Using Demand Uncertainty as a determinant for the Bullwhip Effect

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Bullwhip Effect

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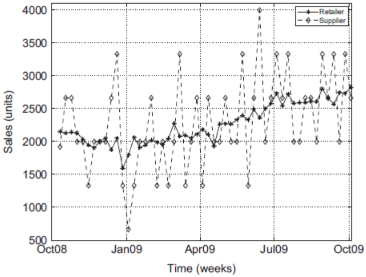

Retrieved from Trapero et al. (2012)

Consequences of the Bullwhip Effect

The Bullwhip effect results in:

- Mis-alignment of Production Schedules.
- Increased Inventory.
- Increase in Stock-outs and customer dissatisfaction.
- Improper use of capacity.
- Increase in Transportation Costs.
- To name a few...

Origins of the Bullwhip Effect (Lee et al., 1997)

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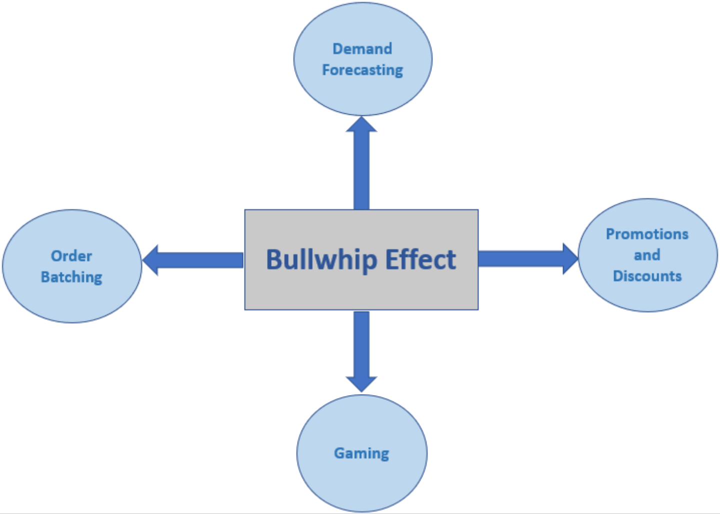

Bullwhip Measurement

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In order to measure the Bullwhip Effect, the following ratio of variabilities is used (Chen et al., 2000):

$$BWR = \frac{Var(Orders)}{Var(Demand)} \quad (1)$$

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$$BWR = \frac{Var(Orders)}{Var(Demand)} \quad (1)$$

Its interpretation is:

- BWR $= 1 \implies$ No Bullwhip.
- BWR $> 1 \implies$ Bullwhip exists.
- BWR $< 1 \implies$ Anti-Bullwhip.

This falls in line with the definition of measuring the propagation of variability upstream.

Issues with the current measurement

Issues with the current measurement

- Empirical Studies report the Bullwhip as an over-estimated issue due to this measurement (see for e.g Cachon et al., 2007)
- Does not reflect cost impacts.
- Concealed by both Temporal and Product Aggregation (Chen and Lee, 2012).
- Variance is only meaningful on stationary time series. It fails on series with trend, seasonality etc...

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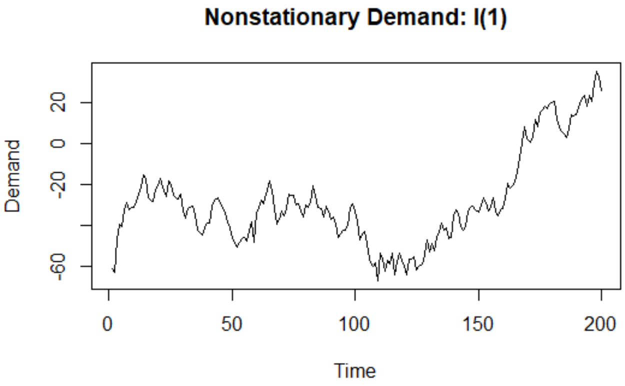
Trending Demand



