CHAPTER

1 Economic Order Quantity Model for successive generations of a high technology product: An Introduction

Technological progress has impacted virtually every part of our lives. It was beyond the human imagination in the twentieth century that a technology product that can monitor one's total activity, compute the energy consumption, and guide one for the appropriate diet intake throughout the day. It would also have been difficult to imagine the role that a smartphone can play in controlling the home devices remotely. Since the time internet came up in the 1990s, it has evolved into first the IoT (Internet of Things) and now into the high technology by seamlessly connecting the devices with the cloud, enabling the exchange of data. Our social life has been conquered, expanded, and transformed by social networks, personalized internet, and always on-mobile connectivity; and our lives have got an everlasting connectedness (Rainie and Wellman, 2012). Technology developments have economic, social, and political implications (Rheingold, 2002). The innovation and social transformation are happening at an accelerated pace with the advent of high technology products (Castells, 2011), creating a need for businesses to become tech-savvy. The collaboration between humans and the machines has increased immensely today making the organizations more flexible and adaptive (Daugherty and Wilson, 2018).

There is no better time to embrace technology than now. The companies that work towards technological up-gradation and upskilling have a higher chance to win in the competitive market by being able to increase their productivity significantly. Every business needs to become a technology

Sacolick, 2017; Porter and Heppelman, 2017). The societies and firms need to adapt to the technological disruption taking place all around the World (Schwab, 2017). The re-engineering of the business model is also becoming a source of innovation, and helping firms think from a holistic perspective (Amit and Zott, 2012). Waller and Raskino (2015) in their book titled "*Digital to the Core: Remastering*

Leadership for Your Industry, Your Enterprise, and Yourself" spoke a lot about GE and its technology enablement journey. Rogers (2016) in his audiobook titled "*The Digital Transformation Playbook*" said that work automation is not just concerned with updating the technology but also with upgrading strategic thinking. Uber, Wikipedia, Airbnb, Amazon, Apple, and PayPal became industry leaders by disrupting their respective markets (Parker et al. 2016).

1.1. Technological Products and Technology Generations

The vast nature and the extent of technological disruption as discussed above in the various sectors has led to the third wave of the IT revolution. The first wave of IT revolution happened in the 1960s, when the individual activities in the value chain got automated, leading to a drastic increase in the productivity of activities. The second wave of IT revolution that came in the 1990s was concerned with increasing the coordination among different activities, different functions, different business partners, and different geographies. Both these waves were characterized by the transformation of the value chain but not by the change in products. Now, in the third wave of the IT revolution, there is a drastic improvisation in the performance and function of the product by embedded sensors, data capturing and storage devices or cloud, microprocessors, software, embedded operating systems, controllers, remote servers, security tools, user interface and connectivity components such as ports, antennae, protocols, etc. Such products have the potential of bringing in another upward swing in the productivity of resources and growth of the economy. These products perform multiple functions such as monitoring (as in the case of blood glucose meter), control (such as turning on and off the lightbulbs with a smartphone or dimming them at night), and optimization (such as microcontrollers to adjust the blades of the windmill for capturing of maximum wind energy, or predictive maintenance of the systems when the failure is imminent, as is done by *Diebold* for its automated teller machines). Thus, these high technology products are much more than just being mechanical or electrical products (Porter and Heppelman, 2014; Iansiti and Lakhani, 2014).

These technology products have offered tremendous scope for increasing the reliability, functionality, capability, and utilization of systems. This, in turn, has disrupted the value chains and has led the organizations to reconsider and re-equip everything that they do. Thus, the emergence of high technology products has exposed the firms to competitive threats and opportunities, compelling them to strategically innovate the business models, expand the industry boundaries, and redefine the relationships with business partners. Primary reasons for the growth in the market size of technology products are the breakthrough in system performance, miniaturization of systems, and the emergence of big data analytics. Some of the other factors are the tools for rapid software development, increasing the energy efficiency of batteries and sensors, the evolution of compact and low-cost data storage devices, processors, connectivity ports, and wireless connectivity.

These technology products have led to an increase in market rivalry and opened up a plethora of opportunities for product differentiation and value-added services. The industry has witnessed a shift from offering a physical product to offering experience, thereby, creating a bundle of products and services (Coreynen et al. 2020). This so-called "servitization" has also led to an increase in the market for technology products (Zheng et al. 2018). The data analytics capabilities are also being built into the service systems leading to the continuous journey of technology up-gradation (Akter et al. 2020). **High technology products** can be defined as cutting edge products that are using the most advanced and state-of-art technology. These products involve a higher consumer perceived risk as compared to the functional products (Truong et al. 2017).

The pursuit of launching newer products, as discussed above, gives birth to something that can be called "**technology generations**". Technology generations are a set of product brands and models that offer similar functionality as perceived by the customer. Technology generations can be defined as "*a set of product brands and models similar in customer-perceived functionality characteristics*" (Bass & Bass, 2001, p: 7). Abell (1980) incorporated three dimensions in the definition of technology generations- "function, customer, and technology". The new technology generation should perform a similar function to the one performed by earlier generations; should expand the market to a new set of customers although it may be used by existing customers also (Islam and Meade, 1997); and should be characterized by either of the three: new technology, or new application of existing technology, or enhanced performance level of existing technology.

