The First Half-Century of Decision Modelling for Substitutable Products: A Literature Review and Bibliographic Analysis

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ABSTRACT

Due to the resource constraints of the factors of production (land, capital, capacity, etc.), the firms have to rationalize the assortment of products that they deal in. In such a situation, a consumer whose requirement for a preferred product may not get served from the existing inventories with the seller, may go for some other alternative product. A lot of research work in the past has been done on this demand substitution and its implications upon the assortment optimization, inventory optimization and price optimization. The first work on modelling for substitutable demand is attributed to 1970. Considering the same, the authors decided to do a review of the half-century of work on the modelling for substitutable products. The paper gives a detailed analysis of the published research articles around demand substitution and also discusses the achievements of the existing research. The article also gives a few possibilities of the future extensions to this body of knowledge on the management of substitutable products.

Keywords: demand substitution, substitutable products, inventory optimization, pricing optimization, assortment optimization, demand estimation, technological substitution

1. INTRODUCTION

In the retail environment, the needs of a customer can be served by any of the multiple products (Nagasawa et al. 2014). Considering this demand substitution in serving the customer influences the stocking decisions. If a few of the items are understocked, the resulting demand substitution leads to an increase in the demand for other items, and thus, changing the optimal inventory decisions. The product assortment decisions are particularly very important in a retail scenario with limited shelf space. Ignoring the substitution of consumer demand in these situations can lead to inefficient or sub-optimal assortments. Optimal assortment planning helps a retailer in deciding which items to carry and in what quantity. Demand substitution is the use of one product to serve the demand for some other product belonging to the same product category (Chopra and Meindl, 2010). The product category is defined as a set of similar products having alternative attributes like features, form, shape, colour, size, specifications, etc. The domain of product substitution has received good focus in Operations Management because of the influence it carries upon the effectiveness of the decisions made by the firms on the inventory planning, production planning and control, product basket rationalization, pricing, etc (Rajaram and Tang 2001, Ganesh et al. 2008, Goyal and Netessine 2011).

Many of the industries have been successfully practising something that is called ‘demand conditioning’ by constantly changing the product value proposition (in terms of pricing and configuration) to influence customer demand (An and Ramachandran 2005, Song and Xue 2007). Song and Xue (2007) pointed out that companies like ‘Dell Computers’ are also practising ‘demand conditioning’ based on present inventory levels to influence the potential customer. They consider the current inventory levels while practising this concept and thereby, aim to ensure high inventory velocity. Smith and Agrawal (2000) suggested that while offering a variety of products has its advantages however it will also increase the inventory-related cost. Thus firms’ should optimize their assortments of product and accordingly plan the inventory levels of each item.

The emergence of big data revolution has also enabled the availability and processing of huge demand data of substitutable products (Yudhisytra et al. 2020) so that the managers can make sound business decisions. The number of variants of any product has increased immensely over some time in the pursuit of mass customization. This has led to tremendous scope for optimization of business decisions using data analytics and quantitative modelling. Some of the common examples of quantitative methods that can be seen in the daily life of a business are markdown optimization by the retailers, shelf space planning in the retail industry, capacity planning and inventory planning.

With the importance that the topic of demand substitution modelling has gained, it is very important to collate the existing literature under these domains for the substitutable products. Although new knowledge is getting...
generated in this domain at a fast pace, it is fragmented and multi-disciplinary. This makes it challenging for the researchers to keep themselves up to date with the latest research. That is the reason this review has been done to enable the research scholars to do a fair assessment of the collective work.

Demand substitution of products is a double-edged sword because it provides the opportunities of inventory pooling while increasing the uncertainty around the expected demand of each variant. Demand substitution not only influences the supply chain relationships downstream of the manufacturer but also influences the decisions upstream of the manufacturer. The substitution of a product by another can be because of multiple reasons such as the launch of a new product in the assortment, or stocking out of the customer’s first choice, or the sudden jump in the price of the first choice product, or increase in the technology acceptance or technology needs of the customer leading him to switch to a more advanced product within the same category. Netessine and Rudi (2003) discussed an optimal stocking of substitutable products using a consumer-driven substitution model under competition for a random number of products. Chen and Plambeck (2008) suggested that the inventory level of substitutable products also affects the demand and buying behaviour and hence it is important to know the demand distribution and substitution pattern. Thus store footprint can be reduced and assortment can be downsized by estimating the substitution effects in a retail basket.

Also, the substitution is sometimes propelled by the vendors, and many a time by the customers. While some situations are characterised by uni-directional substitution, other situations may be a bi-directional substitution. The nature of choice decisions is also different in the literature with three popular choice phenomenon being multinomial logit, bayesian logit, markovian and few other location choice models (Timmermans and Golledge 1990). The objective of this review paper is to classify the research papers based on the nature of demand substitution, the propelling agent behind the substitution and the direction of substitution. This paper presents a comprehensive review and discussion on inventory models based on varied type of substitution models that are available in the literature. Also, solution approaches used to solve these substitutions-based model will be discussed in detail.

