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Bullwhip Effect
Demand Variation and Amplification within Supply Chains

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Abstract. *The consumers of the present, and especially those of the future, no longer expect products and services in themselves, but the maximization of the satisfaction they promise. In addition, today's consumer has a complex consumption behavior, is increasingly well informed, knows what he wants to receive and reacts quite firmly if his expectations are not considered by suppliers. For these reasons, at the level of specialized literature but also at the level of business practice, an innovative business philosophy, called the bullwhip effect, according to which demand variation or amplification, is progressive augmentation or diminishing of the demand, has become increasingly interesting to study. That is ascendingly propagating within the supply chain driving order variation to grow exponentially from the final consumer to the raw material supplier. The main thematic axes analyzed during this paper concerned: supply chains growing complexity both as an effect and a cause of the asymmetries that are observed at the level of demand-offer equilibrium; relevant correlations and causal relationships identifiable between the determinants of the general or specific environment in which a company is operating and the optimization together with the efficiency of the activities developed by it can be anticipated by adopting various business models; how distorted demand is propagating within the supply chain; the bullwhip effect as an amplification phenomenon inside the supply chain. The authors of this paper opted for a combination of positivist-type research, prioritizing the main causes of the bullwhip effect, and a phenomenological-type research, during which the most robust of the correlations supporting the starting hypotheses were highlighted. Therefore, we believe that increased attention to minimizing the bullwhip effect within organizations will lead to improved performance of supply chains and, implicitly, of the companies involved. This remains an area of significant interest in scientific research as well as in the practice of commercial entities focused on increasing profits.*

Keywords: new competitiveness, supply chain, bullwhip effect, demand-offer equilibrium, transaction costs, correlativities and causal relationships.

Introduction

The consumers of the present, and especially those of the future, no longer expect products and services in themselves, but the maximization of the satisfaction they promise. In addition, today's consumer has a complex consumption behavior, is increasingly well informed, knows what he wants to receive and reacts quite firmly if his expectations are not considered by suppliers. For these reasons, at the level of specialized literature but also at the level of business practice, an innovative business philosophy, called the bullwhip effect, according to which demand variation or amplification, is progressive augmentation or diminishing of the demand, has become increasingly interesting to study. That is ascendingly propagating within the supply chain driving order variation to grow exponentially from the final consumer to the raw material supplier. Demand

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variation or amplification, known also as the bullwhip effect, is progressive augmentation or diminishing of the demand, that is ascendingly propagating within the supply chain driving orders variation to grow exponentially from the final consumer to the raw material supplier. The term is associated with the bullwhip strike that determines through a small move at one side of the object a significant oscillation and noise on the other side of the object.

A first hypothesis from which the authors started is that supply chains growing complexity is both an effect and a cause of the asymmetry that is observed at the level of demand-offer report, especially in cases where there are strong interferences in communication between the final users and the raw material suppliers. *A second hypothesis* tested during the research carried out considered the fact that price level setting, production volume forecast, configuration and management of efficient logistic routes, drawing the remote relationship diagram and controlling the most important transaction costs and also the configuration of the operational scheme that would guarantee an acceptable level of transactional efficiency are influenced by both offer related factors and demand related factors. *A third hypothesis* tested started from the assumption that, considering the increasing turbulence in the business climate, it is compulsory to maintain an active surveillance of the business environment nurturing a proactive attitude towards the market stimulus by combining properly the level, nature, diversity and substitutability of demand.

The situation analysed may refer to an extra season product, a luxury car coming from a limited batch, a product that is vital for a sanitary crisis or an alternative product in an energetic crisis, the demand evolution forecast is helping the suppliers of goods or the services providers to make accurate estimations on the quantity of products they need to validate through customer purchases, to manage properly the timing in space, to minimize the costs and maximize the benefits. The pressure of honouring the received orders, the exccess of production in certain periods of time or other asymmetry that are connected to demand or supply are enhancing the risks concerning the optimal development of deliveries and have an impact on price. All these factors can materialise in certain cost increases for the transaction that affects the efficiency of ongoing operations by following activities: requesting mandatory capacity increase management, extending working hours for employees or applying penalties to the commercial partners. Alternatively, we find that sudden demand drops without immediate perspectives of rebound can lead to comprising the market share or even eliminating off the market a certain economic agent who's is activity becomes incongruent with the sub-optimal demand level over a a considerabile period of time. Within its supply chain an organisation is facing erratic demand evolution following the crisis kaleidoscope visible not only in the regional economy but also the global economic indicators we are currently facing. The attitude of the decision makers must be proactive and flexible in managing the diverse phases of the supply chain. Correlations and causal relationships identifiable between the determinants of the general or specific environment in which a company is operating and the optimisation together with the efficiency of the activities developed by it can be anticipated by adopting various business models, implementing production management schemes and applying targeted management practices. Supply chain activity efficiency can be evaluated using a risk management process implemented at each company level through the production policies and the stock management policies. We find in practice two main categories utilised depending on the control location of the stock levels: Customer Managed Inventory (CMI) and Vendor Managed Inventory (VMI). Considering complex supply chains, that integrate high value added operations, long transit times and higwh technical complexity, VMI is offering companies a solution that can reduce the production associated risks, transport risks, storage, packaging risks, inventory stock risks (managed through picking list goods receipts where the materials are being invoiced only