In the technology market, the new products with better value and added features get introduced from time to time to meet the customer requirements or reach out to the wider customer base. However, the existing products do not disappear from the market instantly upon the introduction of new products (Chanda & Agarwal, 2014), since the customers take time to adopt newer products based on the expected utility and cost dynamics. Due to this for multiple generations of products, the co-existence of several generational products may take place in the market at least for some time. (Kohli et al. 1999; Agarwal and Bayus, 2002; Van den Bulte and Stremersch, 2004; Chandrasekaran and Tellis, 2008). Stremersch et al. (2010) suggested that each generation may take a different time to reach the milestone corresponding to reaching 5% penetration as well as to reach the take-off stage when there is an explosion in the diffusion rate.

The technological product industries differ from the conventional industries, the primary difference being that they are highly and frequently influenced by innovation. The multi-generation products are a subset of substitutable products that are advanced versions of the same platform-based product and are intended for the same function and scope of work. A new technology product often cannibalizes the

The newer technologies

replace older ones, but that replacement is not instantaneous. There are periods in which multiple generations of technology co-exist. For example, in the case of smartphones, the 5G is ultimately going to replace 4G the way 4G devices have replaced the earlier generations. The CAGR (Compounded Average Growth Rate) for 5G smartphone devices is expected to be 179.9% over four years from 2019 to 2023, and the market will reach the figure of nearly 1.9 billion devices by the end of 2023[1].

It has also been observed that some of the successful companies in the technology products business create new products from time to time. Also, they do not hesitate to cannibalize the existing products for the sake of a better future. The firms into this business have to embrace cannibalization pro-actively with the changing customer preferences to prevent the competitors from cannibalizing their market share. A few examples of the technology giants that have grown immensely during the past decades by embracing self-cannibalization are Google, Apple, Amazon, and Facebook. These companies have been proactive in replacing the existing products with newer products that are worth more in terms of functionality, form, or features. Even Tim Cook, the CEO at Apple Inc, after taking over as the CEO said "I see cannibalization as a huge opportunity for us. One, our base philosophy is to never fear cannibalization. If we do, somebody else will just cannibalize it, and so we never fear it. We know that iPhone has cannibalized some iPod business. It doesn't worry us, but it's done that. We know that iPad will cannibalize some Macs. That doesn't worry us" (Dormehl, 2019, p:1)[2].

In 2005, the demand for Apple iPod mini was enormous. Nevertheless, Apple launched the iPod nano that brought about a substantial impact on the sales of the iPod mini. Two years later, Apple launched its smartphones that eliminated the need for dedicated music devices. Apple sees cannibalization as a

avoids cannibalizing its existing products, then somebody else will cannibalize it. Apple has taken many such decisions in the past with the iPod nano replacing iPod Mini in 2005, iPhones replacing iPods in 2007, iPad cannibalizing Mac sales in 2014, iPad mini cannibalizing the larger iPad sales, larger phablet iPhones cannibalizing iPad Mini and now health-tracking AirPods cannibalizing the smartwatches.

The firms believe that cannibalizing their existing products by themselves is better than that by their competitors. Therefore, they are in the constant pursuit of identifying the stated and implied needs of the consumer, and anticipating the changing consumer preferences to incorporate the suitable features and functions to the products that can bring more value to the consumer. Netflix is another example of

[1] https://www.telecomlead.com/smart-phone/5g-smartphone-forecast-for-china-north-america-91072
[2] https://www.cultofmac.com/608052/can-apple-keep-cannibalizing-its-core-creations-opinion/

such a firm since it switched its business from selling DVDs to streaming media services that can be used on all the devices (Littleton & Roettgers, 2018). Some of the firms also track the metrics that mandate a certain percentage of their revenues to come from the newer range of products. For example, 3M has a rule that thirty percent of its revenues in any year has to come from the products launched in the last four years, a metric that it monitors rigorously (Govindarajan and Srinivas, 2013).

1.2. Supply chain challenges for technology generations product

As discussed, the technology products are at the constant risk of being outflanked. And therefore, the technology firms have to work with two faces, like the Roman God “Janus”, with one face looking inward for the sustaining incremental innovations in the existing products, and the other face looking outward for the disruptive business innovations. Also, the customers redefine their needs when they see a new technology generation being introduced. The increase in the functionality of newer generations also causes generation shifts. These generational shifts in technology are of great interest to supply chain managers as the transitions may replete with new possibilities, whereas, there is a danger of failure also.

Furthermore, the impact of these kinds of products on the economy of a nation can't also be ignored. Hence, it becomes all the more important to achieve the operational efficiencies in the supply chain for such technology products. The traditional economic ordered quantity (EOQ) models are based on the assumption that the demand rate of a product remains constant all through the planning horizon. However, for technology products, the product life cycle is very short with fast-changing consumer preferences and evolving product features. The demand for such kind of products not only varies with time but can also characterize by adoption-substitution between two competing technology generations' products. The classical multi-generation adoption model by Norton and Bass (1987) suggested that the demand curve of new technology generation follows the S-shaped growth pattern. Nunez-Lopez (2014) proposed that the launch and the diffusion of competing technology products are also influenced by the supply of financial resources.

These technology products are generally managed as product families (or as multiple items). Product families are generally a group of related goods that are managed as a whole. This kind of management helps in optimizing the logistics and inventory costs, and also helps in deriving the better efficiencies by pooling the limited resources available to the supply chains. If these product families are closely observed, it would be discovered that many SKUs (stock-keeping units) in them are substitutable. That is, one or more products serve a similar purpose, and may have a very small differentiation among them in terms of features, packaging, brand, price, aesthetics, etc. Since they are substitutable, they have cross elasticity of demand with price as well as with the stock.