This literature review intends to document and analyse literature relating to the integration and implementation of supply chain management practices. As such, it is organized into the following sub-sections. In Section 2, the methodology considered for selection of papers has been discussed, and the papers written in the last five decades have been classified into broad categories as per the objective of the study considered. In Section 3, a few important papers related to substitution demand pattern published in the latest two decades have been discussed in greater detail. In Section 4, a detailed classification of the existing work has been done not only in terms of the objective of the study but also by the nature of substitution, the direction of substitution and the propelling force behind the substitution. In Section 5, the existing literature has been classified based on optimization methods used. Section 6 illustrates the statistics of the existing research done on modelling for substitutable products. Section 7 serves to summarize the accomplishments of the work done in the five decades. Section 8 outlines the limitations of the existing research, introduces the directions for further research in modelling for substitutable demand, and captures the conclusions of the paper.

2. METHODOLOGY AND ANALYSIS OF INVENTORY PAPERS RELATED TO SUBSTITUTION DEMAND PATTERN

This section discusses the methodology adopted for performing the review and the outcome of the review in terms of analysis of the comprehensive research papers on the theme.

2.1 Research Methodology

This is a semi-centennial review on the models developed for the products with substitutable demand. Since Scopus is generally considered to be the most popular and comprehensive database of research articles, the review began with the keyword search of “demand substitution” in the Scopus database, and 7,505 document results were obtained. Then, the authors limited themselves to the area of “Business, Management and Accounting” and the list was filtered down to 760 documents. Now, these papers had multiple themes such as business implications (pricing, inventory, assortment decisions, etc.), environmental implications, trade implications, sustainability implications, etc.) Also, while some dealt in demand substitution of physical goods, others dealt in the demand substitution of currency, services, energy, fuels, etc. Only those research papers were considered that deal in the business and management implications for demand substitution of the physical products and selected 156 papers. Also, the studies that were pure empirical studies were excluded since our emphasis was on the modelling for substitutable items. Citation chaining was also done and the references of the articles were mined to search for all the useful references. Preference was given to the articles published in the journals that are rated by ABDC (Australian Business Dean’s Council) to ensure the quality of the review. It was the endeavour that the review is very trustworthy, rigorous and thorough. The selected papers were given a thorough reading to come up with the insights on the key themes, research objectives, nature of substitution, model types and the solution approaches proposed by these articles. The guidelines by Torraco (2005) and by Snyder (2019) were followed for this integrative literature review.

2.2 Categorization of Modeling Papers Related to Substitution Demand Pattern

The research on substitution demand modelling dates back to the early 1970s. Mosenson, a PhD student at MIT, in the PhD thesis submitted by him in 1970, proposed the solution to the product substitution problem. Mosenson and Dror (1972) came up with the possible patterns of qualitative substitution and complementarity among different goods. They defined substitution patterns as the system of
substitution relationships among $\binom{n}{2}$ in the context of consumer demand. In this study, the word cloud has been used to identify the major research topic in the inventory literature and to underline the most used words in the cloud. Figure 1 shows the word cloud drawn based on the keywords in the research articles. Since the models on demand substitution were the key agenda of our review, the word cloud captured these words as the prominent key terms in these papers. The upcoming subsections are going to discuss some prominent articles that appeared in inventory literature based on the keywords as found in figure 1.

Figure 1 Word cloud formed from the keywords and abstracts of the research articles

2.2.1 Articles related to assortment optimization

The early papers in the 1970s (Pentico, 1974 and Pentico, 1976) focussed on assortment optimization where the seller deals in limited product variety owing to the resource constraints. Pentico (1988) extended the assortment-based substitution to two factors by taking into consideration the length as well as the strength of the steel beams while studying their substitutability. The strategy of assortment optimization is used by many retailers (Quelch & Kenny, 1994). Rationalizing the range of assortment helps retailer optimize the costs and profits (Smith & Agrawal, 2000). The cost reductions with the rationalization results from the fact that demand volumes for each of the variants increase with a smaller range. While the papers written in the twentieth century considered the identicalness of prices and cost structures among the substitutable products for the sake of modelling simplicity, the latter set of papers in the current century have considered the case of un-identical costs and prices also (Li et al., 2007).

Huddiniah et al. (2018) linked the product variety with the increasing supply chain sophistication and proposed the framework of facilitating it with information technology. Ishichi et al. (2019) performed assortment planning and shelf space planning for substitutable products with the use of demand learning.

