the bullwhip effect. It is a good measure, but only when units of flow along the chain do not change, which is not the case of many logistics problems. Chen et al. (2000) suggest that in order to avoid this problem, the bullwhip effect should be measured by changing the ratio of σ^2/μ upstream of the supply chain, where μ is the expected value of the intensity of flows. Once again however, it does not help to avoid the effect of changing the unit of measure. Chen

et al. (2000) suggest that a measure of the bullwhip effect could be the ratio of these parameters either between the input and output flows at each activity cell in a supply chain upstream when considering only one stage or between final demand and the first manufacturing stage when the total supply chain is to be evaluated as it has more stages.

$$Bullwhip = \frac{\sigma_O^2 / \mu_O}{\sigma_D^2 / \mu_D} = \frac{\sigma_O^2}{\sigma_D^2} \qquad (1)$$

Unfortunately σ^2/μ is not a measureless ratio. Therefore, it is difficult to understand the ratio of these measures between the input and output flows, especially where assemblies and disassemblies change the unit of measure of μ between input and output, and when we wish to compare this phenomenon in different supply chains. Thus in this paper, we assume that the unit of measure does not change in our supply chain.

In the statistical analysis, the actual variation described by variance or standard deviation is often replaced with the measure of relative dispersion. If absolute dispersion is measured by standard deviation σ as the root mean square of the deviation from the mean, and if the average is the mean intensity of supply chain flows μ, then the relative dispersion normally used in basic statistics is the coefficient of variation $V = \sigma/\mu$ and the estimation is generally expressed as a percentage, which would also be a good indicator here. But following the approaches of previous authors, we maintain the bullwhip measure, as suggested by Chen et al. (2000), and we shall not change the units upstream of flows.

3.   Formulation proposal

We propose the following transformation of Formula (1) provided by Chen et al. (2000) to measure the bullwhip effect for the purpose of easily using it with spreadsheets.

In order to compute the measure proposed by Chen et al. (2000), and considering the importance of calculating performance measures to supply chain behavior, we built a spreadsheet based on its measure.

The calculus of the bullwhip effect is based on the variance of both variables: sales and orders. As the bullwhip effect is an amplification of orders in the supply chain as a result of unshared information at all the supply chain levels, we analyze these variables as follows.

First, the calculus of the variance of sales is done by utilizing the spreadsheet variance formula because it must be calculated by using all the dates available; i.e., the dates associated with each period, from zero to the *t* period.

Moreover, the variance associated with the variable of orders must be calculated only to each period. This presents some differences between sales and orders. Given the assumption that it depends only on the current period (periods in which differences between orders and sales differ from zero), it can be interpreted as follows: the vector of orders x_i to period *n* is a vector of *n* elements, for which the first *n-*1 elements are equal to zero and the *n*-th term is the value of the orders to period *t*. As a result of this assumption, the calculus of the variance of orders is based on the general formula of the variance, as shown in Equation (2). This formula considers *n-*1 elements because it is a sample variance, generally for a limited number of data.

$$Var\,(x) = \frac{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}{n-1} \tag{2}$$

As the assumption that the vector of orders is composed of *n-*1 terms which are equal to zero, the variance calculus implies a sum of the t terms that has *n-*1 identical terms and that one term is associated with the *n*-th period. Given the structure of the vector of orders, we can express the variance formula as shown in Equations (3) and (4).

$$Var\,(x) = \frac{\left(\sum_{i=1}^{n-1}\left(x_i - \overline{x}\right)^2\right) + \left(x_n - \overline{x}\right)^2}{n-1} \tag{3}$$

$$Var\,(x) = \frac{(n-1)\,(-\overline{x})^2 + \left(x_n - \overline{x}\right)^2}{n-1} \tag{4}$$

According to the assumption of the vector of orders, the mean of orders can be calculated as the orders in *n* periods divided by *n*. As a result of the replacement of the mean of orders in Equation (4), we can express the formula of the variance of orders as follows:

$$Var\,(x) = \frac{(n-1)\left(-\dfrac{x_n}{n}\right)^2 + \left(x_n - \dfrac{x_n}{n}\right)^2}{n-1} \tag{5}$$

The expression shown in Equation (5) can be implemented easily in a spreadsheet because it depends only on data quantity (*n*) and on the last orders information.