With the increased emphasis on lean supply chain and pull-type production and distribution systems, the companies have become more demand-driven. Thus in the changing circumstances, inventory models need to be designed to adapt the demand uncertainty. The inventory managers have to plan the inventory replenishment norms while considering the interplay of demand for the various generations of the products. Therefore, the research in this direction shall help the technology products industry in cutting down the costs and partial percolation of this cost-saving benefit to the consumer. Thereby increasing the long-term sustainability of this industry. Such optimization is also expected to benefit the consumers by bringing out the innovations in the market at the customer-friendly prices. But the manufacturers and supply chain practitioners have not drawn their attention towards the influence of this unique nature of substitution on their policies and processes.

1.3. Importance of demand forecasting for Supply Chain Management

Demand forecasting has a very important role in the business. It helps immensely in planning the product assortments, and also the supply planning for the raw materials and manufacturing planning for the finished products (Eckman, A.L., 2004). Integrated planning of sales and operations offers higher visibility, increased accountability, and more flexibility and helps to understand the business better (Smith, 2004). The importance of *Sales and Operations Planning* can be understood well if one looks at how frequently the literature reviews have been conducted by the researchers on this topic, some of the latest reviews are being by Pareira et al. (2020); Danese et al. (2018) and by Naroozi & Wikner (2017). There is a tight linkage between demand planning and inventory management in an organization. Hence, the inventory norms that are worked in isolation will never result in a global optimum for the organization. Therefore, understanding the demand dynamics is very essential for inventory managers and practitioners.

Conventionally, many demand planning tools such as the simple moving averages method, weighted moving averages method, exponential smoothing forecast method, linear regression analysis, time series analysis, DELPHI Method, etc. have been used for the demand planning by the inventory managers. But in the case of technology products, the conventional demand forecasting techniques will give very high values of MAPE (Mean Absolute Percentage Error) and Tracking Signal. This is because the rate of demand variation with time is too fast to be captured by any of these. This has been elaborated in the next paragraph.

In the case of technology products, their demand is governed by life cycle dynamics. It necessitates using innovation diffusion theory to capture product life cycle dynamics, where the demand for generational products is influenced by the interaction effects of actual users across generations. The interplay of demand among these multiple generations makes it a challenging task to forecast the correct demand and to determine the optimal product availability under optimal promotional and stock-keeping costs. Lee et al. (2016) said that even the product preferences among technology products change with time. Apart from the adoption of the product itself, the usage of newer functions on these products also follows the innovation diffusion theory (Lim et al. 2019). The knowledge of when the new technology will take off is very important for the firms. This shall enable them to ensure that they do not miss upon the opportunity, and nor do they deplete their resources even before the take-off starts.

1.4. Diffusion of Innovations

Rogers (1962) proposed the theory of innovation diffusions, that explained how the innovations get communicated and diffused in the market. The technology products follow the demand pattern governed by life cycle dynamics. Their demand not only varies with time but can also be characterized by adoption-substitution between two competing technology generations' products. Mahajan et al. (2000) in their book titled "*New Product diffusion models*" suggested that diffusion modeling is not only done to generate forecasts but also to help in making strategic decisions related to pre-launch, launch, and post-launch.

The nature of modern technology products is itself helping in faster diffusion. There are five characteristics of an innovation that determine its adoption rate (Rogers, 1962). These five characteristics are relative advantage, compatibility, complexity, trialability, and observability as shown in Figure1.1.

Figure1.1. The five characteristics of innovations as per Rogers

The customers adopt innovative products through the five-stage process of awareness, interest, evaluation, trial, and adoption as shown in Figure1.2. These products are high involvement products for which the customers deliberate a lot before making the purchase decision.