2.2.2 Articles Related to Choice Models

When the choice models are being talked about, the papers also differ in the variety. While some of the papers have considered static choice modelling similar to the one by Gaur & Honhon, 2006, the many others have considered dynamic choice modelling similar to the one by Yuvel et al. (2009). While some papers have assumed the location choice models in which the customers substitute the demand between the neighbouring variants (Li, 2007), many of the papers have assumed multinomial choice logit models (Suh & Aydin, 2011; Aouad et al., 2018), with Hopp & Xu (2005) considering the Bayesian Logit Model. Many of the research articles have taken the decision choice to be a Markov chain phenomenon (Bayinder et al., 2005; Yu et al., 2017; Desit et al., 2020). While Lin & Sibdari (2009) deployed discrete choice model, Etebari (2020) used the nested logit model to capture the customer’s choice process rather than the multinomial logit model considering that the latter one suffers from the independence of irrelevant alternatives limitation. The nature of demand pattern considered in the literature also spans from deterministic (Gurnani & Drezner, 2000; Lang & Domschke, 2010) to probabilistic (Pentico, 1974; Pasternack & Drezner, 1991; Kraseburl et al. 2004; Rao & Swaminathan, 2004) and from Poisson distribution (Yadavalli et al. 2006; Xu et al. 2010; Burnetas & Kanavetas, 2018) governed to innovation diffusion governed (Chanda, 2011; Chanda & Agrawal, 2014; Chanda & Das, 2015).

2.2.3 Articles Related to Inventory Optimization for Substitutable Products

Coming to inventory optimization for substitutable products, McGullivary and Silver (1978) was the first one to consider the demand substitution arising due to the stock-out of the referred product. Drezner et al. (1995) extended the
EOQ Model of Harris to incorporate the effect of product substitution caused by the stock-out of the preferred product. Khourja et al. (1996) came up with the first version of the newsboy model for two items with substitutable demand. Bassok et al. (1999) said that product substitution offers the vendors a chance to pool their inventories and achieve lower inventory costs, which was later reinforced by Hsu et al. (2005). While the studies in the 1990s (Pasternack & Drezner, 1991; Hsu & Bassok, 1999) started with two substitutable products, the later studies (Rao et al. 2004; Shah & Avittathur, 2007; Huang et al. (2011) have been extended to a set of n substitutable products, where n is any positive integer. Also, there have been many joint models on pricing and inventory in the twenty-first-century research such as Hopp et al. (2005); Maddah & Bish (2007); Karakul and Chan; 2008); Akan et al. (2013); Yu et al. (2017) and many others. Within inventory optimization on substitutable products has also covered multiple perspectives such as joint replenishment (Yadavalli et al. 2006), information diffusion (Ganesh et al. 2008), supply chain coordination (Kraiselburd et al. 2004), re-manufacturing (Li et al. 2006; Bayindir et al. 2007). Shah et al. (2019) considered the case for the substitutable products where the demand is a quadratic function of time rather than a linear function.

### 2.2.3.1 Articles Related to Inventory Optimization for Technological Substitutable Products

Looking at the literature that talks of technological substitution, Chanda (2011) proposed the optimal price and quality setting model to determine the optimal price and quality for two substitutable generations of technology products. Chanda and Agarwal (2014) came up with the inventory optimization model for the two substitutable technology product generations. Chanda and Das (2015) discussed the dynamics of how technology generations get diffused in the market. Some of the prominent earlier works in the area of multi-generation substitution are Bass (1969), Norton & Bass (1987), Islam & Meade (1997), Kim et al. (2000), Danaher et al. (2001), Chanda & Bardhan (2008), and Jiang & Jain (2012).

### 3. ELABORATE DESCRIPTION OF WORK IN THE LAST TWO DECADES

After having been introduced to the variety of work in terms of assortment optimization, inventory optimization, pricing optimization, choice models and technological substitution, let us have a look at some of the papers in chronological sequence published in past twenty years. To begin with, the problem related to the approximation of the demand rates and demand substitution rates in case of stock-out based substitution between multiple products was solved through the methods proposed by Anupindi et al. (1998). Extending the concept of product substitution in the manufacturing context, Balakrishnan and Geunes (2000) examined how flexible bill of materials with substitutable components and sub-assemblies can help reduce the inventories. Smith and Agrawal (2000) modelled the stochastic demand for substitutable items and an inventory optimization approach for profit maximization under capacity limitations. Rajaram and Tang (2001) extended the basic version of the newsvendor model to a scenario where an item with extra inventory can substitute the demand for an understocked item. Inderfurth (2004) and Xu et al. (2011) developed the optimal production model for the firms that are into manufacturing of new products as well as refurbishing of used product, both being substitutable. Rao et al. (2004) considered a one-way downward substitution for stochastic demand in multi-item inventory problem. Li et al. (2006) developed an optimal production planning problem for multiple products with demand substitution and remanufacturing of returned products.

