Price Optimization in Consumer Retail

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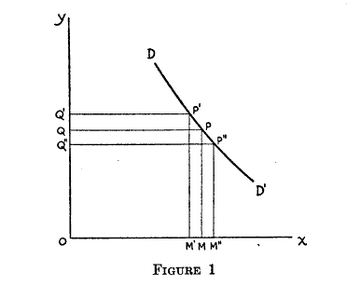
# Abstract

Marketing is a vast area for study. The Four Ps of marketing – Product, Price, Promotion and Place -form the building blocks of any transaction. The Price is a crucial driver especially in a B2C (Business to Consumer) relationship as the Price is what makes the consumer make a go-no go decision and converts the shopping experience to a sale. Pricing has always been an inter-disciplinary field. It uses the principles of marketing, the principal ratios of finance, the quantitative rigor of analytics and the data structures of computer science. I looked at applying this multi-disciplinary approach for pricing in the consumer retail industry. Through an analysis of the transactional data set which contains all the transactions occurring between 01/12/2010 and 09/12/2011 for a UK-based and registered non-store online retail, I computed the elasticity of the products sold using the log-log model and implemented the model using regression. I also logically grouped products using the K-means clustering algorithm to improve estimations. This will help us understand the price sensitivity of the products/product groups and thereby maximize revenue. Maximizing revenue is one of the primary goals of business as it will directly impact the bottom line.

Keywords: Marketing, retail, price, elasticity, regression, log-log, clustering, revenue

# Introduction

The effective quantitative theory of demand was given by [Antoine Augustin Cournot](https://en.wikipedia.org/wiki/Antoine_Augustin_Cournot) around 1838. As a creative economist he introduced the concept of demand as a mathematical function of price. If D=F(p) is the symbolic expression of the relation between the amount of commodity demanded, D, and the price per unit of commodity, p ,then our aim is to find for what value of p the product p F(p) (Revenue) is the maximum (Moore,1922). In the figure below we have the familiar graph of the law of demand, where x=the amount of commodity demanded and y=price per unit of commodity; and DD’ is the demand curve.



*Figure 1.* Demand curve. Adapted from "Elasticity of Demand and Flexibility of Prices", by H. Moore,1922, Journal of the American Statistical Association, 18(137), p. 10. doi:10.2307/2277462

We need to come up with an approximate determination of the value of p which renders the product p\*F(p) a maximum. This has been given by Professor Marshall’s form of statement where he describes demand as elastic or inelastic according as percentage in quantity demanded/percentage change in price is less or greater than unity. Empirically estimating this demand function has been challenging.

Various methods have been suggested to assist in estimating the demand function. Some of the methods from the fields of marketing, economics, analytics and machine learning are as below.

### Marketing methods and models

#### Consumer Interviews and Market Experiments

Two methods widely used for this purpose are Consumer Interviews and Market experiments. In Consumer interviews firms frequently interview consumers to understand their buying habits, motives and intentions. However, these surveys have some well-known limitations. These surveys entail answering hypothetical questions regarding pricing which don’t result in accurate answers. However, more subtle approaches can be useful. Interviews indicated that most buyers of a particular baby food selected it on their doctor’s recommendation and that most of them knew very little about prices of substitutes. This information, together with other data, suggested that the price elasticity of demand was quite low in absolute value (Dean, 1980). Another method of estimating demand functions is to run direct market experiments. The idea is to vary the price of the product keeping other market conditions stable. The disadvantages of this approach are that direct experimentation can be risky and can result in lost profits. Also, it is really difficult to conduct really controlled experiments and often the tests are run for a relatively short duration and hence don’t provide all the information that is needed. Nonetheless, these experiments can be of great value as indicated in the L’eggs products example in DeBruicker, Quelch, &Ward (1980). Jack Ward, group product manager of the firm, was interested in determining the effect on sales of four temporary promotion alternatives: a 40-cent price reduction for a package containing two pairs, a 25-cent price reduction for a package containing two pairs, a 20-cent price reduction per pair, and a coupon mailed to homes worth 25 cents off if a pair was purchased. The results showed that the 40-cent price reduction for a package containing two pairs was the most effective with a net short-term cumulative increase in sales of 53 percent felt over six weeks (DeBruicker, Quelch, &Ward, 1980). In this case, the manager was only interested in short term price reductions but in others we may be interested in more long-term price changes.

#### RFM Model

In addition to the above socio-demographic experiments, the RFM model proposed by Hughes (2000) can also be used to understand demand elasticity. Though this model is widely used for understanding customer lifetime value, it can give an idea regarding how price sensitive your customer segments are. According to You, Si, Zhang, Zeng, Leung, &Li (2015) the RFM segmentation model is a model that differentiates important customers according to three variables: customers’ consumption interval, frequency and amount of money as explained below:

(1) R represents ‘‘recency’’, which is defined as the interval between the time of the latest consuming behavior and the present; the shorter the interval, the greater the value of R.

