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Managing new product definition in highly dynamic environments

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Abstract

In highly dynamic environments, characterized by changing customer preferences and uncertainty about competitive products, managing the development of a new product is a complex managerial task. The traditional practice, recommended in the literature, of reaching a sharp definition early in the new product development (NPD) process may not be optimal, desirable or even feasible in such dynamic situations. Under high uncertainty, forcing early finalization of specifications may result in a firm getting locked into a wrong definition due to incorrect assumptions about market conditions at launch. Based on our study of NPD in the high technology industry, we present a model of an approach called *real-time definition*, in which a firm, instead of force-fitting one particular definition approach to all products, adapts its product definition process to the market and competitive environment as the NPD process unfolds. Uncertainty about product specifications is resolved by frequent, repeated interactions with the customer and with a flexible development process that anticipates changes. The results of our model provide insights into the optimal definition approach for a firm in a dynamic and competitive environment. We find that early definition is optimal only in a limited set of situations. To maximize its anticipated profits, a firm should tune its definition process to the prevailing level of market uncertainty, the marginal value of information obtained from the customer during the NPD process, and its own risk-profile and internal development capabilities. Effects of competition on a firm's definition approach are also examined, and implications for managers of a NPD process are presented using a conceptual framework.

1. Introduction

Due to the recognition of its critical effect on a firm's competitiveness, new product development (NPD) has been attracting increasing scholarly attention in recent years (Wheelwright and Clark 1992, Karmarkar 1996). A growing amount of empirical and modeling work in the management literature is now devoted to the performance improvement of industrial NPD processes (Ulrich et al. 1993, Ahmadi and Wurgaft 1994, Krishnan et al. 1997). Much existing research on product development is, however, focused on the task of realizing a product given its specifications. There exists a related body of work in marketing on identifying and assessing customer needs and test marketing and launching products (Wind and Mahajan 1987, Urban and Von Hippel 1988). Relatively little research attention seems to have been paid to the process of product definition during which the customer needs are translated into product specifications, which will then be used to realize, test, and create an integrated product/system.

To underscore the importance of the product definition phase, we consider the development process of a product in which a "core team" of professionals from many disciplines set out to create a product that satisfies a specific customer need. During the definition phase, input data and information about customer preferences and competitive products are used to finalize key specifications of the product such as its target customers, functionality, and features (Bacon et al. 1994, Cooper 1995). These specifications are used in the product realization and system integration phases to develop a producible and serviceable product. For example, in the development of portable computer systems at one of our study companies, the product specifications constitute parameters such as the product dimensions, weight, battery life, etc.

These specifications are finalized based on market studies, customer feedback, and competitive products and are then used by the realization phase, which involves the design of the boards and the housing, and the integration phase which involves production tooling, pilot testing, and refinement of the design to reduce the product's unit variable cost in production.

The crucial role played by product definition in the success of a NPD process has been highlighted in the work of Cooper and Kleinschmidt (1987), who sought to identify the characteristics that separate new product successes from failures. They found that the effectiveness of the product definition phase is a critical success factor. Also, another conclusion of their work, relevant to our paper, is that it is important to have a sharp product definition early and prior to beginning the development work [Cooper (1993) - page 138], which we refer to as early definition. The key benefit of early definition is that it disciplines the NPD process by ensuring that the subsequent development tasks can begin with certainty and not be subject to needless changes in input information which can be difficult and expensive to implement. This is especially the case if the subsequent phases began with the expectation that specifications will not change, and the changes that happen later lead to significant rework of decisions and prototypes. In industries where customer preferences are well defined at the beginning of a NPD process and do not change much by the time of product launch, early definition can help execute product development smoothly and at low cost.

1.1 Product Definition in Highly Dynamic Environments

There are highly dynamic market situations in which changes are so rapid and discontinuous that information collected at the beginning of a NPD cycle can become obsolete by the time of product launch (Bourgeois and Eisenhardt 1988). In the high technology industry, the advent of new architectures and technologies leads to high levels of initial uncertainty about customer preferences (Bacon et al. 1994, Iansiti 1995). This further intensifies the inherent difficulty faced by customers in articulating their preferences early in the design process (Von Hippel 1992). Attempts by managers to force early finalization of specifications may result in a firm getting locked into a wrong definition and launching a product that is unattractive to the customer and unprofitable to the firm. Delaying commitment in such cases has the benefit of enabling the firm to tune its specifications more closely to customer preferences at the time of launch, potentially leading to a more attractive product with a greater sales potential. This, however, may also cause lack of stability in product specifications which can hamper the smooth progress of realization and integration phase tasks. In particular, changes in certain high-level product specifications can impede the development process, possibly resulting in a product that is not optimized for volume manufacturing by the time of launch. A firm must balance these tradeoffs of commitment to specifications at different points in time, and finalize its product specifications accordingly.

