Dynamics of Successive Product Generation - A System Dynamics Perspective

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Abstract

Current literatures attempted to explain the diffusion and substitution of successive generation of a product through the use of model fitting and forecasting techniques. This research would like to question the assumptions and the structure it was formulated. This research attempts to look back and see what happened in the past rather than the usual forward looking goal of forecasting models. Through system dynamics approach, it questions now the assumptions made in the past that order fulfillment variables such as available production capacity, perceived delay of actual demand, production build-up delay, and the resource interdependency between the current and new product generation were treated as always available or can be adjusted instantly.

Keywords
Successive Product Generation, System Dynamics, Order Fulfillment, Bass Diffusion Theory

1. Introduction

1.1 Rationale of Successive Product Generation

Developing products faster, better, and cheaper than competitors has become a critical success in various markets. This is especially true in fast-changing and technology-intense markets such as semi-conductor industry which is characterized by successive introduction of next generation products [1]. Companies now allocate more efforts and resources in exploiting current scientific breakthroughs and engineering innovations. Thus, creating a superior product that will attract potential customers to adopt it and hoping to gain from the investment made. However, this is not easy as it could be since in this modern age of information and high-speed communications, consumers are more demanding and are normally aware of the options available. This will explicitly force manufacturers to address the shortcoming of the product and thus leaving the companies no choice but to introduce new and better products [2].

In recent years, newer technologies are continually replacing the older ones. The time interval between successive generations of high-technology electronic products has been demonstrated to be relatively brief, which makes the life of a product shorter [3]. A new product generation is not a radical innovation in the sense that the first introduction of the technology was, but it offers a significant improvement in performance. For example, over the past two decades, the PC microprocessor industry (shown in Figure 1) has witnessed distinct hardware generations, each pushing the technological frontier further by offering faster clock speeds, increased number of instructions per clock cycle and superior mathematical computing. Likewise, the dynamic random access memory (DRAM) industry has shown significant increase in capacity since 1970's following the same sales behavior as of the PC microprocessor (shown in Figure 2).

Figure 1 and **Error! Reference source not found.** shows two products in high technology market that describes successive product generation with increasing maximum sales and shortening life cycle time. The introduction of each generation attracts adopters from different constituencies, fresh adopters and adopters of earlier generations of technology who want to replace obsolescent product [4]. The newer technology may also widen the market by allowing applications which were not feasible before. The sales behavior for each generation in its early stage increases through time that indicates a growing number of potential customers coming from untapped market that is caused by increasing product awareness. In later periods, sales decrease as potential market becomes depleted and more and more buyers shift towards the substituting product.

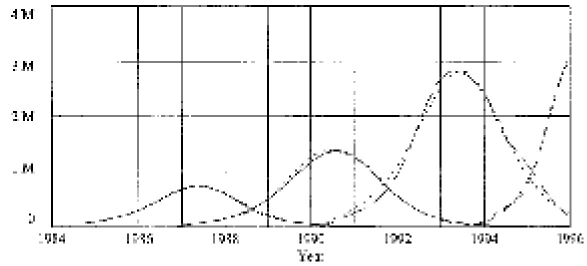

Figure 1: Sales Data of Intel Microprocessor 80286, 80386, 80486 and Pentium (Adapted from Maeir [5])

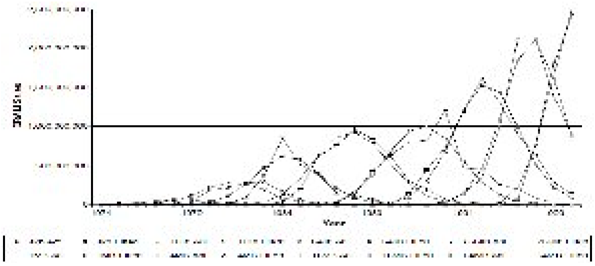

Figure 2: Norton Bass Model Generations of DRAM Chips Actual and Fitted 1974-2000 Data from Gartner Dataquest (Adapted from Bass F. , [6])

1.2 Complexity in understanding Successive Product Generation: Management Implication

Introducing new product generation in the market requires a deep understanding of the dynamics and complexity of the system. Management decisions should be cautioned and frequently consulted so as to prevent possible unwanted outcome made by the company. The launch of new product generation is a phase of new product development that commands a large commitment in time, money and managerial resources. The costs of introduction include investments in production, research and development as well as marketing. Therefore, product launch requires careful planning to ensure the desired market success of a new product [7].