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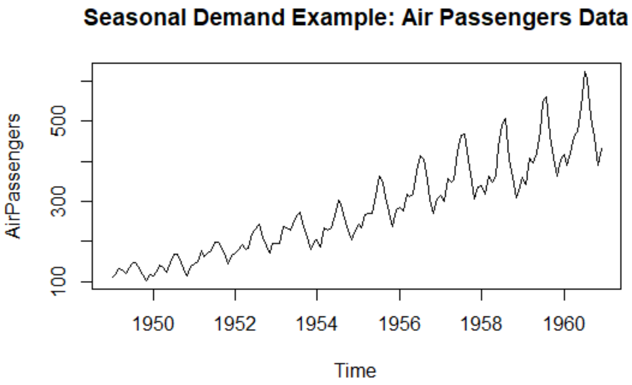
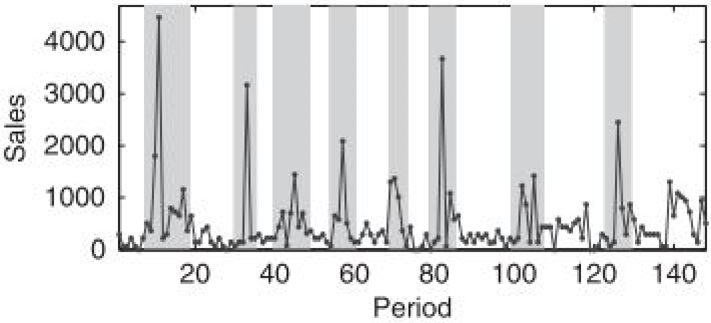
Seasonal Demand



Promotional Demand



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Other metrics

Other metrics have been proposed in the literature, such as:

- Inventory Variance Ratio (Disney and Towill, 2003).
- Time Varying Bullwhip Effect Metric (Trapero and Pedregal, 2016).
- An excellent summary can be found in Cannella et al. (2013).

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- Inventory Variance Ratio (Disney and Towill, 2003).
- Time Varying Bullwhip Effect Metric (Trapero and Pedregal, 2016).
- An excellent summary can be found in Cannella et al. (2013).
- This is where our research comes in!

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Uncertainty

Definition

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- It is captured by forecasting error metrics.
- Forecasting is one of the four origins of the Bullwhip Effect.
- Uncertainty is not Variability!

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Uncertainty vs Variability

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- Demand variability: the fluctuations of demand around its mean.

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Uncertainty vs Variability

- Demand Uncertainty: The random variation in the forecasting model, assumimg the **TRUE DEMAND** is known!
- Forecasting Uncertainty: How much is not captured by the forecasting method. It includes demand uncertainty and the effect of model mis-specification.
- Demand variability: the fluctuations of demand around its mean.
- Demand variability is forecasting uncertainty, if we use the average as a forecasting model.
- These terms are often confused in the literature.
- Forecast Uncertainty is a cost driver, not demand variability.

Uncertainty vs Variability Example

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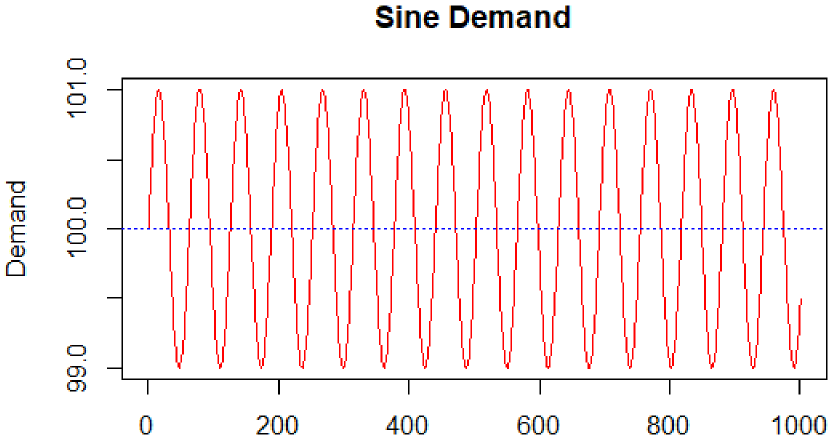