Existing research on product definition does not recognize these tradeoffs underlying the definition process. One contribution of this paper is to expose and formalize these tradeoffs towards providing managerial insights on the appropriate definition approach for different market and competitive environments. We studied over half a dozen projects at three different firms (in the computer, electronic instrumentation and telecommunications industries), and found that force-fitting one particular definition approach (such as early definition) for all processes and specifications can be counter-productive. Based on this study, we present a stylized model of definition for dynamic environments called real-time product definition. In this approach, the product development team (PDT), instead of presupposing that it must define all specifications early, bases its finalization decision on the market risk, the marginal value added by customer information, and the time available for integration. It is noteworthy that real-time definition is not an alternative to**,** but a generalization of, early product definition because the real-time approach may lead to early definition in certain situations (which we also characterize in this paper). The model we present is aimed at answering the following research questions: (i) How does uncertainty about customer preferences influence a firm's definition timing, and how must this be balanced with the cost of delaying commitment? (ii) How does the firm's product definition approach differ based on the nature of product specifications and its internal development capabilities? (iii) What impact does competition have on a firm's product definition approach?

We begin answering these questions in Section 2 by formulating a mathematical model of real-time definition, which is not intended as a decision support model but as one that provides insights about the optimal definition approach under different market conditions. Analysis of the model helps characterize the optimal point of definition in Section 3. We consider the impact of competition on definition in Section 4, and in Section 5, summarize the managerial insights as a conceptual framework. Section 6 contains a discussion of the contributions, limitations and avenues for further research, and we conclude in Section 7 with the implications of this work for practice.

2 Model of the Product Development Process

We first discuss the model assumptions before presenting the formulation. For ease of exposition, we begin with a monopolistic environment - competition is modeled in section 4.

2.1 Model Conceptualization and Assumptions

In the high-technology companies we studied, the product development process at an aggregate level followed a phase review process structure (Cooper 1993), although at a detailed level there were differences in the number and names of phases and reviews. Based on our identification of the unifying themes of these processes, we model the development process in terms of three phases: product definition, realization, and integration. At the end of the definition phase, the PDT dedicated to the project finalizes a set of specifications based on customer feedback. During the realization phase, the PDT implements virtual and real prototypes of the product. During the integration phase, the team is primarily concerned with optimizing the process to develop the product at the lowest possible unit variable cost. As shown in Figure 1, these phases run concurrently, exchange information vigorously, and the completion of the integration phase results in the product launch. All these phases are executed under the umbrella of a phase review process, in which management meets at regularly scheduled reviews (shown as diamonds). During the 'phases' (shown as rectangles), product design and development work is completed and at the review points key managerial decisions are made. Such decisions include whether to finalize the specifications now or in a future review, and even whether to redirect/cancel the project because of the product's low profit potential.