when they are consumed – known also as consignment stock), missed deliveries penalties, quality issues and also errors in showing demand in due time between the various supply chain participants. Using this logistic model, the supplier is connected to the demand of the final customer, removing the distortion produced within the supply chain. Although this solution is proposing diminishing of previously mentioned risks, it also incubates its own risks such as: loss of flexibility and reaction to market stimulus for the final customer, losing control of own stocks and sharing potential sensitive information to third parties. CMI represents the conventional approach of supply chains, where the customer is managing its own stock levels and order levels, based on the information received from its commercial partners, suppliers and storage facilities.

Literature review

Reading carefully the specialized literature dedicated to this thematic area allowed us to observe the multitude of studies that placed the bullwhip effect at the center of the research and the diversity of methodological perspectives used. Wang, X. and Disney S.M. (2016) present the bullwhip concept as a demand variation that needs to be permanently monitored, arguing that this study theme has presented an increased interest in the past decades, especially in the last twenty-five years, having in mind the multiple studies have treated this subject to determine the costs associated to this phenomenon and their reduction possibilities by impacting certain factors of the supply chain. Rafati, E. (2022) finds empiric evidence for the hypothesis according to which the improvement of the communication methods used throughout the supply chain and adapting the means used to address the specific company needs can diminish the demand distortion effect. Also, in scientific literature assessed two major types of demand amplification can be found: rational amplification (based on previous experiences of the commercial relationship between the participants in the supply chain) and irrational amplification (based on strategic decisions to increase or decrease abruptly the demand observed on one end of the supply chain). Yu, D. and Yan, Z (2021) analyzed the bullwhip effect as an amplification phenomenon inside the supply chain, after studying more than five hundred articles, shows that the most variety of studies are focusing on identifying the causes and the strategies to prevent the bullwhip effect. Seven theme areas are mentioned of high importance, such as: order policy, inventory control, communication policy, inventory strategies, inventory control, delivery terms and divergent supply chain. Babai, M.Z, et al. (2016) is highlighting the importance of demand communication, that is correlated with a financial benefit associated to efficient stock management. They underlined that there is also beneficial for research accuracy to take into consideration the most relevant specific cost to determine the measure in which significant investments in improving communication means like increasing the number of employees, purchasing improved software programs, ERP systems, increase of digitalization and automatized communication bring a benefit greater than the cost associated with their implementation. There are flows of goods moving in supply chains that can determine significant loss if the demand is not correctly communicated and on time, especially for products with high manufacturing time, high technical complexity, perishable goods or long transit times goods. Studying the phenomenon from another angle, Silitonga, R.Y and Jelly, N. (2018) show the correlation between changes observed at methods and parameter levels and demand variation, with a series of simulations on different scenarios, using as input the methods and the parameters used to forecast demand. Popa, V. (2013) defines the following parameters: inventory – measured in days – representing the number of days that the products remain in inventory before being sold; debt – measured in days – define the time period between the delivery of goods and invoice from the supplier and the actual payment for the inventory, describing in fact the time