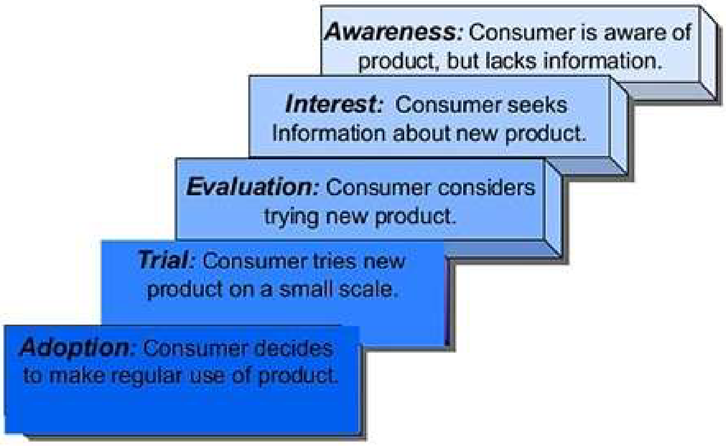

Figure1.2. The five-step adoption process for innovative products

A high technology ecosystem has developed over a few decades, which consists of tech-savvy consumers, competitive industry players, technology business giants, and tech-savvy policymakers and regulators. The development of such an ecosystem has led to the newer innovations being more compatible with the prevalent values and needs of the potential adopters. Therefore, technology products have a higher relative advantage, compatibility, trialability, and observability than conventional products. Technology helps in establishing common beliefs and thoughts among the people, making them more homophilous. The technology is also helping its spread by guiding the consumer in the well-known five-staged purchase decision process of knowledge, persuasion, decision, implementation, and confirmation. Hence, the adoption of technology products is much faster. According to Rogers (1962), technological determinism (*technology shaping the society*) and social constructionism (*society shaping the technology*) were two opposite viewpoints. In modern times, it is often observed that both hold good as there is a two-way influence relationship between social factors and technology. Also, it is noticeable that today's generations are less dogmatic, more rational, more capable of dealing with abstract ideas, more inter-connected in their social networks, and more cosmopolite (Wuthnow, 2010). They are also known to possess a more favorable attitude towards science, risk-taking, and uncertainty. Also, they are more exposed than ever to mass media channels and the use of information and communication technologies (Kwon et al. 2017). There is also a shift in the overall demographics moving towards the higher levels in Maslow's Hierarchy of Needs which can be served using the technological products. These factors have resulted in an increasing proportion of early adopters in the population. Therefore, the adoption of the newer generations of technology products is much faster than the earlier ones, contingent on the condition that they carry higher utility. However, the communicability of innovation influences the success or failure of its diffusion (Downs and Mohr, 2013). The factors affecting the adoption also differ across the categories of innovations in terms of radical vs routine, or major vs minor. The communicability of innovation influences the success or failure of its diffusion (Downs and Mohr, 2013).

Bass (1969) suggested that the diffusion of innovative products is driven by two effects: innovation and imitation effect. He also predicted the peak sales and the timing of peak sales on the historical data for consumer durables with fairly good accuracy. This model differed from the earlier ones proposed by Heins (1964) and from Fourt and Woodlock (1960) that had suggested the exponential growth of consumer durables leading to an asymptote. The model also differed from Bain (1964) that suggested a lognormal distribution.

The nature of substitution in the case of technology generations is very different as compared to one in the case of the normal substitution. This is because the technology generations have a diffusion that is changing very fast with time, and hence, has a very high degree of non-stationarity as compared to the functional products. Multi-generational high-technology products are characterized by uncertain growth behavior, competition within generations, and short product life cycle. Hence it is important to assess the impact of cannibalization effects of the advanced generation products along with the effect of credit period on Economic Order Quantity (EOQ) policies.

1.5. Diffusion Modelling fort Multi-Generation Products

Fisher and Pry (1971) first proposed the technological substitution models for two-generation products. Later on, many extensions of the model were from different dimensions (Blackman, 1974; Stern et al., 1975; Bretschneider and Mahajan, 1980; Kamakura and Balasubramanian, 1987). The classical multi-generation adoption model (Norton and Bass, 1987) suggested that the demand curve of new technology generation follows the S-shaped growth pattern as shown in Figure3. Also, Figure1.3 shows that these innovation products also have a unique characteristic, i.e. they are first adopted by the innovators and last, adopted by the laggards. The product life cycle is very short on account of fast-changing technology, consumer behavior as well as the changing dynamics of the overall supply and demand ecosystem (Gaurav & Shainesh, 2016). There are multiple generations of the same technology in the consumer markets that cannibalize the sales of one another. Also, with the increasing advancement of technology, the adoption rate of these products is very fast, which further leads to a shortening of the product life cycle for given market potential.

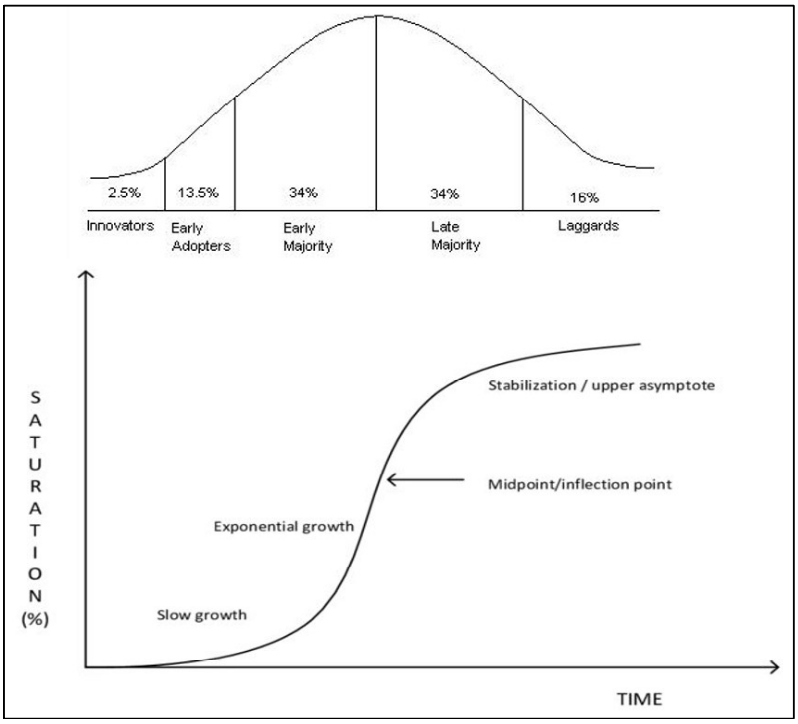

Figure1.3. The S-shaped curve of innovation diffusion (Self-composed by the author)

With the ever-increasing speed of technology up-gradation, technology products have become an integral part of human life. This has led to an increase in the penetration of these products, thereby increasing the size of the overall market, and attracting more players. With the advent of the newer players and with the increased scale to justify the capital expenditures required in product development, the companies are always in the pursuit to introduce new features, add new functionality to the products. The augmentation of product features further expands the market, causing businesses to upgrade the technology to a higher level. The increased technology up-gradation, in turn, leads to the expansion of the market and product augmentation. Thus, there is a multi-faceted relationship between these factors. As shown in the Figure1.4, there is a two-sided causal relationship among these factors.

