The bullwhip effect is a supply chain phenomenon where orders to suppliers tend to have a larger variability than sales to buyers, which results in an amplified demand variability upstream. In part, this results in increasing swings in inventory in response to shifts in consumer demand as one moves further up the supply chain. The concept first appeared in Jay Forrester's Industrial Dynamics (1961)[1] and thus it is also known as the Forrester effect. It has been described as "the observed propensity for material orders to be more variable than demand signals and for this variability to increase the further upstream a company is in a supply chain".[2]

Research at Stanford University helped incorporate the concept into supply chain vernacular using a story about Volvo. Suffering a glut in green cars, sales and marketing developed a program to sell the excess inventory. While successful in generating the desired market pull, manufacturing did not know about the promotional plans. Instead, they read the increase in sales as an indication of growing demand for green cars and ramped up production.[3]

Research indicates a fluctuation in point-of-sale demand of five percent will be interpreted by supply chain participants as a change in demand of up to forty percent. Much like cracking a whip, a small flick of the wrist - a shift in point of sale demand - can cause a large motion at the end of the whip - manufacturers' responses.[4]

Causes

Bullwhip effect

Because customer demand is rarely perfectly stable, businesses must forecast demand to properly position inventory and other resources. Forecasts are based on statistics, and they are rarely perfectly accurate. Because forecast errors are given, companies often carry an inventory buffer called "safety stock".

Moving up the supply chain from end-consumer to raw materials supplier, each supply chain participant has greater observed variation in demand and thus greater need for safety stock. In periods of rising demand, down-stream participants increase orders. In periods of falling demand, orders fall or stop, thereby not reducing inventory. The effect is that variations are amplified as one moves upstream in the supply chain (further from the customer). This sequence of events is well simulated by the beer distribution game which was developed by MIT Sloan School of Management in the 1960s.

Disorganisation

Lack of communication

Free return policies

Order batching

Price variations

Demand information

Simply human greed and exaggeration

The causes can further be divided into behavioral and operational causes.

Behavioral causes

The first theories focusing onto the bullwhip effect were mainly focusing on the irrational behavior of the human in the supply chain, highlighting them as the main cause of the bullwhip effect. Since the 90's, the studies evolved, placing the supply chain's misfunctioning at the heart of their studies abandoning the human factors.[5]

Previous control-theoretic models have identified as causes the tradeoff between stationary and dynamic performance[6] as well as the use of independent controllers.[7] In accordance with Dellaert et al. (2017),[8] one of the main behavioral causes that contribute to the bullwhip effect is the under-estimation of the pipeline.[9] In addition, the complementary bias, over-estimation of the pipeline, also has a negative effect under such conditions. Nevertheless, it has been shown that when the demand stream is stationary, the system is relatively robust to this bias. In such situations, it has been found that biased policies (both under-estimating and over-estimating the pipeline) perform just as well as unbiased policies.

Some others behavioral causes can be highlighted:

Misuse of base-stock policies

Mis-perceptions of feedback and time delays. In 1979, Buffa and Miller highlighted that in their example. If a retailer sees a permanent drop of 10% of the demand on day 1, he will not place a new order until day 10. That way, the wholesaler is going to notice the 10% drop at day 10 and will place his order on day 20. The longer the supply chain is, the bigger this delay will be and the player at the end of the supply chain will discover the decline of the demand after several weeks.

Panic ordering reactions after unmet demand

Perceived risk of other players' bounded rationality. Following the logic of the example of Buffa and Miller, after several weeks of producing at the classical rate, the producer will receive the information of the demand drop. As the drop was 10%, during the delay of the information's circulation the producer had a surplus of 11% per day, accumulated since day 1. He is thus more inclined to cut more than the necessary production.[2]

Human factors influencing the behavior in supply chains are largely unexplored. However, studies suggest that people with increased need for safety and security seem to perform worse than risk-takers in a simulated supply chain environment. People with high self-efficacy experience less trouble handling the bullwhip-effect in the supply chain.[10]

Operational causes

A seminal Lee et al. (1997) study found that the bullwhip effect did not solely result from irrational decision making: it found that under some circumstances it is rational for a firm to order with greater variability than variability of demand, i.e., distort demand and cause the bullwhip effect. They established a list of four major factors which cause the bullwhip effect: demand signal processing, rationing game, order batching, and price variations.[2] This list has become a standard and is used as a framework to identify bullwhip effect.[citation needed]

Demand forecast updating is applied individually by all members of a supply chain. In order to guard against unexpected events, a member of the chain who is ordering will add safety stock to the amount actually needed. When the supplier of that member places an order to its own supplier, it will also add safety stock. The more members of the chain, the more safety stock will be made, resulting in an artificial increase in demand.[11]

Order batching is the preference of most companies to accumulate demand before ordering, with the intent of reducing cost and simplifying logistics. This approach allows them to benefit from more revenue per order without a comparable increase in transportation cost via economy of scale. That can manifest by allowing them to order a full truck or container load, where partial loads are less efficient in terms of transportation cost per unit. Consolidation of orders in this way creates an artificial variability in demand, which potentially increases the bullwhip effect.

Price fluctuations can be a result of inflationary factors, quantity discounts, or sales. This instability tends to stimulate customers to buy larger quantities than they require. In cases where sales economy is higher than stocking expense, they may buy more than is immediately needed in order to gain bulk discounts. This increases the variability by having large spikes of demand followed by longer periods without orders while the excess stock is sold off, which makes it more difficult for suppliers to predict demand. The resulting uncertainty can contribute to the bullwhip effect. While suppliers can counter this by removing or reducing discounts, this risks loss of business to competitors who continue to offer more or larger incentives.

Rationing and gaming is when a retailer limits order quantities by providing only a percentage of the order, but the buyer acts on this knowledge by placing larger orders in hopes of getting closer to the actual desired quantity. Rationing and gaming generate inconsistencies in the ordering information that is being received, and may feed into the bullwhip effect.[12]

Other operational causes include:

Dependent demand processing

Forecast errors

Adjustment of inventory control parameters with each demand observation

Lead time variability (forecast error during replenishment lead time)

Lot-sizing/order synchronization

Consolidation of demands

Transaction motive

Quantity discounts

Trade promotion and forward buying

Anticipation of shortages

Allocation rule of suppliers

Shortage gaming

Lean and JIT style management of inventories and a chase production strategy

Consequences

In addition to greater safety stocks, the described effect can lead to either inefficient production or excessive inventory, as each producer needs to fulfill the demand of its customers in the supply chain. This also leads to a low utilization of the distribution channel.

In spite of having safety stocks there is still the hazard of stock-outs which result in poor customer service and lost sales. In addition to the (financially) hard measurable consequences of poor customer services and the damage to public image and loyalty, an organization has to cope with the ramifications of failed fulfillment which may include contractual penalties. Moreover, repeated hiring and dismissal of employees to manage the demand variability induces further costs due to training and possible lay-offs.

The impact of the bullwhip effect has been especially acute at the beginning stages of the COVID-19 pandemic, when sudden spikes in demand for everything from medical supplies such as masks or ventilators[13] to consumer items such as toilet paper or eggs created feedback loops of panic buying, hoarding, and rationing.[14]