Kok and Fisher (2007) proposed an approach to modelling the assortment decisions in which the customer may buy a substitute in the event of unavailability of his/her favourite product. Chen and Plambeck (2008) proved that inventory levels can be reduced by incorporating the learnings of substitution probabilities in the demand model. Li and Ha (2008) studied how the reactive capacity can help reduce the deviation between the supply and uncertain demand in case of substitutable products. Hopp and Xu (2008) studied how the interdependent decisions of assortment, inventory and price under demand substitution can be optimized by approximating the demand substitution behaviour. Shumsky and Zhang (2009) worked upon the optimal capacity allocation policy when multiple products correspond to multiple demand classes and customers can upgrade to higher demand class in the event of capacity depletion of their original demand class. Yucel et al. (2009) did the research work on optimal assortments in customer-driven demand substitution considering the practical issues related to supplier selection, product quality and shelf space limitations.

Bish et al. (2009) while exploring the case of a monopolist manufacturer of two products with substitutable demand under flexible capacity showed how the optimal capacity decision gets influenced by key demand parameters such as market size, market risk and nature of uncertainty. Tang and Yin (2009) developed a model for the joint determination of lot size and selling price under fixed as well as variable pricing strategy for two products with substitutable demand. Dawande et al. (2010) said that the production decisions in case of substitutable products are dependent upon the trade-off between the changeover costs and substitution costs. Gurler and Yilmaz (2010) considered a supply chain relationship between a retailer and manufacturer for two substitutable products under the buyback provision of the unsold inventory. Xu et al. (2010) worked upon optimal replenishment norms of substitutable products when the demand follows the Poisson distribution which is non-stationary by nature. Dutta and Chakraborty (2010) studied single period inventory optimization problem for two items with unilateral substitution in the imprecise business environment.

Goyal and Netessine (2011) said that demand uncertainty in case of substitutable products can be better mitigated by product flexibility rather than volume flexibility in the supply chain processes. Huang et al. (2011) studied the extension of the newsvendor problem with multiple products and partial product substitution. Amini and Li (2011) developed the integrated production planning and sales planning model when the new products are getting diffused in the market and substituting the earlier products.
et al. (2011) deployed dynamic programming to optimize the inventory and assortment under stock-based substitution. Suh and Aydin (2011) formulated and proposed the solution to the price-setting problem for substitutable products whose demand is governed by a multinomial logit choice model influenced by the product price. Kim and Bell (2011) studied the influence of price-driven substitution on a firm’s pricing decisions when it sells to multiple customer segments.

Akan et al. (2013) discussed how the manufacturer’s ability to synchronize the product returns with the sales of a refurbished product can help optimize the profit in case of substitution between a new product and a refurbished product. Sainathan (2013) considered the demand substitution between competing perishable product variants where the product in the initial period of its shelf life has a higher perceived quality than the one in the later period of its shelf life. Saure and Zeevi (2013) showed how a retailer can derive useful insights on the consumer preferences by offering diverse types of assortments and observing the consumer’s reactions, and incorporate that learning into his assortment planning exercise. Although Ganesh et al. (2014) said that the substitution reduces the need for information sharing by pooling the inventories. However, that is valid only for functional products and not for technology gadgets. Fisher and Vaidyanatham (2014) also developed a demand estimation method for substitutable products in retail assortments. Newman et al. (2014) examined how choice-based models can be estimated using the sales data in case of multiple substitutable products being sold by a single firm. Krommyda et al. (2015) optimized the order quantities for two substitutable products with stock dependent demand.

Wei and Zhao (2016) studied pricing for substitutable products under fuzzy environment, Zeppetella et al. (2017) considered the demand substitution under make-to-stock environment under capacity and production constraints; and optimized the production schedule. Pan et al. (2018) developed a stock-based substitution model for two products. Shlapp and Fleishmann (2018) derived the optimal inventory policy for a firm selling multiple products that are partially substitutable under capacity constraints. Chen et al. (2015) and; Chen and Cao (2020) showed how the information on substitution rates and primary demand rates can be learnt from the sales data on the fly. Dong et al. (2020) developed optimal pricing strategies for maximizing the expected profit.