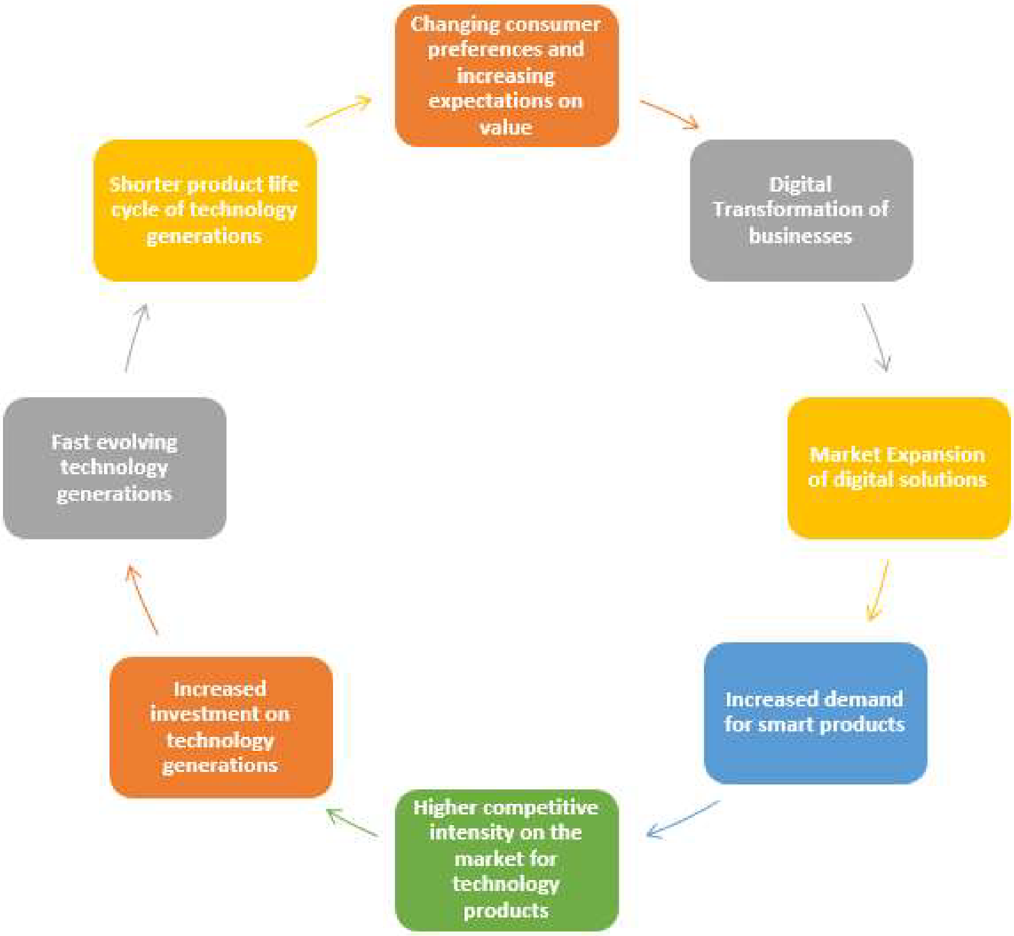

Figure1.4. The cyclical relationship between technological enablement of business models and product innovation (Source: Composed by the author)

With the large investments going into product development, there has been a change like the technology products also. There was a time when the products were made up of mechanical and electrical components. Now, the products offered by technology firms are sophisticated systems comprising sensors, microprocessors, data storage devices, connectivity devices, and software in multiple ways. Such products are here referred to as technology products.

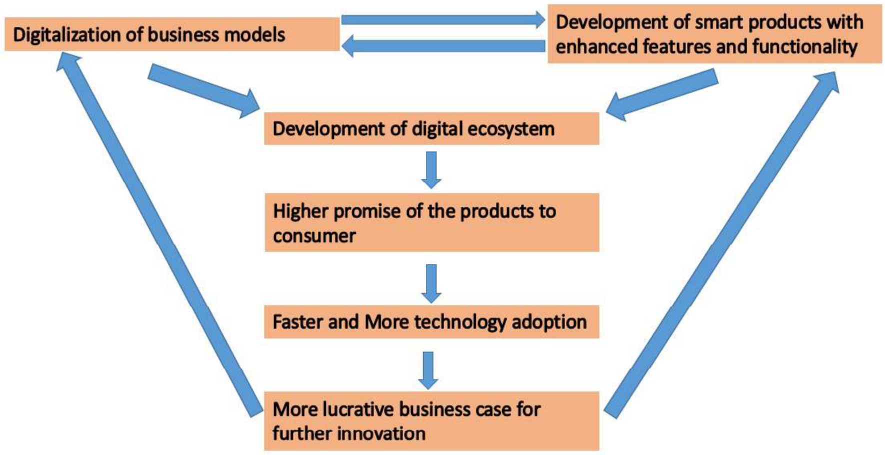

Figure1.5. The complementarity between the tech-savvy business models and the development of technology products (Source: Self-composed by the author)

As shown in Figure1.4 and Figure1.5, higher technological enablement of businesses pushes the consumer to adopt more of technology products, thereby driving the volumes that can make the economic activity of product improvement more viable and promising. This increase in the diffusion rates of innovations lures the firms to invest further in technology improvements. This, in turn, increases the intensity of the market rivalry and encourages the competing players to come up with a better value proposition to the consumer. Due to intense competition in the hi-technology market, the continued survival and growth of a firm largely depend on its innovation capacity and aggressive marketing strategy. Product innovation can help a firm to distinguish itself from its competitors and to spread out to the masses. Therefore, the products get improvised over some time. More advanced features and functionality get embedded into the newer generations of the technology products. This causes higher buy-in of the consumer towards these products and also enables the businesses to reach the consumer through the technology chord. This leads to a shortening of the product life cycles and a higher degree of demand substitution among the different versions of the same product. It is important to note that this demand substitution is consumer-driven by nature.