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- It is the **conditional** standard deviation of the forecast errors, provided they are homoscedastic.
- In the literature, the term variance (standard deviation) is used to denote the unconditional variance (standard deviation), which is asymptotic.
- From the Bias-Variance Decomposition, the MSE (RMSE) encapsulates the variance (standard deviation):

$$\text{MSE} = \underbrace{\text{Bias}^2 + \text{Variance} + \underbrace{\text{Irreducible Component}}_{\text{Demand Uncertainty}}}_{\text{Forecast Uncertainty}}$$

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RMSE link to cost

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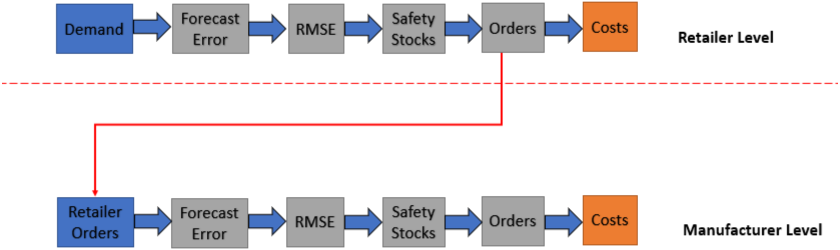

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Why RMSE?

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Why RMSE?

- RMSE is fed into the calculation of Safety Stocks. For example, in an OUT policy, safety stocks are calculated as:

$$\text{SS} = \widehat{F}_{t+L} + \Psi_{\alpha}^{-1} \underbrace{\sqrt{\sigma^2_{t+L|t}}}_{\text{RMSE}} \tag{2}$$

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- Captures the propagation of demand uncertainty.
- Accounts for the Lead Time over which decisions are made.
- Handles Nonstationarity, seasonality and promotions.
- Captures modelling uncertainty and mispecification. Improvements in the process will be reflected in the metric.

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Proposed Measure

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RMSE ratio

We propose to measure the Bullwhip as the ratio of Root Mean Squared Error (RMSE) over Lead Time of Manufacturer to Retailer.

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The current metric we propose is:

$$RMSE_{Ratio} = \frac{RMSE_M}{RMSE_R} \tag{3}$$

RMSE Equations

In order to get the ratios:

1. Calculate the point forecasts and the point errors for both.
2. Calculate the Aggregate Forecasts and Errors over Lead-Time for both.
3. Calculate the RMSE of the Aggregate Errors for both.
4. Take the ratio of RMSE of Manufacturer to Retailer.

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RMSE Equations

$$RMSE_M = \sqrt{\frac{1}{(n_M - L_M + 1)} \sum_{t=1}^{n_M - L_M + 1} \left(\sum_{i=1}^{L_M} d_t - \sum_{i=1}^{L_M} f_{t|t-L_M} \right)^2} \tag{4}$$

$$RMSE_R = \sqrt{\frac{1}{(n_R - L_R + 1)} \sum_{t=1}^{n_R - L_R + 1} \left(\sum_{i=1}^{L_R} d_t - \sum_{i=1}^{L_R} f_{t|t-L_R} \right)^2} \tag{5}$$

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Information Sharing

Information Sharing

- Proposed remedy to the Bullwhip Effect (Lee et al., 1997).
- The manufacturer has access to the Point of Sales data, and bases his forecasts on demand rather than incoming orders.
- In the context of demand uncertainty, this implies a reduction in MSE and RMSE.
- Its benefits are contested: theoretically, the value of Information Sharing depends on the process and parameters((Babai et al., 2013, 2016; Teunter et al., 2018; Ali et al., 2012), while empirically it has appeared to benefit the manufacturer (Trapero et al., 2012).

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Information Sharing

- From a forecasting perspective, it can result in a lower MSE.
- $MSE_{IS} < MSE_{NIS} \implies RMSER_{IS} < RMSER_{NIS}$.
- Under this logic, we expect that Information Sharing should reduce manufacturer costs and thus be beneficial.
- In this presentation, it is used as a forecasting scenario in the simulation.
- We will later (but not today) compare the Total Costs, Bullwhip Ratio and RMSE Ratios of sharing versus not sharing information.