4. MULTI-CRITERIA CATEGORIZATION OF WORK ON THE PARAMETERS OF THE RESEARCH OBJECTIVE AND SUBSTITUTION CHARACTERISTICS

In this section, the existing literature has been classified thoroughly as per multiple criteria, such as the objective of the research, the propelling force behind the substitution, nature of substitution, the direction of substitution, etc. Table 1 captures the objective (viz. assortment optimization, inventory optimization, price optimization, demand estimation and capacity optimization), the nature of demand substitution (viz. assortment based, inventory-based, price-based or technology-based), the propelling factor behind the substitution (viz. customer or vendor) and the direction of demand substitution (unidirectional or bi-directional), and the type of model used (viz. profit maximization or revenue maximization or utility maximization or cost minimization).

It can be observed that most of the research has been done on stockout based substitution, with the objective of inventory optimization for maximum profit. Although, many of the research papers have considered the other types of objectives and substitution scenarios.

| Work                  | Study Objective | Nature of substitution | Propelling Force | Direction | Optimization Model |
|-----------------------|-----------------|------------------------|-----------------|-----------|--------------------|
|                        | A    | I    | P    | C    | D    | AB | S | P | T | C | V | U | B | P | M | R | M | U | M | C | M |
| Pentico (1974)         | ✓    | ✓    | ✓    | ✓    | ✓    | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pentico (1976)         | ✓    | ✓    | ✓    | ✓    | ✓    | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| McGillivray and Silver (1978) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| McGuire and Staelin (1983) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Norton and Bass (1987) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Parlar (1988)          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pentico (1988)         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Pasternack and Drezner (1991) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bitran & Dasu (1992)   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Table 1 Analysis of existing literature on modelling for substitutable products in terms of objective, nature of substitution and model used.
Table 1 Analysis of existing literature on modelling for substitutable products in terms of objective, nature of substitution and model used (Con’t)

| Work                                      | Study Objective | Nature of substitution | Propelling Force | Direction | Optimization Model |
|-------------------------------------------|-----------------|------------------------|------------------|-----------|--------------------|
| Bitran and Gilbert (1994)                 | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Chand et al. (1994)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Drezner et al. (1995)                    | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Khouja et al. (1996)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Lippman and McCardle (1997)              | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Birge et al. (1998)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Bassok et al. (1999)                     | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Ernst and Kouvelis (1999)                | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Hsu and Bassok (1999)                     | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Van Ryzin & Mahajan (1999)               | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Batakrishnan and Geunes (2000)           | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Duanyas and Tsai (2000)                   | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Gurnani and Drezner (2000)               | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Smith & Agrawal (2000)                    | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Rajaram & Teng (2001)                    | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Mahajan and van Ryzin (2001a)            | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Mahajan and van Ryzin (2001b)            | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Avsar and Gursoy (2002)                  | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Agarwal & Smith (2003)                   | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Netesine and Rudi (2003)                 | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Kraiselburd et al. (2004)                | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Rao et al. (2004)                        | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Bayindir et al. (2005)                   | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Boyaci (2005)                            | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Cachon et al. (2005)                     | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Hopp & Xu (2005)                         | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Hsu et al. (2005)                        | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Gaur & Honhon (2006)                     | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Li et al. (2006)                         | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Bayindir et al. (2007)                   | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Cachon & Kok (2007)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Kok & Fisher (2007)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Li (2007)                                | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Liu and Lee, (2007)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Maddah & Bish (2007)                     | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Serin (2007)                             | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Shah and Avittathur (2007)               | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Tang and Yin (2007)                      | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Wu et al. (2007)                         | ✓               | ✓                      | ✓                | ✓         | ✓                  |
| Work                                    | Study Objective | Nature of substitution | Propelling Force | Direction | Optimization Model |
|-----------------------------------------|-----------------|------------------------|------------------|-----------|--------------------|
| Aydin and Porteus (2008)                |                 |                        |                  |           |                    |
| Ganesh et al. (2008)                   |                 |                        |                  |           |                    |
| Hopp and Xu (2008)                     |                 |                        |                  |           |                    |
| Karakul (2008)                         |                 |                        |                  |           |                    |
| Karakul and Chan (2008)                |                 |                        |                  |           |                    |
| Nagarajan and Rajagopalan (2008)       |                 |                        |                  |           |                    |
| Sivakumar (2008)                       |                 |                        |                  |           |                    |
| Bish et al. (2009)                     |                 |                        |                  |           |                    |
| Dong et al. (2009)                     |                 |                        |                  |           |                    |
| Gurler, Oztop, and Sen (2009)          |                 |                        |                  |           |                    |
| Hsieh and Wu (2009)                    |                 |                        |                  |           |                    |
| Vaagen (2009)                          |                 |                        |                  |           |                    |
| Yang and Schrage (2009)                |                 |                        |                  |           |                    |
| Yucel et al. (2009)                    |                 |                        |                  |           |                    |
| Akcay et al. (2010)                    |                 |                        |                  |           |                    |
| Bish and Suwandechochai (2010)         |                 |                        |                  |           |                    |
| Chiang (2010)                          |                 |                        |                  |           |                    |
| Dawande et al. (2010)                  |                 |                        |                  |           |                    |
| Deniz et al. (2010)                    |                 |                        |                  |           |                    |
| Dutta and Chakraborty (2010)           |                 |                        |                  |           |                    |
| Fadioglu et al. (2010)                 |                 |                        |                  |           |                    |
| Gurler & Yilmaz (2010)                 |                 |                        |                  |           |                    |
| Honhon et al. (2010)                   |                 |                        |                  |           |                    |
| Karakul and Chan (2010)                |                 |                        |                  |           |                    |
| Lang and Domschke (2010)               |                 |                        |                  |           |                    |
| Pineyro & Viera (2010)                 |                 |                        |                  |           |                    |
| Tang & Yin (2010)                      |                 |                        |                  |           |                    |
| Xu, Yao, and Zheng (2010)              |                 |                        |                  |           |                    |
| Chanda (2011)                          |                 |                        |                  |           |                    |
| Huang et al. (2011)                    |                 |                        |                  |           |                    |
| Stavrulaki (2011)                      |                 |                        |                  |           |                    |
| Xia (2011)                             |                 |                        |                  |           |                    |
| Burkart et al. (2012)                  |                 |                        |                  |           |                    |
| Pan & Honhon (2012)                    |                 |                        |                  |           |                    |
| Akan et al. (2013)                     |                 |                        |                  |           |                    |
| Deflem and Nieuwenhuyse (2013)         |                 |                        |                  |           |                    |
| Gilland and Heese (2013)               |                 |                        |                  |           |                    |
| Honhon & Seshadri (2013)               |                 |                        |                  |           |                    |
| Tan and Karabati (2013)                |                 |                        |                  |           |                    |
Table 1  Analysis of existing literature on modelling for substitutable products in terms of objective, nature of substitution and model used (Con’t)