One of the key elements in the new product launch strategy is its introduction time. New product introduction and substitution effects will ultimately diminish the potential, if not the actual sales, of earlier technologies. Customers, who would otherwise have adopted the earlier device, will, instead adopt the later one [3]. Furthermore, a substitutive new product that is introduced too early into the market could lead to product cannibalism. On the other hand, being too late could cause a sharp decline in sales or market position [8]. However, optimal introduction time is only one of the most important decisions to be made by a company. Decisions such as - When to phase out old generations? What pricing decisions mechanisms to follow for both old and new products? What marketing mix strategies to be implemented to make sure high profits, market position and returns in investment are achieved? - are also equally important as well, for the very reason that these measurements are interconnected with each other [9].

1.3 Current Literature: Attempts to understand the complexity and management implication

Recognizing these management issues, there are substantial literatures attempted to understand the diffusion and substitution of products in the market characterizing the sales behavior in successive product generation. These researches were actually rooted from diffusion of innovation theory made popular by Frank Bass [10]. The Bass Diffusion Theory describes the diffusion process as one when innovators become aware of the product and adopt without being influenced by other customers, while imitators adopt the new product only after coming in contact with previous customers who communicate the product benefits to them. This model is limited only in explaining the growth of sales in one product generation and the process of substitution and product cannibalism is not present in the traditional bass model.

Bass diffusion theory has been extended and used to explain this new phenomenon. The most quoted of which is the work of Norton and Bass [3], the model assumed for each successive product generation a fixed number of potential adopters consisting of innovators and imitators. The future buyers can also switch over to the next generation product giving the current generation a miss. The model assumed that the coefficient of imitation and innovation remain unchanged from generation to generation. Islam & Meade [4] relaxed this assumption on the basis of assumption that a learning process will take place as soon as the second or higher generation product is introduced in the market. However, more recent research of Bardhan & Chanda [2] pointed out that the assumption of Islam & Meade model is unreasonable because it completely ignored the leapfrogging aspect of successive generations of new product. The model assumed that customers who have already adopted the first generation product have to purchase the second generation if they want to purchase the third generation product. Moreover, the first generation adopters can't skip second generation or any earlier generation product if they have to get the services of more advanced generation product. Bardhan & Chanda [2] attempted to resolve this problem by creating a model that for multiple generation diffusion in which both repeat sales and sales due to the first time purchasers are identified separately. They also included a leap-froging multiplier to capture the influence of advance generation product on sales figure of earlier generation product.

There are also set of literatures that focuses on the optimal timing of introdcution of new product generation, the most quoted are the researches of [7, 8, 11, 12]. The common objective of these researches is basically to create a model that will find an optimal time to introduce new product generation. These models should be able to maximize the sales potential of the current and future product generation given a set of constraint considerations such as product cannibalism, investment decions, technological improvements, sales potential, diffusion and substitution processes. They use parameter estimates based on historical sales figures to assess the optimality of the new generation timing decisions.

1.4 Research Problem

The current models attempted to explain the diffusion and substitution of new product introduction through limited number of variables but they did not consider explicitly the operational or the intra-firm variables which deemed important in any management decisions, assessment of firm's performance as well as its implications to resource allocation and strategy/policy formulation. Moreover, understanding the complexity of the successive product introduction in a forecasting model may limit the process of understanding the structure of the system for these current models neglect time delay factor in the relationship of the model such as the order fulfillment process of the firm that includes capacity adjustments and production ramp-up especially in the earlier stage of its life cycle.

This research would like to question the assumptions and the structure it was formulated. This research attempts to look back and see what happened in the past rather than the usual forward looking goal of forecasting models. Through this approach, it questions now the assumptions made in the past that order fulfillment variables such as available production capacity, perceived delay in actual demand, production build-up delay, and the resource interdependency between the current and new product generation were treated as always available or can be adjusted instantly. However, based on other researches this may have an implication for it directly affects consumer buying behavior either by the availability of products or by its attribute factors [8, 13, 14].

2. Methodology

As business firms recognize that product life cycles have increasingly become shorter, the need to effectively manage their resources and be able gain from their investment is only one way to survive the competition. This created the need for the managers to understand the underlying dynamics and complexity of business to recognize the interactions of important elements of business. A system dynamics model will be used as a simulation tool (using STELLA software) for the design and evaluation of strategic management decisions. This will enable the development of policies leading to the effective management of resources. The development of the simulation model was done through the formulation causal loop and stock flow diagram. The causal loop diagram is based on the study of Peter Milling [14].