(2) F represents ‘‘frequency’’, which is defined as the frequency of consuming behavior over a period of time.

(3) M represents ‘‘monetary’’, which is defined as money value of consumption over a period of time.

This model uses a more aggregative approach unlike the experiments which may be conducted at a more granular level. RFM models are easy to understand and don’t require knowledge of any statistical software. However, the RFM approach only looks at past data and does not involve a predictive approach (Webber, 2013).

### Economics Models

We have looked at the basic demand function and the various techniques that are used to collect the data needed to estimate this function (drawn from marketing fields). Now, let us walk through the functional forms that can be used to estimate demand models (drawn from economic theory). These can be classified into 4 categories (Oum, 1989):

1. Linear demand model
2. Log Linear demand model
3. Logit model
4. Translog demand system

Let us look at the intuitive properties of each model as explained by Oum (1989):

1. **Linear demand model**

The linear function has been extensively used in sales forecasting because it is simple to estimate and easy to interpret. However, as discussed previously the assumption of a linear effect may not be realistic.

1. **Log-Linear demand model**

The log-linear (double logarithmic or Cobb-Douglas) model specifies the logarithmic of quantity sold as a linear function of the logarithms of potential determinants, such as price and quality variables. This is the most widely used model because (a) the coefficients themselves are the respective elasticities of demand; (b) the log-linear function is capable of modeling non-linear effects and (c) it resembles the demand function obtainable from Cobb-Douglas utility function.

The main drawback of this model is that elasticity is invariant across all data points.

1. **Aggregate Logit model**

The logit model is used because (a) the discrete choice version of the logit model provides an intuitive and theoretical rationale (b) it can be estimated using any regression program (c) the S- shaped curve realistically describes the behavior of decision makers. Oum has used this model for modeling market shares of alternative modes of transport. This model has two forms (a) ratio form and (b) difference form. The difference form is preferred as it is independent of base taken.

1. **Translog demand system**

Since the mid-1970s, economists have begun to use a demand system derived from a flexible utility or production function. This flexible function provides a quadratic approximation to the unknown true function. As per Oum, this includes the translog (Christensen, Jorgenson and Lau, 1973), generalized Leontief (Diewert, 1971) and generalized Cobb-Douglas functions (Diewert, 1973). The translog function is the most widely used of all.

The demand system derived from the translog utility has is consistent with the neoclassical theory and allows free variation of the elasticities and cross-elasticities. These advantages, of course, come at the cost of substantially increased computation when compared with the above 3 models.

Oum had explained the above demand models for the transportation industry. However, he emphasizes that the theoretical and methodological discussions are directly applicable to demand studies for any goods and services.

Extending the above discussion to consumer retail, we see the below three model functions to represent demand obtained from economic demand theory. These model functions are used in my daily work at a retail company.



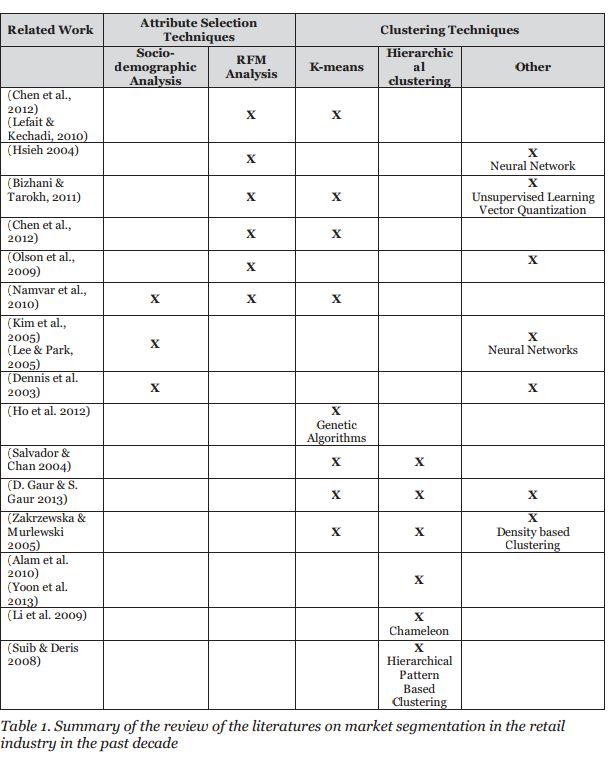
It can be inferred from the equations above that log/log model is easy to implement and interpret as the elasticity is the coefficient as opposed to the other two where the elasticity is a function of the coefficient and price. The other two models are similar. The difference is the second one gives the price whereas the third one gives a discount value.