| Work                        | Nature of substitution | Propelling Force | Direction | Optimization Model |
|-----------------------------|------------------------|------------------|-----------|--------------------|
|                             | A | I | P | C | D | AB | S | P | T | C | V | U | B | P | M | R | M | U | M | C | M |
| Chanda & Aggarwal (2014)    | ✓ | ✓ | ✓ | ✓ | ✓ | x  | x  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bernstein et al. (2015)     | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | x  | x  | ✓ | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chanda & Das (2015)         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chen et al. (2015)          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | x  | x  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cosgun et al. (2017)        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | ✓  | ✓ | ✓ | ✓ | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Li & Fu (2017)              | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Mukhopadhyay & Goswami (2017)| ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Transchel (2017)            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Yu et al. (2017)            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Aouad et al. (2018)         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | x  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Burnetas et al. (2018)      | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | x  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ceryan et al. (2018)        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Farahat & Lee (2018)        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | x  | x  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Khademi & Eksioglu (2018)   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | x  | x  | x  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Schlapp & Fleischmann (2018)| ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Surft et al. (2018)         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Van et al. (2018)           | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Zhang et al. (2018)         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Aouad et al. (2019)         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Feng et al. (2019)          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Fu et al. (2019)            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Geunes & Su (2019)          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Jing & Mu (2019)            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Kim & Bell (2019)           | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chan et al. (2020)          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Jing & Mu (2020)            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Majumder et al. (2020)      | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Rasoul et al. (2020)        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Hsieh & Lai (2020)          | ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Antipov and Pokryshevskaya (2020)| ✓ | ✓ | ✓ | ✓ | ✓ | ✓  | ✓  | ✓  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

**Legends**
- A: Assortment Optimization, I: Inventory Optimization, P: Price Optimization, C: Capacity Optimization, D: Demand Estimation, AB: Assortment Based, S: Stock-Based, P: Pricing-Based, T: Technology-based, C: Customer Influenced, V: Vendor Influenced, U: Unidirectional, B: Bi-directional, PM: Profit Maximization, RM: Revenue Maximization, UM: Utility Maximization, CM: Cost Minimization
In the next section, the key methods used for the optimization of inventories used in the research papers of the past five decades on modelling for substitutable demand have been elaborated.

5. DISCUSSION ON THE METHODOLOGIES USED TO SOLVE OPTIMIZATION MODELS

A variety of methods have been deployed to solve the optimization models, the most prominent of them being game theory, dynamic programming and newsvendor model. Shah and Avittathur (2007) developed the heuristics for solving the twin problem of the optimal assortment and optimal inventory in the retailing context under demand substitution and cannibalization. While studying the problem of substitution between a new product and remanufactured product, Pineyro and Viera (2010) found it to be NP-hard, and solved the same using tabu search. Rusmevichientong et al. (2010) and Agrawal et al. (2016) worked on an online assortment optimization problem with a multinomial logit model based consumer choice model and dynamic demand learning by the retailers. Asad and Demirli (2010) developed MILP for optimal production scheduling under demand substitution in the steel rolling mills.