necessary to pay a supplier; sales – measured in days – represent the difference in days between the selling of the goods and sending invoice to the customer and actual invoice payment by the customer. Cantor, D. E. and Katok, E. (2012) considers supply chain management a dynamic activity that can be prone to systematic errors called the bullwhip effect. For example, resources spent on oil and gas drilling fluctuate three times more than actual oil production, mechanical tool demand is at least twice as variable as automobile sales (with the auto industry being the main consumer of mechanical tools), and semiconductor production is much more variable than industrial production as a whole. Harrison, E. (2023) addresses the bullwhip effect as an inherent aspect of supply chains, which has a negative impact on their performance and efficiency. There are several causes that contribute to the occurrence of this effect, one of the most important being uncertain demand. Therefore, it is crucial to understand how to quantify the bullwhip effect in this context. Thiell, M., & Wilmsmeier, G. (2022) shows that supply chain strategies evolve according to the environment in which they operate. In recent decades, the objective of becoming increasingly efficient has come hand in hand with the idea of agility. The progress of globalization has largely been built on these two principles, as they have benefited from the relative stability of the environment. Thus, globalization has been stimulated by the standardization of structures and processes in the supply chain. However, in the more volatile and uncertain context of these days, the traditional concept of globalization and the paradigm of economic growth are being questioned. In search of a "new" balance in sustainable development, supply chain strategies must adapt to this complex environment, which can bring both opportunities for success and increased risks. Kulp & et al. (2004) exemplifies in their study that companies with a high profit margin are using information beyond its communication purpose of some indicators used in daily practice, using it as a means with high value add within the supply chain, that allows additional flexibility to all partners regardless of the place they occupy on the supply chain distribution, several case studies showing the effect of increased level of cooperation and partnership in improving supply chain performance.

Methodology

A first main hypothesis from which the authors started is that supply chains growing complexity is both an effect and a cause of the asymmetries that are observed at the level of demand-offer report, especially in cases where there are strong interferences in communication between the final users and the raw material suppliers. *A second hypothesis* tested during the research carried out considered the fact that price level setting, production volume forecast, configuration and management of efficient logistic routes, drawing the remote relationship diagram and controlling the most important transaction costs and also the configuration of the operational scheme that would guarantee an acceptable level of transactional efficiency are influenced by both offer related factors and demand related factors. *A third hypothesis* tested started from the assumption that, considering the increasing turbulence in the business climate, it is compulsory to maintain an active surveillance of the business environment nurturing a proactive attitude towards the market stimulus by combining properly the level, nature, diversity and substitutability of demand. Secondary hypotheses considered are following: within a two-level supply chain, the bullwhip effect will not occur when customer demand distribution is known and stationary (it does not have a seasonal component); within a two-level supply chain, the bullwhip effect will not occur when customer demand distribution has a seasonal component; within a two-level supply chain, when order changes are costly and demand setting is seasonal, order smoothing should occur and when order changes are costly and demand setting is stationary, order smoothing should not occur.

The authors of this paper opted for a combination of positivist-type research, prioritizing the main causes of the bullwhip effect, and a phenomenological-type research, during which the most robust of the correlations supporting the starting hypotheses were highlighted. Therefore, we believe that increased attention to minimizing the bullwhip effect within organizations will lead to improved performance of supply chains and, implicitly, of the companies involved.

The forecasting methods used were: mean demand, mobile mean, exponential smoothing, demand signaling and squared medium error expected. The parameters considered are: the mobile means and the smoothing parameter. The parameters considered are: mobile means, smoothing parameter, signaling factor and minimum stock levels.

Results and discussions

In a highly competitive environment we often find supply chains also in a competitive dynamic, surviving those that prove high quality standards in meeting the customer needs – which can be achieved through efficient supply chain management defined as continuous multilateral cooperation between production plants, storage facilities, retailers, *en gros* sellers and customers. Considering the many interested parties and processes involved, management needs to provide a in depth attention to this synergy, especially because there is a significant degree of uncertainty regarding the demand at its realization date which can impact the full supply chain if not treated and approached unitarily. A simplified approach of the supply chain can consider two major processes as most important: goods ordering and delivery. The lack of coordination between the supply chain participants can appear due to either some steps in the supply chain have conflicting objectives, either the information exchanged between steps is shared late and distorsioned. Cooperation and coordination of the supply chain members is facilitating fluid and successful commercial relationship while their absence can determine the creation and perpetuation of the bullwhip effect. Based on an appropriate econometric model, measuring the size of the bullwhip effect, resulted that there are four known causes of the bullwhip effect:

a) *Methods used to forecast the demand and choosing the considered parameters*: if and economic agent is using only the information received from the other participants in the supply chain it can be disconnected from the level of real demand. Also, if the methods or parameters defined are not aligned with the specific of the activities of the economic agent it can create interference in provisioning that can determine the creation and perpetuation of the bullwhip effect.
b) *The rationalization and deficit strategies*: ordering a higher quantity than the actual need as a risk management tool used to avoid shortage in the future is actually contributing actively to stock building that will attract the cancellation or diminution of future orders, contributing therefore to the bullwhip effect.
c) *Orders grouping in bigger lots*: to manage efficiently the costs of packaging, transport, processing of the order and other benefits related to batch size order, the supply chain participants can be stimulated to wait a significant period of time to group multiple orders, their order being therefore cumulated and no longer reflecting the real demand coming usually from a supply chain partner, following to generate additional efforts in the upstream through the amplification of augmented figures composed with each participant's margin included.
d) *Price fluctuation*: the incentives offered through the supply chain for bigger orders can determine increase in batch order size and can also be a consequence of promotional campaigns, following that when the prices return to the regular levels the batch order size is reduced and stock levels increased, which is actively contributing to bullwhip effect.