2.1 System Definition and Boundary

The industry that this research would like to study is High-Technology industries where products are usually related to computer and electronics. This industry is one of the most dynamic and demanding in the world economy today. Competition is intense. Rapid growth, increasing complexity of Technology, globalization and other changes pose enormous challenges for core business processes such as the supply chain and product development. Prices fall at a tremendous rate while speed and functionality grow with each new product generation. Product Life cycles of year or less mean companies have only a few months in which to sell sufficient volume of a new product at high enough margins to generate the profits needed for product development and growth [15].

2.2 Model Development

The model will focus on the three most important elements of the successive product generation system and these are market demand, the company and its marketing and Research and Development function. These elements interact with each other by information and physical transfers. The firm's marketing and research and development function will analyze current market demand and opportunities to decide what product to introduce in the market. Based on their target market, the company will build the right production capacity to fulfill the expected orders. The market will purchase the product at certain rate of diffusion in which the company periodically adopts to adjust capacity for the fulfillment of demand when it changes. The resulting feedback from the perceived customer buying behavior will be the basis for the future products that the firm will be creating. The resources needed to develop and produce the future product will be dependent on the success of the current product for it dictates the amount of resources gained from the investment made.

Figure 3 is the stock flow diagram for Consumer Subsystem (left side) and Firm Subsystem (right side).Consumer Subsystem shows three important stocks that represent the major states of the market entities. The first stock is the Potential Market which represents the target market that a company would like to penetrate. The stock of Potential Market is being decreased by the committals rate where customers post their intention to buy the product. The rates of committals are being influenced by imitative and innovative demand. Innovative demand is a function of price and advertising effectiveness where as the imitative demand represents the influence of the current customers who already adopted the product. The stock of potential market can also be increased as new markets realized some other use of the product [8].