Zhao et al. (2012a and 2012b) analysed the price-setting decision modelling of two substitutable products under imprecise manufacturing cost and customer demand using the game theory. Ma et al. (2015) extended the basic single product newsvendor model to a multi-product newsvendor model with demand substitution and developed computational algorithms for optimal assortment and optimal order quantities. Goyal et al. (2016) showed that assortment optimization modelling with dynamic substitutions under stochastic demand is NP-hard even it may be the simplest form of consumer choice model. Xu et al. (2016) developed inventory model for flexible substitution scheme in which the supplier has the flexibility to offer or not to offer the substitution and the customer has the flexibility to accept or reject it, and solved it using stochastic dynamic programming approach. Antipov and Pokryshevskaya (2020) examined the potential of machine learning methods—elastic nets, gradient boosting and random forests in identifying the complex substitution patterns from the POS data of the retailers.

Table 2 captures the solution approach used in the papers (viz. genetic algorithm, linear programming, game theory, newsboy model, nonlinear programming, mixed integer programming, stochastic programming, dynamic programming, etc.).

Table 2 The solution methodologies used in the research articles

| Method Deployed            | Modelling studies in chronological order                                                                 |
|----------------------------|-----------------------------------------------------------------------------------------------------------|
| Markov                     | Duenyas and Tsai (2000); Bayindir et al. (2005); Sivakumar (2008); Yu et al. (2017); Desir et al. (2020) |
| Logit choice model         | Rusmevichientong et al. (2010); Agrawal et al. (2016); Aouad et al. (2018)                                |
| Bayesian Logit Model       | Hopp & Xu (2005)                                                                                         |
| Game Theory                | McGuire and Staelin (1983); Parlar (1988); Avsar and Gursoy (2002); Netessine and Rudi (2003); Boyaci (2005); Serin (2007); Wu et al. (2007); Hsieh and Wu (2009); Chiang (2010); Tang & Yin (2010); Xia (2011); Hsieh & Lai (2020) |
| Newsvendor Model           | Pasternack & Drezner (1991); Ernst and Kouvelis (1999); van Ryzin & Mahajan (1999); Mahajan and van Ryzin (2001a); Bayindir et al. (2007); Maddah & Bish (2007); Serin (2007); Shah and Avittathur (2007); Wu et al. (2007); Vaagen et al. (2009); Yang and Schrage (2009); Dutta and Chakraborty (2010); Gurler & Yilmaz (2010); Karakul and Chan (2010); Huang et al. (2011); Stavrulaki (2011); Deflem and Van Nieuwenhuyse (2013); Maddah et al. (2014); Bernstein et al. (2015); Li & Fu (2017); Surti et al. (2018) |
| Dynamic Programming        | Pentico (1974); Pentico (1976); Pentico (1988); Bitran and Gilbert (1994); Rao et al. (2004); Hsu et al. (2005); Li et al. (2006); Nagarajan and Rajagopalan (2008); Dong et al. (2009); Akcay et al. (2010); Honhong et al. (2010); Xu, Yao, and Zheng (2010); Wan et al. (2018); Fu et al. (2019) |
| Heuristics                 | Shah & Avittathur (2007); Nagarajan & Rajagopalan (2008); Deniz et al. (2009)                             |
| Stochastic Programming     | Bitran & Dasu (1992); Netessine et al. (2002); Kraiselburd et al. (2004); Bish et al. (2009); Bish and Suwandehochai (2010) |
| Linear Programming         | Agarwal & Smith (2003)                                                                                    |
| Greedy Search              | Bassok et al. (1999)                                                                                      |
| MILP                       | Balakrishnan and Geunes (2000); Gaur & Honhon (2006); Lang and Domschke (2010); Pineyro & Viera (2010); Burkart et al. (2012) |
| Non-Linear Programming     | Chand et al. (1994); Anupindi et al. (1998); Li (2007); Tang and Yin (2007); Honhon & Seshadri (2013); Chanda & Aggarwal (2014); Chen et al. (2015) |
6. KEY STATISTICS ON THE RESEARCH DONE TO DATE ON SUBSTITUTION MODELING

This section discusses the key statistics of the existing research on modelling for substitutable demand. **Figure 2** captures the fifteen most widely cited papers that have more than ten citations per year. The literature review by Khouja (1999) is the most widely cited paper, followed by Netessin & Rudy (2003) and Kok & Fisher (2007).