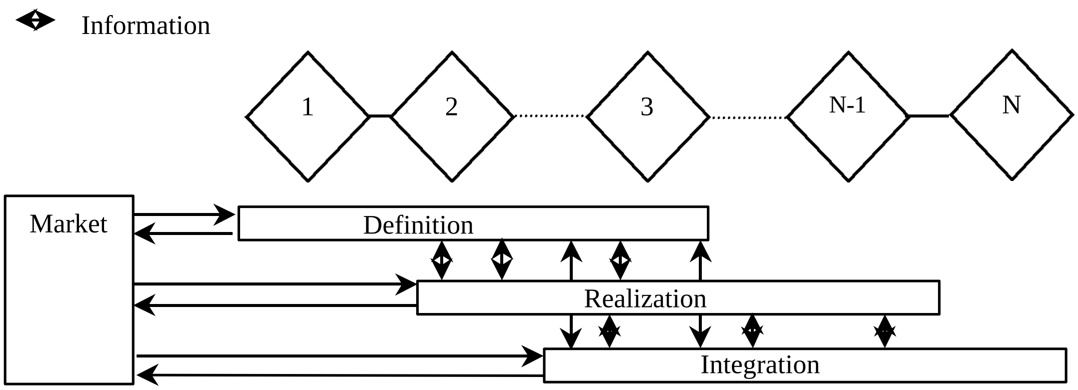

Figure 2.1 : Structure of the Phase Review Process

During the definition phase, the PDT is charged with finalizing a set of specifications that make the product attractive to its customers[1]. The team collects customer input/feedback on the firm's product concept and prototypes, and uses this information to refine the specifications. Because the realization phase runs concurrently, the team can make changes in the design and prototypes, and take these changes back to its customers for further feedback. In our model this repeated interaction with customers and the utilization of their feedback serves to enhance the "attractiveness" of the product. By attractiveness, we mean the extent to which customers like the product with its current specifications when it is offered at a nominal price p_{nom}. The team

[1]It is worth noting that there is some ambiguity about what is included under product specifications due to the way in which different companies treat product definition. For example, in the case of mature products where markets have been well segmented, some firms do not consider the target market as a specification to be finalized but assume that as a given information. Collecting information from customers is not possible unless the target market is at least broadly known. However, this may be refined as more information is collected and design changes are made.

presents customers with a prototype and asks them to rate their liking for the product on an itemized scale with a lower bound of Φ_L and an upper bound of Φ_H. Details of such itemized scales are presented in the literature (Urban and Hauser 1993). For simplicity, we assume that a sufficiently large number of customers are being sampled, and that the product attractiveness data obtained from customers can be approximated by a normal distribution. (Our model can be extended to other distributions of attractiveness without difficulty.) We, denote the attractiveness of the product from data collected at the end of the n^{th} review by $\Phi(n)$, which is a normally distributed random variable with a mean of μ_n and a variance of s^2_n.

The sequence of events in our model is as follows. The PDT begins the first phase of the definition process with a rough idea of developing a product that satisfies a distinct customer need but whose specifications have not yet been finalized. Based on its understanding of the customer need and a range on each of the product specifications, the team develops a suitable product concept. During the definition phase, the team is focused on tuning the specifications closer to the customer preferences. One of the primary deliverables from the realization phase is the implementation of prototypes of the suggested design of the product, by instantiating the specifications at particular points if necessary. This facilitates the evaluation of the product by customers. Specific activities during the realization phase include detailed product design, and virtual and soft prototyping of the product (using materials such as foam, fiberglass, and less expensive metals and plastic, which are relatively inexpensive to change). Using this, the team collects not only the customers' attractiveness information (on the itemized scale) but also makes suggestions about changes in the product specifications desired by individual customers that would make the product more attractive to them. During the integration phase, the PDT optimizes the design of the product and the production process to manufacture the product at the lowest possible unit variable cost. Examples of activities during the integration phase are production tooling, pilot testing and value engineering activities. At the first phase review, the PDT and senior managers assess if the current level of customer attractiveness is adequate for finalization. If it is not, the team makes changes in the product definition and design (based on the customer feedback) to increase the mean attractiveness and/or to reduce the variance of attractiveness. Once these changes are made during the next phase and customer responses to the changes collected, the customer-provided data will again be evaluated in the next review to see if customer attractiveness is adequate for finalization. This iterative process of collecting customer feedback, and changing the specifications is repeated until the team and development managers decide at one of the reviews (called the "optimal point of definition") that it is time to finalize the specifications.

While deferring commitment to specifications enables a firm to create a product that is more in tune with customer preferences at launch, it can also hamper the progress of subsequent phases. When the team can absorb changes in specifications with relative ease (by anticipating the changes and by good communication), then the integration phase need not wait until the specifications are finalized, thereby resulting in a period of overlap between the definition and integration phases. However, there exists a limit to this amount of overlap between phases because the team would find it difficult to anticipate changes beyond a certain level or make changes in committed tooling (Krishnan et al. 1997). One of our study companies had to scrap several million dollars worth of production tooling, because too much overlap caused major changes in specifications after tooling commitments were made in the integration phase. We model this operational reality simply by placing an upper bound (K) on the amount of time overlap (*w*) between the definition and integration phases. This upper bound indirectly captures the costs of accommodating changes in the product definition. The more "flexible" the PDT, the more able it is in anticipating and absorbing changes, and greater this upper bound K on the time of overlap[2].