In a nutshell, the firms need to look at their existing products and services from a technological perspective, connect the existing assets, embrace new modes of value creation as well as value capture and reshape the boundaries of what they do. But it needs to be taken care of that opportunities come with risks as well. If the firms mix their enthusiasm with rationale and manage the downside well, the results can be rewarding in the long term. The downside risks of stockouts or overstocking can be mitigated by executing the inventory and supply chain decisions in a judicious and considerate manner. The upcoming section discusses inventory models that can be of help in achieving operational excellence.

1.6. EOQ Models

Inventory can be defined as an idle asset that will give a future benefit. There are multiple purposes for storing inventories. Some of the prominent ones are leveraging the economies of scales in the three stages of production or replenishment, increasing product availability, decoupling two stages in the supply chain, meeting the sudden spikes in demand, keeping a buffer for the quality defects, etc. While there is a benefit of storing the inventories, there is also a loss in terms of obsolescence costs, storage space costs, insurance costs, pilferage costs, supervision costs, blockage of working capital in the stocked inventories, etc. Classifying the inventory-related costs into two broad categories of ordering costs and carrying costs, Harris (1913) proposed the first inventory optimization model considering constant demand, no backlogging, constant price, and instantaneous replenishment. He derived the basic *EOQ* Formula as in equation1.1:

$$EOQ = \sqrt{\frac{2CD}{H}} \qquad (1.1)$$

where C is the ordering cost per order, D is the demand per unit period and H is the holding cost per unit item per unit period.

Conventionally, most of the classical inventory modeling and optimization work has assumed that the product is a non-changing entity with a constant life cycle and a constant demand. However, as elaborated above, this is not true in the modern world where it is visible that the successful products in the market are generally substituted by newer generation products. There exist plenty of examples such as televisions, cellular phones, computers, video-game consoles, etc. Throughout times, such gaps in the inventory literature have been realized, and more robust inventory models have been formulated.

Thus, the basic model of Harris (1913), has witnessed a lot of extensions. A few of the basic extensions to the Harris Model (1913) are relaxation of constant demand rate assumption, the incorporation of backlogging cost, volume-based discounts, and relaxing the constraint of instantaneous replenishment. Numerous extensions of the Basic EOQ Model have been worked upon since then. One of those is the adaptation of this Model to the non-constant demand rate (time-dependent, credit-dependent, stock dependent, price dependent, etc.). Another extension is the consideration of multiple items in the inventory replenishment decisions that encompass assortment optimization and inventory optimization, with related dynamics of pricing, capacity, etc. Multi-item inventory models deal in the management of more than one product in the supply chains. There has been a substantial amount of research work on multi-items inventory modeling and joint replenishment. But the research on the inventory modeling for multi-generational products is still rare. Although there have been many models that have been built to ascertain the demand pattern of technology products. But very limited work has been done on the inventory modeling for technology products that come in generations (Chanda and Aggarwal, 2014).

1.7. Extensions to the basic EOQ Model

Since the studies on the inventory optimization research in the domain of technology generations are rare to be found, this study intends to develop the EOQ Models for the inventory replenishment of technology products. It is also to understand how the implications of trade credits, storage space constraints, price-dependent demand, and imprecise business environment have been incorporated in the inventory models over some time. Price, trade credits, and storage space are the strategic levers for the managers dealing in technology generations to influence the demand of the products and therefore to drive the business in the desired direction. But the research work in this direction is rare. The same has been discussed briefly in the next section.

1.7.1. Trade Credits and Multi-generational products

The role of credit periods in modern trade cannot be ignored. The sellers can identify the prospective defaults more quickly in case of supplier financed credit than the one financed by financial institutions (Smith 1987). Suppliers may also act as debt collectors, and protect the customers against the liquidity shocks (Cunat, 2007). Further, studies suggest that firms tend to use more of it during the crisis (Calomiris et al. 1995). Private firms located in particularly high social trust regions tend to use more of inter-firm credit (Wu et al. 2014). Inter-firm credit terms and credit policies vary widely among the different firms and across the industries (Smith et al., 1999). Trade credits also help in alleviating the problem of information asymmetry that lies between firms and banks (Biais and Gollier, 1997). The increased globalization has also triggered government initiatives on trade finance (Menichini, 2011). Credit financing mechanism is a common phenomenon in the technology market. Primarily due to relatively larger ticket sizes, hence very few buyers are capable of making the down-payment. Another reason for the prevalence of credit period in technology products is the relatively higher working capital cycles in such goods, which is caused by the higher consumer-involvement in the purchase of such goods, and therefore, slows movement across the supply chain. When it comes to the inventory modeling for the technology generations under the trade credits mechanism, the work is hard to find in the existing literature. Chanda and Kumar (2017) formulated the EOQ model for technology products under the trade credits while considering dynamic pricing and advertising. Chanda and Kumar (2019) developed a similar model under trade credits for dynamic market potential.