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Design

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- Dyadic Supply Chain (1 Manufacturer and 1 Retailer).
- 3 Data Generating Processes from the ARIMA family:

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- Forecasting Methodology: Rolling Origin forecasts with automatic ARIMA fitting based on minimisation of the AIC.
- Inventory Policy: Periodic (R,S) inventory policy with $R = 1$ and unmet sales are backordered.
- Point of Sales vs No Information Sharing.

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Simulation Design

- For both, 3 deterministic values $\{1, 3, 5\}$ of Lead Time + Review Period.
- 3 α-service levels for both: $\{90\%, 95\%, 99\%\}$
- 3 Order batching scenarios: No order batching, multiples of 10 and of 20.
- 3 Values for the model error noise: $\{15, 25, 50\}$.
- 500 Replications.
- The Bullwhip Ratio and RMSE Ratio are calculated at the Manufacturer's level.
- 400 Observations (data split explained in the next slide)

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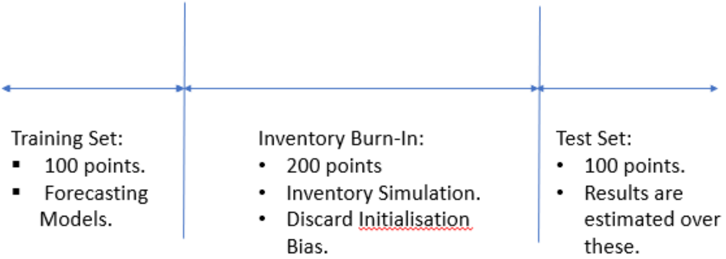
Data Partition



Costs

Costs

1. Two costs are considered: Backordering and Holding.
2. Thez are calculated at the Manufacturer's level.
3. Total Cost = b × Backorders + h × Excess Inventory .
4. Despite the system working on an α Service Level, costs are approximated by a β Service Level.
5. The relationship between the two costs is:

$$b = \left(\frac{\beta}{1-\beta}\right) h \tag{6}$$

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Assessing the two measures

Assessing the two measures

- The objective of this paper is to address the cost impact.
- We will assess which of the two papers is more related to manufacturer costs.
- Fit 3 Linear Regression Models:
    1. Total Cost = f(Bullwhip Ratio)
    2. Total Cost = f(RMSE Ratio)
    3. Total Cost = f(Bullwhip Ratio, RMSE Ratio)
- The assessment will be based on the Akaike Information Criteria (AIC).

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Terminology

- To separate the effect of Information Sharing from Non Information Sharing, we add a dummy, d, to each variable which codes whether it happens or not.
- RMSER = Root Mean Squared Error Ratio.
- BWR: Bullwhip Ratio.
- TC: Total Costs.

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AIC Results

	RMSER	**BWR**	**RMSER,BWR**
ARIMA(1,0,0)	**1st**	3rd	2nd
ARIMA(0,1,1)	**1st**	3rd	2nd
ARIMA(0,1,1)(0,1,1)	**1st**	3rd	2nd

AIC Results

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The model with only RMSE ratio returns the lowest AIC across all processes!

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R^2 Results

	RMSE	BWR
ARIMA(1,0,0)	**96.29%**	83.06%
ARIMA(0,1,1)	**88.65%**	66.44%
ARIMA(0,1,1)(0,1,1)	**64.43%**	49.52%

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- More variations in total costs is explained by using the RMSE ratio instead of the Bullwhip ratio.
- As the series is further away from stationarity, the value of the adjusted R^2 decreases for both ratios.

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Conclusion

- The current Bullwhip Ratio possesses flaws.
- Uncertainty, captured by forecasting errors, is the cost driver.
- We propose to measure the propagation of uncertainty across the supply chain.
- our metric is more related to Total Costs than the Bullwhip Effect

Conclusion

Any Questions?

Conclusion

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A special thank you to Juan Ramon Trapero!

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