Delaying commitment to specifications may delay a firm's launch and translate into an opportunity cost of lost profits (Kalyanaram and Krishnan 1997). We, however, model the case when the PDT has a certain target launch date commitment that must be treated as a hard constraint. This is the case in many high technology firms, where products are launched just before special events such as Comdex (the annual computer trade show), and in the automotive industry where the new models are launched in early Fall. (As we discuss later, this assumption can be relaxed from our model if information about the opportunity cost of delayed launch is available.) With the launch date fixed, delaying the finalization of specifications would leave less time available for integration based on finalized specifications. Since a key aspect of the integration phase is the refinement and optimization of the product design details resulting in a lower unit variable cost, we make the modeling assumption that the less time the firm puts into the integration phase, the greater would be the unit variable cost of the product at launch. Let

[2]At a high level our usage of the term flexibility is similar to that of Upton (1994) and Thomke (1996) in that it refers to the ability to change or react to changes. However, at a detailed level we regard flexibility as a measure of

c(n, w) denote the unit variable cost of the product when the definition is finalized at the end of the n[th] review with a time of overlap w between the definition and integration phases. For a given review n at which the definition is finalized, greater overlap w would allow more time for integration and lead to a reduction in the unit variable cost (see Figure 2a).

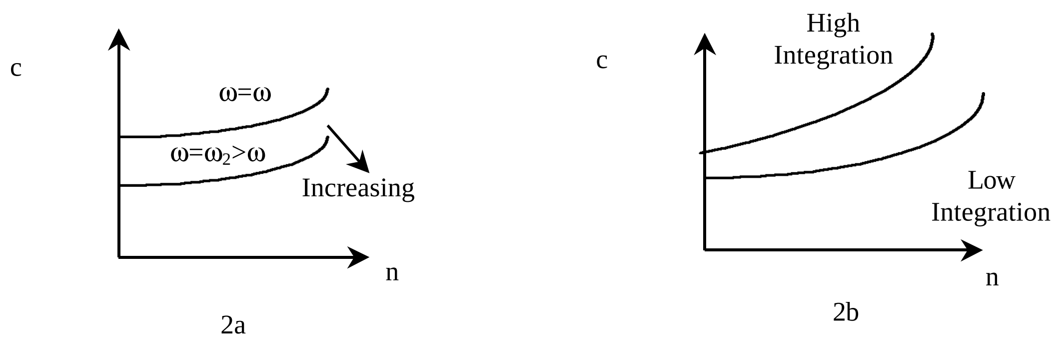

Figure 2.2 Relation of Unit Variable Cost with Review n for Different Specifications

However, for a given w, increasing n (delaying finalization) leaves less time for integration and increases the unit variable cost. This effect of increase in c(n, w) with n will be more pronounced in the case of certain specifications at the top of the design hierarchy, which significantly influence the design of the entire product and have high integration needs (see Figure 2b). Delaying their definition would result in a greater increase in the unit variable cost of the product than delaying definition of other specifications with lower integration needs. For all specifications, the PDT faces the following tradeoff: more time spent in the definition process can improve the product's attractiveness and sales potential but would leave less time for integration and unit variable cost reduction by design refinements.

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the PDT's ability to overlap the development phases, while Thomke (1996) regards it as the "incremental cost and

2.2 Model Formulation For A Risk Averse Firm

Let the managerial reviews of the phased process be indexed as 1,2,3, ... n,.., N until the time of launch, where review n is the point at which the specifications are finalized in an optimal fashion. We model the demand of the product as a function of the product's attractiveness and price[3]: $D(n) = M[\alpha(\Phi(n)-\Phi_L) - \beta(p - p_{nom})]$, where $D(n)$ is the aggregate lifecycle demand of the product anticipated at the point of finalization n, M is the potential market size (or number of units of the product that can be sold), $\Phi(n)$ is the attractiveness of the product at the point of finalization n, α is the fraction of the market that will buy for a unit of attractiveness exceeding the lower bound Φ_L, p is the price of the product, b *is* the fraction of the market that will drop out for a unit price above the nominal price p_{nom}. For brevity, we will refer to the positive constants α and b as the sensitivity of the demand to the attractiveness of the product and the sensitivity of the demand to the price of the product, respectively. This model assumes that a higher attractiveness of the product due to careful product definition would result in higher sales and a higher price would result in lower sales. Without loss of generality, we can choose Φ_L and P_{nom} such that $\alpha\Phi_L = \beta p_{nom}$. The above model then simplifies to: $D(n) = M[\alpha\Phi(n) - \beta p]$.