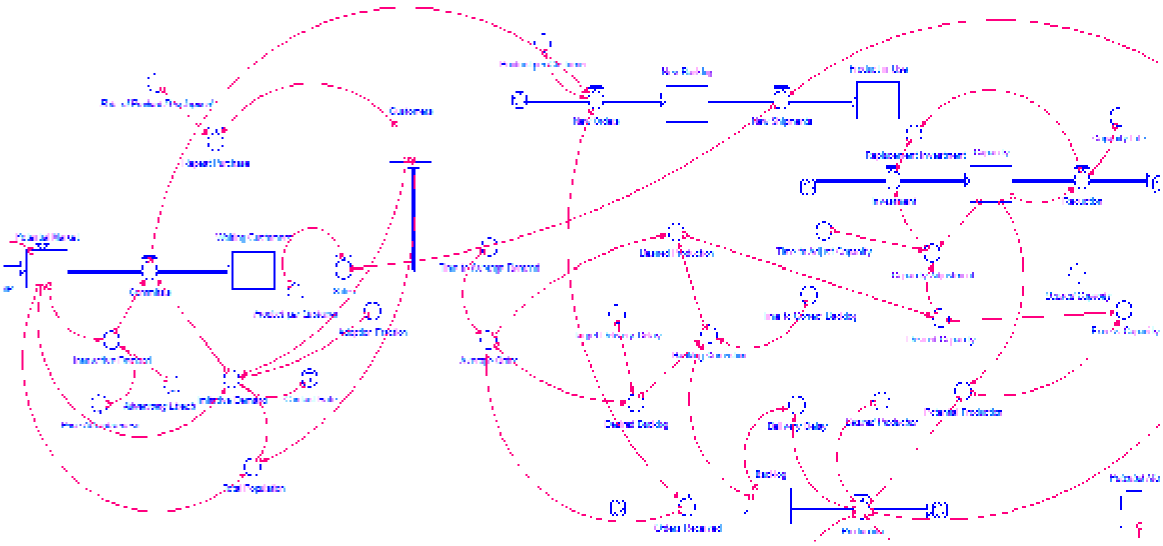

Figure 3: Stock- Flow Diagram of Consumer Subsystem

The adoption process will follow the diffusion theory of Frank M. Bass. Since the process of adoption requires that someone in still the idea of the technology into someone else, we are interested in the frequency with which someone who is not an adopter encounters someone who is an adopter. Therefore we start with potential customer contacts with anyone, and then multiply by the fraction of people who are adopters (customers). Customer with non customer contacts represents contacts between someone who is a user of a product and someone who is not user. There is a chance that, as the result of this encounter, the non customer will purchase the product. The probability that this happens is called the adoption fraction. The second stock is the Waiting Customers. This stock has to be included in the model since not all who intended to buy the product will be satisfied. Waiting customers should not be treated as adopters of the product as for the moment since they were not able to purchase or use the product yet. They are just waiting for the right timing and/or waiting for the product to be available. This stock is decreased as firm's is able to produce the units demanded.

The last stock is the pool of Customers. The customers are the actual adopters of the product where sales are realized by the company. The stock will be increased every time that the company were able to deliver and satisfy the need of the waiting customers. The rate of outflow on the other hand however is dictated by the products as it approaches its maturity stage/end of life or as soon as the company launches new generation product and therefore increasing again the stock of potential market. If they opt to buy the new generation of product they will again be waiting customers and eventually be a customer.

The second part of Figure 3 shows the stock flow diagram for the Firm subsystem (right side). It consists of two important functions in a business organization, the research & development and the production function. There are two important stocks in this model and that is Backlog and Capacity. Backlogs are the demanded units of the market that is yet to be produced and delivered. This stock is being increased by the firm's perceived demand in the market and its being depleted by the rate of production. Capacity on the other hand is being increased if the current capacity is not enough to meet the current desired production. The rate of outflow of this stock is dependent on the life of the capacity currently in place. In order to model the production side there is a need to determine capacity (how much can be produced) and track the fulfillment of orders with shipments. The determination of capacity is formulated as a goal adjustment based on a desired production. In this model, capacity is thought of as including both capital and labor (a composite ability to produce), so the time constant for adjusting capacity is longer, reflecting the long lead times in acquiring facilities and capital equipment.

The tracking of orders is done through a backlog (orders placed but not yet fulfilled). A backlog is, in many respects, the opposite of an inventory. The stream of orders is averaged when calculating target capacity and backlog this is represented as change in expected demand. People do not, based on a good day or a good month, immediately reformulate all plans for the future. The other stocks, auxiliary and constants represent performance measures such profitability which eventually dictate the resources allotted to Research and Development and advertising expenses. Profitability is a function of sales and production cost.

3. Results and Analysis

The results were verified and validated through structure assessment, boundary adequacy, behavior reproduction and sensitivity analysis. Indeed, Figure 5 shows that the model was able to replicate the same sales behavior relative to the real data shown in Figure 1 and Figure 2. Furthermore, the pattern generated in Figure 5 is very consistent with bass model of diffusion. It shows that at the early stage of the product life cycle, sales growth is slow as only few people are informed about the product. As the level of customers increases, the stronger it influences the potential market to buy the product resulting to the burst in demand. However, sales growth will suddenly decrease as the level of Potential Market decreases and reaches to zero transferring all entities to become customers. The following sections discuss the major results of this research.

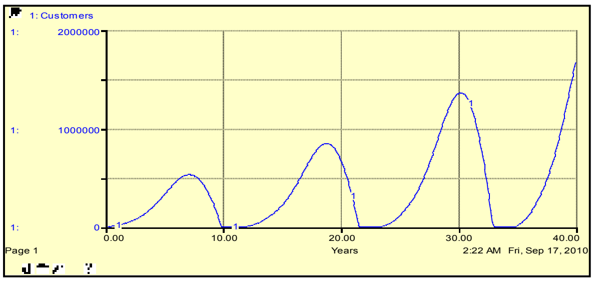

Figure 4: Successive Product Generation considering market growth

Figure 5: Successive Product Generation assuming no growth in Potential Market

3.1 Effect of Delays in Order Fulfillment

Figure 6 shows the details of the order fulfillment performance of the company. High-Technology companies consider a very cautious investment strategy in building-up capacity [15, 8] for they believe that investing so much will hinder them to be flexible when they introduce new product generation. This resulted to an increase in the level of backlog when demands suddenly increase and capacity cannot meet the requirements. As shown in Figure 6 at the early stage of product introduction the capacity cannot meet the demand (committals) and therefore backlog accumulates. As a result, companies do increase/adjust capacity to accommodate incoming orders as well as the remaining amount in the backlog. However capacity adjustments and the actual production takes time that delays the delivery of goods in the market. As soon as the company reaches their target capacity, backlog begins to decline however capacity is still changing but not realized instantaneously by the company since again capacity adjustment takes time to realize that you have already ample amount to satisfy the customer. But because of the pressure of the sudden increase in demand companies continuously adjust capacity.