Supply chains are facing several challenges in their attempt to improve processes and optimize their activities in order to provide the customer with high quality and competitive goods and services, thus identifying the following challenges and associated causes: the use of internal information management systems not adapted to the actual practical information flow; issues with systems functionality and their flexibility compared with the time allocated for their utilization; errors generated by management imposed systems without a quantifiable effect in resolving day to day activities; increase of time spent on administrative tasks instead of high value added tasks that the employees could perform in the same time period. To these challenges we can find a series of solutions adapted for each organizational model so that the time spent working could be optimized and focused on value added time instead of administrative repetitive tasks that could easily be taken over by systems and programs adapted to business needs of reporting. Maximizing the professionals strategic and operational time can bring additional value to the company's supply chain and guarantees the efficient use of resources at company level. One challenge that occurs for organizations when they decide the level of information to share within their supply chains is coming from the analysis of the benefit brought by the use of this information, reason why any investment in systems and information digitalization processes needs to be comparatively analyzed with the financial benefit gained either from stock reduction, decrease of cancelled orders or stock levels improvement. Certain factors in the supply chain contribute to the bullwhip effect, including updating demand forecasts, order batching, price fluctuations, and rationing, while other factors such as restructuring the supply chain network can help mitigate it. A number of behavioral factors have also been shown to contribute to the bullwhip effect in laboratory settings, such as inappropriate team decisions, failure to share customer demand information, and incorrect perception of retro planning. Demand smoothing can be an important factor in effectively managing the supply chain. This can help prevent sudden and unexpected demand fluctuations, leading to more efficient resource utilization and better production planning. However, demand smoothing can be difficult to achieve in practice and can be affected by numerous factors, including customer behavior, economic and political fluctuations, and others. Production smoothing is defined as the decrease in the standard deviation of orders as one moves up the supply chain. In other words, if there is production or order smoothing, then the standard deviation of orders for the ith level of the supply chain, ri, is smaller than that for its immediate customer ri-1 (for all i in {R, F}). If there is amplification (the bullwhip effect), then the standard deviation of orders for the ith level of the supply chain, ri, exceeds that of its immediate customer ri-1 (for all i in {R, F}). Production smoothing is a solution identified and used by Japanese researchers in Toyota's automobile production, achieved through strategically slowing down all activities to meet customer demand, drawing an analogy with turtles, which despite their slow movement produce fewer residues compared to the fast hare that in its haste misses key points.

Conclusions

The results of this study show that the drop of the parameter mobile means, the increase of soothing parameter and the increase of signaling demand can determine the increase in bullwhip effect rate, while the minimum stock did not have an impact on the bullwhip effect.

Based on our results we can mention few of the most influential themes with high impact on bullwhip effect: ordering policy, inventory variation, information sharing policy, demand forecasting method, inventory policy, company strategy and divergent supply chain. Recent studies evaluate the benefit of efficient information management within the supply chain, which has been

identified as one of the most important means to reduce the demand amplification effect. Practice such as Vendor Managed Inventory (VMI), Efficient Customer Response (ECR), Continuous Replenishment (ER), Electronic Data Interchange (EDI) are used in multiple industries to improve information visibility and lead to advanced cooperation within the supply chain.

The fragilities and structural dependencies have become evident and should prompt a general reevaluation of supply chain structures and processes, and their limitations in terms of efficiency, agility, and even resilience when applied in complex environments. The overly idealized concept of globalization has been and continues to be disrupted by the COVID-19 pandemic, not only by re-establishing physical borders but also by cutting global supply chains through political or unilateral decisions that prioritize national interests over global solidarity. Referring to force majeure, managerial decisions have followed the same paths. These interruptions and threats of repetition have led to: limiting equal access to markets, creating an excessive risk perception for businesses and society, promoting excessive inventory variations and delays, changing consumption patterns, and revealing almost monopolistic and monopsonic relationships throughout the supply chains.

The uncertain situations generated by the health, political, security, and energy crises of the last three years have led to a series of economic crises, visible at multiple levels of international supply chains, even among the largest players in key industries such as IT, Automotive, Pharma, FMCG, and GCG Retail. The slowing down of economic activities due to social distancing, the closure of financial markets, companies, businesses, and events has generated a high degree of uncertainty regarding the magnitude of the situation and significantly reduced investment and consumption rates.

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