### Machine Learning methods and models

1. **Attribute Selection and Clustering methods**

There are various research papers which use attribute selection techniques and machine learning methods such as clustering to perform market segmentation.

This has been summarized by Singh & Rumantir (2015) in a concise table which is reproduced below:



*Figure 2.* Table of Machine Learning methods used in retail. Adapted from “Two-Tiered Clustering Classification Experiments for Market Segmentation of EFTPOS Retailers”, by A. Singh and R. Grace, 2015, Australasian Journal of Information Systems,19, p. 119.

As noted in Singh & Rumantir, all of these techniques segment markets or customers based on various attributes. However, I am more interested in the key market driver which is Price and how the demand is affected by the price of the product.

Like the RFM Model, clustering also uses an aggregative approach. In You et al. (2015), we see a framework that uses the K-means clustering algorithm on RFM data to predict the amount of inventory that needs to be carried for each customer category. This is done from a customer category perspective and not from a product demand perspective. It mainly looks at identifying the commercial activities of key customers for a particular product.

1. **Regression**

Another way of estimating the demand function is to use a common statistical, machine learning technique called regression. The purpose of a regression analysis is to obtain the mathematical equation for a line that describes the average relationship between the dependent and independent variables. Regression analysis assumes that the mean value of Y, given the value of X, is a linear function of X (“Estimating demand functions”, n.d.). The assumptions of regression analysis should at least be approximately satisfied to carry out this analysis. As shown in Figure 1, the demand curve is a curve-linear function. Hence the linearity assumption is not valid when using the data directly. Hence suitable transformations need to be applied to use this technique to estimate demand.

1. **Time Series forecasting**

Gahirwal and Vijayalakshmi (2009) define time series as a sequence of data points, measured typically at successive times spaced at uniform time intervals. In the same paper Gahirwal and Vijayalakshmi (2009) define time series forecasting as the use of a model to forecast future events based on past events to predict data points before they are measured. There is a need to have a view of sales over time as it helps to estimate the inter-temporal nature of demand. A very common method used for forecasting is the moving average method. In this method, the most recent data points are used to forecast the future. This is very applicable in retail as the recent trend has more weightage than other long-term projections.

Exponentially weighted moving averages (EWMA) were widely used for smoothing data around 1957. However, this forecast was limiting. It was at this time that Holt realized that the EWMA concept can be used not only as a way to smooth the level of a variable but also to smooth trends, seasonals and other components that can be forecasted. Winters worked on assessing the performance of the method (Holt,2004). As indicated in Charles Holt’s paper, the Holt-Winters method greatly improved forecast accuracy, especially for retail, as this method was made by Holt when he had to make forecasts for over 200,000 products of a sand-paper company.

It has also been suggested to combine various time series models to improve forecast accuracy. Once the series is decomposed into the seasonal, trend and irregular components, statistical methods like ARIMA and Holt Winters can be used to forecast each of these components. This can be done by an approach called Association mining (Gahirwal and Vijayalakshmi, 2009).

As explained above, we see the advantages and drawbacks of various approaches drawn from the fields of marketing, machine learning and economic theory. Some papers look at the problem from a different perspective. The objective of my paper is to create a simplified model that looks at demand from a product/product group perspective to find the optimal price thereby leading to the ultimate goal of revenue maximization.

# Research Objective

The methodological position in this paper is the machine learning technique called regression. This starts the epistemological debate if regression can represent demand accurately. The demand is curvilinear so transformations have been done to represent the data in a regression. The regression equation is derived from the well-known Cournot Theory and this model is widely known as the Log-Log model.

The over-arching research aim is to maximize the revenue at a product/product group level. Revenue is taken as a driving factor as that is one that captures demand more accurately. Revenue is the product of unit price and number of units sold. The number of units sold is a function of the demand. Though Margin is important for the business to survive in the long run the more pertinent question especially in consumer retail is whether you are creating value and what people are willing to pay for the value created.

Various approaches have been explained in this literature review. The common component among these approaches is that they all use transactional data. This data is aggregated at various levels to achieve the goals set out by each paper.

The specific questions or areas I am interested in are

* Based on historical data, is it possible to plot the demand curve at a product/ product group level?
* Is it possible to find the optimal price point on the curve where the revenue is the maximum?
* Is it possible to estimate the elasticity (∆Q/∆P) or price sensitivity at the product or product group level in order to set prices in the future?
* Is it possible to group products based on price/demand to have meaningful product categories?

Once these questions are answered we can achieve the over-arching goal of maximizing revenue. This is important in the field of pricing whose goal is the optimization of prices based on the customers’ willingness to pay. The approach in this paper combines analytics, finance and economic theory to answer the above questions and achieve the goal of pricing.

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