The perceived demand of the company may not also be reflective of what is really happening because of the time it takes to consolidate their previous sales performance that will dictate their future production plan. So by the time they are adjusting their capacity to accommodate their perceived increase demand the actual demand now may be in decline already that resulted to have an excess capacity at the end of product life cycle. Figure **7** shows the excess capacity for every period for both fixed and growing market. The reason why such delay occurs is because of the adjustment time in capacity to meet market demand. Adjustment in capacity has the greatest influence in the delay in the production of product for it dictates the quantity that the company is capable of delivering at certain point in time. Figure 8 shows the impact of adjustment time from the base value of 1 month to 5 month delay. As expected, delivery delays significantly increased.

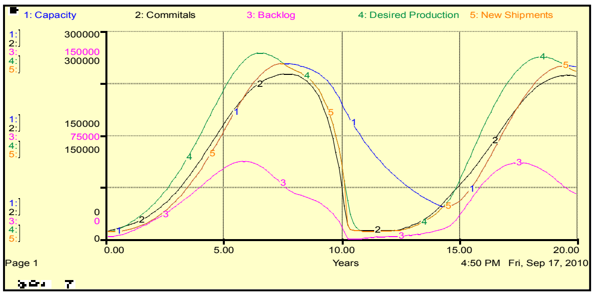

Figure 6: Order Fulfillment Variables in Successive Product Generation

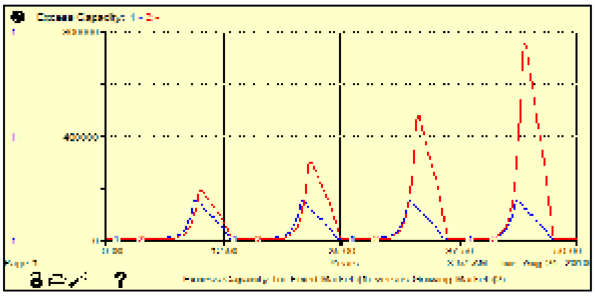
Figure 7: Excess Capacity

Alternatively, a more aggressive investment policy at the early stage of product life will yield better results since it provides sufficient production volume for in time delivery as soon as demand gains momentum even at the cost of temporary excess capacity at early stage of product life. Figure 9 show that aggressive investment policy will yield less excess capacity (shown in blue line) than a cautious strategy.

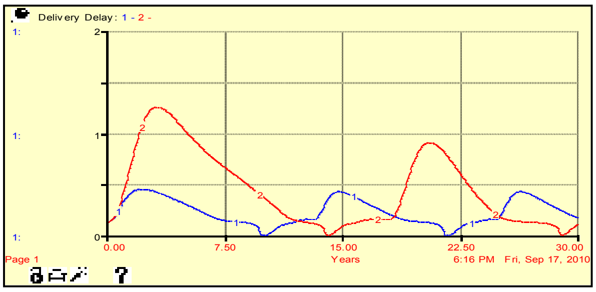

Figure 8: Deliver Delay

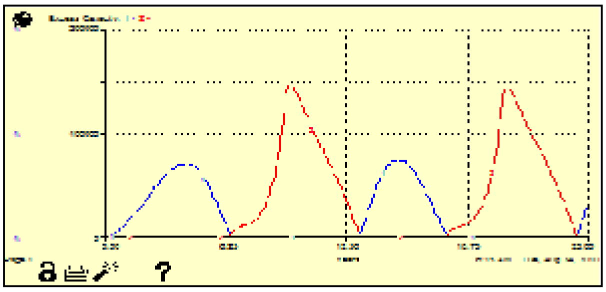
Figure 9: Cautious vs. Aggressive production investment policy impact on capacity

3.2 Effect of Rate of Development to Production Capacity and Financial Performance

The effect of excess capacity (measured either in terms of excess inventory or machinery) at the end of each period will degrade the profitability of the company since the company is underutilizing its resources or there are products produced but not sold. This is especially apparent in slower rate of product introduction since the excess capacities will be sitting for a longer period of time. On the other hand, faster rate innovation may hasten the excess capacity by using it immediately after the previous product has been discontinued. The behavior of Gross profit comparing its response to faster rate (red line) versus the slower rate (blue line) is shown in Figure 10: Impact of rate of innovation to Gross Profit under varying rate of innovation. The graph also shows that recovery from negative gross profit will be faster when company introduces products at a faster rate.