**Figure 2** Papers with more than 8 citations per year since the year of publication

**Figure 3** shows the number of research articles written around the theme of demand substitution over each of the periods of five-year length. It can be observed that the research interest in this domain has increased drastically over the two decades from 1990 till 2010 due to increasing substitutable product variety in every industry with the mass customization concepts becoming popular.

**Figure 3** Trends in the five decades for research studies on demand substitution modelling

**Figure 4** shows the most popular journals that have published the works on modelling for substitutable demand items. European Journal of Operational Research and Operations Research are the two most popular journals for publishing the work in this domain.
In the next section, different methodologies used to solve the optimization models in the inventory literature have been discussed.

7. ACHIEVEMENTS OF THE PAST WORK

From this review, one can observe that the five decades have seen a lot of progress when one observes the research on the modelling for substitutable products. Irrespective of the nature of the substitution, the purpose of research in most of the articles is the maximization of the profit. Revenue maximization and Cost minimization are the other two models, while utility maximization or capacity maximization or planning horizon optimization are a few other models that have also been explored. Demand substitution carries both advantages as well as disadvantages for the firms. While the product substitution raises the level of demand uncertainty for each product variant, it also enables the firms to pool the risks and meet the demand of one product with the inventories of the other substitutable product.

The past work done on modelling for substitutable items is a good learning ground for the businesses in the realm of operations, supply chain management, business strategy, product management and marketing management. The papers written on demand modelling have given useful insights on the customer choice models and the purchase behaviour of the consumer. The studies to date have been able to cover a wide range of demand substitution models with diverse objectives and optimization approaches. This has been of good help to the industry practitioners and policymakers in making sound decisions related to assortment rationalization, pricing and inventory. The retail industry, in particular, has a lot to benefits to derive from these studies.

This review has been a decent attempt at collating all the existing research on the mentioned topic onto a common platform and classifying the same into broad categories. The review has also been a very exhaustive and comprehensive one and has touched upon multiple interdisciplinary perspectives of demand substitution. The review is expected to guide the academicians in disseminating the existing body of knowledge in the classroom related to demand substitution. It can be useful particularly in the teaching of subjects such as marketing, supply chain management, optimization and consumer behaviour. This review can be a point of reference for all the industry practitioners faced with the problem of managing items with substitutable demand. The review can also be of immense help to the researchers in finding out what has been done to date, and what needs to be done ahead.

8. LIMITATIONS AND FUTURE DIRECTIONS

Despite significant research progress in this domain, the work on the modelling for substitutable products can be extended further to bring it closer to the practical realities of the modern world business phenomenon. First, there needs to be more research on the consumer-driven locational choice models. Much of the existing research is on multinomial logit choice models that are not fit in the situations where the chance of choosing a product is independent of the chance of choosing another. Also, multinomial choice models are inappropriate when the product attributes are in the form of a continuous function. Second, even the uni-directional research in case of locational choice models is very rare while so many cases are known such as technological substitution, where the customer buys a model in the neighbouring range only, and will always upgrade to a higher version.

Third, most of the research assumes that customers make a rational choice, while it is known that cognitive biases have a strong influence on the choices made by the consumer. Apart from the cognitive biases, the customers are sometimes subjected to information asymmetry or peer pressure or time constraints, which lead them to the path of making irrational and non-stationary choices that cannot be specified by fixed preference relations. Therefore, there exists a need to have more of research that can entertain the unexpected choices of the consumer under the bounded rationality.

Fourth, while decisions related to assortment, inventory and price have received the attention, the work on capacity
optimization has a much more scope to offer than what has been explored. The inadequate capacity at the manufacturer’s end or the supplier’s end can result in stockouts, and the allocation of the fixed capacity to the multiple substitutable products can be optimized within the constraints. Fifth, the areas of risk mitigation through the supply chain contracts and the three Cs of coordination, cooperation and collaboration may be explored for substitutable products. Sixth, the work on the inventory modelling for technology generations can be strengthened, given the fact that the World is witnessing the digital age where the conventional products are being transformed into intelligent and connected products.

Seventh, with the advent of business intelligence, a lot of data is available at the click of the mouse, and the real time decisions can be made on the basis of algorithms built in the computing systems. This has reduced the response time of the businesses to the changing environment, and therefore, can also have the implications for the type of decision models to be used. The research can happen on integrating the models with the latest development in information systems to leverage the effect of the computing revolution.

Eight, we have seen that much of the literature on decision modelling for substitutable products has considered only one objective at a time. While in the real world, we may have multiple conflicting goals that need to be optimized at the expense of one another. This would call for the goal programming or multi-criteria decision making. If future research can address this gap, that shall be useful.

Last but not the least, it has been observed quite often that the value of unit inventory changes (generally depreciates) with time, a fact that can be considered in the future papers on optimization for substitutable products.

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