1.7.2. Pricing dynamics and Multi-generational products

The selling price of a product has a predominant influence over its demand. Some of the pioneering works in this regard have been by Simon (1979), Parker (1992), and Tam and Hui (1999). There also exist a good number of research studies that have been done on inventory optimization for price-dependent demand. Most of the studies cited above have considered conventional products only. Kreng and Wang (2013) argued that most of the classical multi-generation models are of little use for policy decisions; as they do not consider explicitly the effect of marketing variables, such as pricing or advertising to understand the demand dynamics.

1.7.3. Storage Space Constraints and Multi-generational Products

A few of the pioneering research studies on linking inventory norms with the storage space have been done by Homer (1966), Evans (1967), Page and Paul (1976), Zoller (1977), and by Buffa and Reynolds (1979). The demand functions being worked upon by the existing research on storage space constraints has been very varied, with a few studies considering the constant demand, while most of them considering the variable demand. When it comes to the studies on variable demand, some of them have considered time-dependent demand, while many have considered stock dependent demand or credit-linked demand. While a few have used the stochastic demand pattern, most of the studies have used a deterministic demand function. Some studies (Hubner & Schnaal, 2016 and Hubner and Schnaal, 2017) have also used space elastic stochastic demand in which larger warehouse-size spurs the demand. Sana (2015), Minner and Silver (2005), Cheung & Simchi (2019) also used the stochastic demand patterns. A few studies have also considered the ramp type demand (Agarwal et al, 2013 and Chakraborty et al, 2018), the Poisson distribution of demand (Minner & Silver, 2007), and the exponential demand (Singh & Pattanaik, 2016). There has been only one study for the technology products under warehousing space constraints by Kumar & Chanda (2018). Although this study is very enriching and a pioneer in the inventory modeling for diffusion dependent demand under storage space constraints, but it has considered only the single generation technology products.

1.7.4. Imprecise Business Environment and Multi-generational Products

In the modern world that is often described as chaotic and ambiguous, it is impossible to have access to perfect information; making the traditional deterministic EOQ models irrelevant. An effective way to overcome this challenge is the use of fuzzy set theory postulated by Zadeh (1965). Zadeh defined the fuzzy set and proposed that it is characterized by a membership function that assigns a grade to each object. The real-world environment in which to make decisions, the objectives, the constraints as well as the results expected from the possible actions are not known precisely (Bellman & Zedah, 1970). Introduction to fuzzy set theory and the basic idea of fuzziness has been laid down by Zimmermann (1976). When it comes to the products with substitutable demand under imprecise environments, there is plenty of existing literature on the demand modeling and the inventory modeling of such products. But when it comes to the products with successive technology generations, the literature is very limited. There has been some work by Chanda and Kumar (2017) and Chanda and Kumar (2019), but that has not considered the technology generations.

1.8. Development of Research Questions

The shorter lifecycle of the technology generations coupled with the dynamic substitution effect, as discussed earlier, makes it a challenging task for the operations manager to achieve efficient supply chains. It is very common to see the supply chain practitioners in a fix when the multiple technology generations are launched successively at very short intervals of time. This is because the consumer behavior for the existing technologies in the market changes with the advent of newer technologies. This phenomenon is more valid in the case of the early adopters, who have a flair of trying something new in the market. Thus, the operational efficiencies in the supply chain can be achieved only if the diffusion dynamics and demand substitution dynamics of these technology generations are given due consideration.

To survive in such a competitive industry, the manufacturers of technology products need to either differentiate their products and command premium, or achieve operational efficiencies and lower the costs, or do both of these activities. Since the selling price is predominantly governed by the market forces of demand and supply, achieving operational excellence becomes of paramount importance in the case of the firms dealing with technology products.

It is here that the inventory optimization of the substitutable technology generations becomes very important. In such a case, it is critical for the supply chain practitioners to factor in the demand model and the dynamics of innovation diffusion dependent demand while developing operational norms, and executing the supply chain decisions. The diffusion phenomenon of the innovations and the demand substitution models among the technology generations need to be incorporated into the inventory optimization models for the products. The cost efficiencies can be achieved if the perfect balance between the two conflicting costs- one time fixed cost of ordering and the recurring inventory carrying cost is achieved. This is because while the former of these costs rise with the replenishment frequency, the later fall with the same.

Since it is important to optimize the inventory policies, such models for the technology generations need to be worked upon. Since there are so many variables into play, these decisions cannot be taken arbitrarily or by the human gut feel. The decisions made using the quantitative techniques have a definite advantage over the human judgment when the human mind is not capable of deriving the optimal solution given numerous constraints and decision variables. Hence, mathematical models will be helpful to derive the optimal inventory policies.

1.9. Formulation of Research Objectives

This thesis is going to formulate the appropriate demand model for technology generations and then, use it for inventory modeling and optimization under different practical scenarios. The objectives have been outlined as under:

Objective 1: To study the demand behavior of the technology generations, and to examine the influence of their life cycle dynamics and the inter-generational substitution on their inventory policies

Objective 2: To study the effect of the trade credits on the different technology generation products on their optimal inventory policies, and to make recommendations on the same for the economic conditions

Objective 3: To study how the product pricing dynamics influence the inventory norms for the different technology generation products, and how the change in prices of one generation affects the inventory norms for the other generation products, and to infer the pricing insights over the life cycle of the technology products for profit maximization

Objective 4: To study how the limitations on the storage space have a bearing on the inventory policies of multiple generation products and to examine the pros and cons of using rented warehouses

Objective 5: To formulate the inventory optimization problem for technology generations under imprecise and uncertain business conditions, with the use of fuzzy logic and determine the implications of uncertain business environment on the inventory costs and total profit function

1.10. STRUCTURE OF THE THESIS

Chapter 2 shall cover a review of the literature on inventory modeling for non-constant demand, for multi-product inventory models, and demand substitution. Upon doing these three reviews, the thesis shall come up with a review of the small work done on the inventory modeling of technology generations, which is an integration of innovation dependent demand dynamics into the inventory decisions. Thus, the chapter with a review of innovation diffusion modeling literature for developing a better understanding of the demand dynamics for technology products.