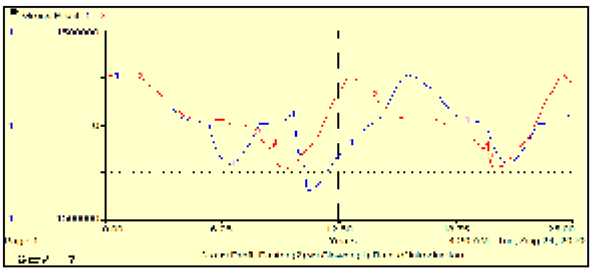
Figure 10: Impact of rate of innovation to Gross Profit under varying rate of innovation

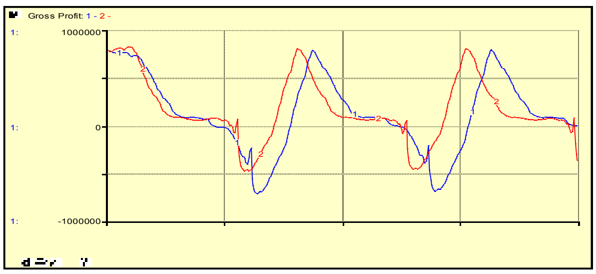

Figure 11: Impact of reducing capacity adjustment time to Gross Profit

3.3 Impact of reducing capacity adjustment time

Improved performance can be achieved by reducing the time it takes to adjust capacity. It can be seen that the impact of the strategy to Gross Profit (shown in Figure 11) is significant. Profit can be realized earlier if capacity adjustment time was reduced and therefore companies can now use the profit earned from investment for the development of new product generation. It can also be observed that there is also improvement in Gross Profit for the periods where companies experience negative values. By reducing the time to adjust capacity, the level where the negative gross profit occurred was reduced returning more profits to the company. Figure 12 shows the strategy impact on delivery delay time. This will improve customer brand loyalty since customers perceived that products are always available when they need it.

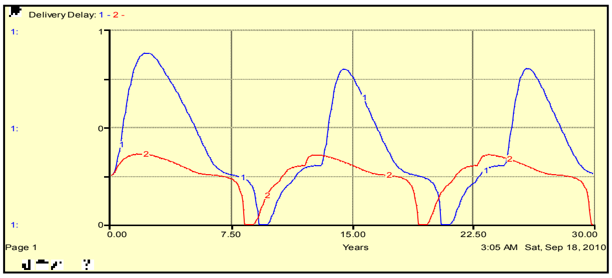

Figure 12: Impact of reducing capacity adjustment time to Delivery Delay time

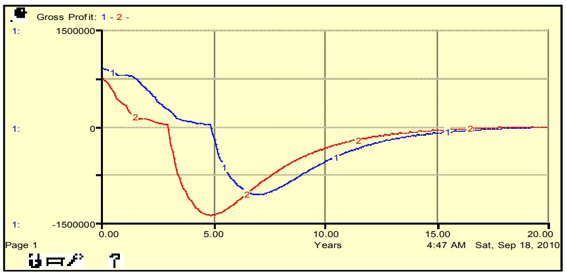

Figure 13: Impact of Increasing Advertising Effectiveness on Gross Profit

3.4 Effect of Advertising Initiatives to adjustments in Production Capacity

On the marketing side of analysis, putting so much effort in advertising without proper consideration in the order fulfillment capabilities may backfire to the company's image and financial performance. This strategy will just increase the level of waiting customers and therefore increasing the risk of unsatisfied customers when demands are met immediately. **Error! Reference source not found.** show the impact of increasing advertising effectives on Gross Profit and Capacity adjustments. It also suggests that increasing drastically the stock of waiting customers through the increased advertising effectiveness will lead to a more negative gross profit since it gives a shock to the production facility to drastically adjust its capacity leading to a more costly move.