Then, we implement the expression of the bullwhip effect measure (BEM) to the *t* period, BEM_t, as a cumulative expression of the effect of individual period distortions by using a conditional expression presented in Equation (6).

$$BEM_t = \begin{cases} BEM_{t-1} & if\ orders_t - sales_t = 0 \\ BEM_{t-1} + \dfrac{Var\ (Orders)}{Var\ (Sales)} & in\ other\ wise \end{cases} \tag{6}$$

Note that the BEM can be calculated as a cumulative value to each period. The formulas in Equations (5) and (6) were implemented by using a numerical example in order to evaluate their performance. In the next section, we present a numerical example and the spreadsheets used to calculate the bullwhip effect.

4. Numerical example with spreadsheets

The example presented in Figure 1 shows the BEM, which was calculated by using the expressions presented in Equations (5) and (6). Demands were generated by a discrete uniform distribution between *x* and *y*; i.e., they are identically distributed.

Figure 1
Spreadsheet implementation of the BEM formula

t	Sales	Orders	Receptions	Differences	Orders Variances	Sales Variances	BEM
0	0	0,00	0,00	0,00			0,00000
1	1	1,60	0,00	0,60	1,28000	0,50000	2,56000
2	1	1,48	0,00	0,48	0,73013	0,33333	4,75040
3	2	2,98	1,60	0,98	2,22606	0,66667	8,08950
4	2	2,79	1,48	0,79	1,55370	0,70000	10,30906
5	1	1,03	2,98	0,03	0,17673	0,56667	10,62095
6	2	4,37	2,79	2,37	2,72693	0,57143	15,39307
7	1	0,25	1,03	-0,75	0,00781	0,50000	15,40870
8	1	0,25	4,37	-0,75	0,00694	0,44444	15,42432
9	2	2,75	0,25	0,75	0,75625	0,45556	17,08439
10	1	0,25	0,25	-0,75	0,00568	0,41818	17,09797

The spreadsheet formulation used to calculate the BEM should be carried out as detailed below.

Differences formula in Cell N8

=L8-B8

Variance orders formula in Cell O8

=(IF(N8<>0;(A8)*POWER(L8/(A8+1);2)+PO-WER(L8-(L8/(A8+1));2);0))/A8

Variance sales formula in Cell P8

=VAR(B$7:B8)

Bullwhip Effect Measure formula in Cell Q8

=Q7+IF(N8=0;0;(O8/P8))

The first expression corresponds to the difference between the values of orders and sales to the period one. Sales and orders are presented in Figure 2.

Figure 2
Sales and orders versus time; a numerical example

The second expression shows the form in which the current relationship to the variance of orders is calculated. Here, the formula is only calculated when the difference between orders and sales differs from zero (N8); n is the period in which the variance of orders is calculated, and it is the value in cell A8 plus 1 (because the period zero is included in the data quantity); n-1 is the value of cell A8; L8 represents the orders in the period, which is used to calculate the mean of orders.

The formula of the variance of sales is merely a spreadsheet formula of the variance, which is calculated according to the sales from the zero period to the current period (the period is in the A column).
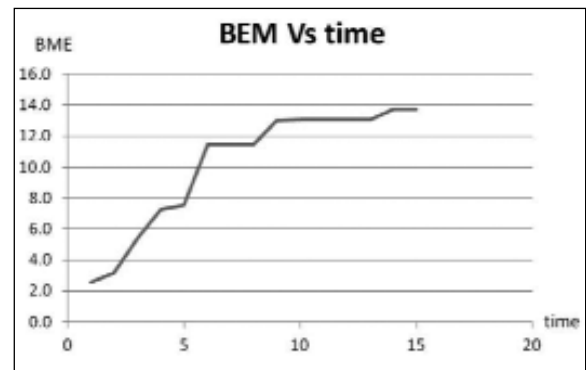
The last column is the BEM, and it is the cumulative value of the variance of orders divided by the va-

riance of sales. The implementation of this measure is presented in Figure 3.

All the expressions can be extended to the period in which we need to calculate BEM.

Figure 3
The bullwhip effect measure (BEM); a numerical example

5.   Conclusions

In this paper, we present a transformation of the formula by Chen et al. (2000) to measure the bullwhip effect in supply chains for the purpose of being easily implemented with spreadsheets and without having to develop VBA macros. Then, we show in detail the implementation of this modified formula to calculate the bullwhip effect in supply chains via spreadsheets.

A forthcoming work is related to the transformation of the formula by Fransoo and Wouters (2000), which measures the bullwhip effect at a particular level in a multi-level supply chain as the quotient of the demand variance coefficient generated by this level, and as the coefficient of the demand variance received by this level, in order to also implement it easily with spreadsheets.

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