Chapter 3 shall propose a demand model for the multiple technology generations and validate it on a historically available dataset in terms of the prediction accuracy. After proving that our proposed demand model has a significant predictive ability, it shall be used in the basic single-period inventory model for the technology generations to be developed in the same chapter. And then, the basic single-period inventory model shall be extended to the basic multi-period inventory model. A few important theorems will also be developed, along with the numerical illustration and sensitivity analysis with key parameters. The implications for the managers shall also be drawn.

Chapter 4 shall witness the extension of the single-period inventory model developed in chapter 3 to consider the dynamics of interest earned or lost owing to the credit terms in business transactions. Then, the multi-period inventory model developed in chapter 3 will be extended to incorporate the influence of the permissible delay in payments.

Chapter 5 shall introduce the price dynamics on the innovation diffusion dependent for multiple generations, and see how the pricing of one generation product influences the inventory decisions for the other generation product. For this, a multi-period inventory model for innovation diffusion dependent under price elasticity will be developed using the Generalized Norton Bass Model. It will be discovered how the price dynamics of one generation of technology products influence the demand for another generation product. The important implications of this work for the pricing strategies will also be discussed.

Chapter 6 shall discuss how the constraints on the warehousing space influence the inventory decisions in the case of multiple generations of technology products. Generally, the own space is cheaper than the rented space. So, the inventory carrying costs per unit inventory vary not only with the lot size but also with the time. Here, the P-type model will be formulated instead of a Q-type model. In the P-type inventory model, the inter-replenishment time interval remains fixed while the ordering lot size may vary. While in the case of the Q-type inventory model, the ordering lot size will be constant while the inter-replenishment time may vary.

After this, Chapter 7 shall explore how the imprecise business parameters such as trade credit period and the imprecise procurement cost in the business environment can be handled to make the inventory decisions using a fuzzy set theory in the case of multi-generational technology products. This chapter shall make use of fuzzy set theory to optimize the inventory norms.

In Chapter 8, the concluding chapter, a summary of the thesis and scope for further research are presented. Also, the limitations of the thesis that the author could identify and possible directions have been given.

1.11. Research Publications on the Work

The work presented has also been made into the following research papers:

Papers published or accepted for publication in peer-reviewed journals

1. Nagpal, G. & Chanda, U. (2021). "Inventory Replenishment Policies for Two Successive Generations' Price-Sensitive Technology Products", *Journal of Industrial and Management Optimization,* Accepted for publication. [ABDC B, SCI-E, Scopus, Web of Science]
2. The Five Decades of Modelling for Substitutable Products: A Comprehensive Literature Review", *Operations and Supply Chain Management: An International Journal,* Accepted for publication. [ABDC C, Scopus, Web of Science]
3. Nagpal, G. & Chanda, U. (2021). "Economic Order Quantity Model for Two-Generation Consecutive Technology Products under Permissible Delay in Payments", *International Journal of Procurement Management, 14(*1), 193-225. [Scopus]
4. Nagpal, G. & Chanda, U. (2020). "Adoption and Diffusion of Hi-Technology Product and Related Inventory Policies- An Integrative Literature Review", *International Journal of e-Adoption, 12*(1), 1-14. [Scopus, Web of Science]

5. Nagpal, G. & Chanda, U. (2021). "Optimal inventory policies for short life cycle successive generations' technology products", *Journal of Management Analytics,* Accepted for publication. [Scopus, ABDC-C]
6. Nagpal, G. & Chanda, U. (2021). "Nagpal, G. & Chanda, U. (2020). "P-Model of Inventory Optimization for high technology multi-generation products under limited warehouse storage space", *International Journal of Applied Management Science,* Accepted for publication [Scopus]

Papers under review for publication in peer-reviewed journals

1. Nagpal, G. & Chanda, U. (2021). "Inventory Replenishment Policies for Two Successive Generations of Technology Products under Permissible Delay in Payments", *International Journal of Information Systems and Supply Chain Management* (Revision Submitted after the Reviewer's comments)
2. Nagpal, G. & Chanda, U. (2021). "Use cases of Innovation Diffusion and Adoption Theories in diverse industries: A Literature Review", *International Journal of e-Adoption* (Under Review)
3. Nagpal, G. & Chanda, U. (2021). "Inventory Modelling for technology generation products with demand influenced by innovation diffusion and uncertain trade credit terms under imprecise procurement costs", *International Journal of Advanced Operations Management* (Under Review)
4. Nagpal, G. & Chanda, U. (2021). "Multi-period Q-type Inventory Model for multi-generation digital gadgets with short product life cycle", *International Journal of e-Adoption* (Under Review)

Published papers as book chapters in peer-reviewed books

1. Nagpal, G. & Chanda, U. (2020). "Review of Innovation Modeling Literature". *Transforming Management using Artificial Intelligence techniques,* Edited by Garg, V., and Agrawal, R., Published by CRC Press, 157-168.