4. Conclusion

This study has proven the need for considering simultaneously market and order fulfillment variables in understanding sales behavior under successive product generation. The model emphasizes that market performance of an innovative product is heavily influenced by intra-firm factors. It is not only the product with its intrinsic attributes itself, nor the pricing strategy or the advertising efforts dictates its market success but also how goods were made, how resources are managed and on-time fulfillment of orders are equally important as well.

The study shows three important results:

- The cautious strategy for the introduction of new product at its early stage will eventually backfire resulting to more excess capacity at the end of its life. Building-up larger capacity at the early stage of new product introduction will be more lucrative compared to the cautious investment strategy. The idleness that resulted to the increased capacity in early stage exceeded the benefit of the total cycle when demand gain momentum (consistent in the research findings of Milling [14]).
- Increasing drastically the stock of waiting customers through the increased advertising effectiveness at the early stage of product introduction will lead to a more negative gross profit since it gives considerable shock to the production facility to drastically adjust its capacity. Adjusting capacity cannot be done instantaneously same way as it cannot match instantly the perceived market demand. By the time the production reached its target volume actual market demand may change already that may lead to more excess production.
- The slower the rate (longer period between the introduction of new products) of new product introduction the greater the excess capacity/production capability that the company would have and therefore decreasing profit potential since the excess capacity/production capability will be sitting for a longer period of time.

Further studies can explore the possibility of expanding the model to include a much detailed decision making process of the consumers in buying successive product generations. This model only includes an aggregate view of the system that describes how generally customers behave when new product was introduced. Consumers may have different buying behavior that is so complex and uncertain. Question such as – How does the rate of introduction affects brand image and loyalty? - may be explored. Another research opportunity would be is to implicitly include competition in the model. Competition plays an important role in influencing consumer buying preferences and therefore by studying its factors would be very beneficial for market with several players competing in same need. Competition can be viewed from a company perspective or as a whole industry.

Acknowledgements

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References

1. Ford, D., and Sterman, J., 1998, "Dynamic modeling of product development process," System Dynamics Review, 14(1), 31-68.
2. Bardhan, A.K. and Chanda, U., 2008, "A Model for first and substitution adoption of successive generations of a product," International Journal of Modelling and Simulation, 28(4), 487-494.
3. Norton, J., and Bass, F., 1987, "A Diffusion Theory Model of Adoption and Substitution for Successive Generations of High-Technology Products," Management Science, 33(9), 1069-1086.
4. Islam, T., and Meade, N., 1997, "The Diffusion of Successive Generations of a Technology: A More general model," Technological Forecasting and Social Change, 56, 49-60.
5. Maier, F., 1996, "Substitution among Successive Product Generation – An Almost Neglected Problem in Innovation Diffusion Models," Proc. of the 14th International Conference of the System Dynamics Society, December 4-7, Cambridge, Massachusetts, 345-348.
6. Bass, F., 2004, "Comments on A New Product Growth for Model Consumer Durables," Management Science , 50 (12), 1833-1840.
7. Mahajan, V., and Muller, E., 1996, "Timing, Diffusion, and Substitution of Successive Generations of Technological Innovations: The IBM Maingframe Case," Technological Forecasting and Social Change, 51, 109-132.
8. Maier, F., 1998, "New Product diffusion models in innovation management - A Systems dynamics perspective," Systems Dynamics Review, 14(4), 285-308.
9. Arslan, H., Kachani, S., and Shmatov, K., 2009, "Optimal product introduction and life cycle pricing policies for multiple product generations under competition," Journal of Revenue and Pricing Managemenr, 8, 439-451.
10. Bass, F., 1969, "A New Product Growth for Model Consumer Durables,"Management Science, 15(5), 215-227.
11. Krankel, M., Duenyas, I., and Kapuscinski, R., 2006, "Timing Successive Product Introductions with Demand Diffusion and Stochastic Technology Improvement," Technological Forecasting and Social Change, 8(2), 119-135.
12. Wilson, L., and Norton, J., 1989, "Optimal entry Timing for a Product Line Extension,"Managament Science, 9(1), 1-16.
13. Goncalves, P., Hines, J., and Sterman, J., 2005, "The Impact of endogeneous demand on push-pull production systems," System Dynamics Review, 21(3), 187-216.
14. Milling, P., 2002, "Understanding and Managing innovation process," System Dynamics Review, 18(1), 73-86.
15. Sterman, John D., 2000, Business Dynamics: Systems Thinking and Modeling for a Complex World, Irwin McGraw-Hill.