The profit the firm actually realizes depends on conditions subsequent to launch. However, the team must make its (pre-launch) definition decision at a review point based on what it anticipates to be the profit with the available information. This "anticipated profit" P(n) is a

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time of modifying a design".

random variable because of the probability distribution associated with the demand. Given the above model of demand, the anticipated profit is given by $P(n) = M[\alpha\Phi(n) - \beta p]\ [p\text{-}c(n,\omega)]$, where *[p* - c(n, *w)] is* the margin on each unit.

The firm and PDT's risk aversion is one of the major factors that influences the NPD process. A team that is risk averse would choose a more certain but somewhat less profitable alternative over a less certain, more profitable one. In decision theory, this is formalized by the notion of certainty equivalent (Pratt et al. 1995). For a risk-averse firm, it is much more appropriate to base the definition decision on maximizing the certainty equivalent of profit P(*n*), than the expected value of profit itself, because the certainty equivalent captures the effect of both the expected value and variance of attractiveness at the point of definition. In fact, the objective of maximizing the expected value of the anticipated profit forms a special case of maximizing the certainty equivalent when the firm is risk neutral, which we consider in Section 3.

We replace the random variable P(n) by its certainty equivalent $\Pi(n)$ at the point of definition. To derive the certainty equivalent, we follow established practice in the literature (Pate-Cornell et al. 1989, Huddart 1993), and use an exponential risk averse function to capture risk aversion in our model: The utility of *x* is expressed as: $U(x) = 1\text{-}e^{-rx}$ where r is the coefficient of risk aversion ($r > 0$). A tedious derivation, left out of the body of the paper for brevity but presented in the appendix, shows that the certainty equivalent of the anticipated profit II(n) is given by: $M[p - c(n, w)]\ [\alpha\mu_n - {}^{M}/_{2}\, \sigma^2_n\, r\alpha^2(p - c(n, w)) - \beta p]$. Note how the firm's risk aversion is

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[3]In this section, we use a static, linear model of demand that is similar in form to those used by Mansfield (1975) and Bulow (1982), because it clarifies the exposition. We show in Section 3 that the model is easily extended to dynamic demand situations.

reflected by the fact that any variance (nonzero σ^2), is penalized in the above equation, and a higher degree of risk aversion, *r*, results in a higher penalty. Using this expression for the certainty equivalent of profit (CEP), we formulate the trade-offs as Problem CEP.

Problem CEP

$$\text{Max}_{p,\,n} \quad \Pi = M[p - c(n,w)][\alpha\,\mu_n - \frac{M}{2}\sigma_n^2 r \alpha^2 (p - c(n,w)) - \beta p] \qquad (1)$$

$$\text{s.t.} \qquad w \le K \qquad (2)$$

A risk-averse firm, therefore, makes its definition timing decision so as to maximize the certainty equivalent of its anticipated profit. We now begin to analyze this model to derive insights about the optimal point of definition.

3 Model Analysis

Our first step in the analysis is to derive an expression for the CEP-maximizing price. This can simply be obtained by using the first-order optimality conditions because the objective Π is concave in p (the second partial derivative of Π w.r.t. p* is $-2M\beta - rM^2\alpha^2\sigma^2_n$). The

CEP-maximizing price p* for the firm is given by:

$$p^* = \frac{1}{M\sigma_n^2 r\alpha^2 + 2\beta}\alpha\,\mu_n + \frac{M\sigma_n^2 r\alpha^2 + \beta}{M\sigma_n^2 r\alpha^2 + 2\beta}c(n,w) \qquad (3)$$

The above expression for p* confirms what we would intuitively expect : a higher sensitivity to price (β) tends to result in a lower CEP-maximizing price and a high value of μ_n would permit the firm to charge a higher price for the product. However, the effect of the variance is interesting and not so direct. A high value of variance results in a low contribution from the first term based on the mean of the product attractiveness leading to the dominance of the term based on the unit variable cost. This suggests that firms that force an early definition should follow a marginal pricing scheme based on cost and forsake contributions due to product attractiveness. High variance at an early point of definition would also lead to lower margins

$$p^* - c(n,w) = \frac{1}{M\sigma_n^2\rho\alpha^2 + 2\beta}\alpha\mu_n - \frac{1}{M\sigma_n^2\rho\alpha^2 + 2\beta}c(n,w) \qquad (4)$$

because it can be easily seen that the margin (p* - c(n, *w*)) is inversely proportional to σ^2_n.

Substituting p* back into the expression for the certainty equivalent of profit, we have[4]:

$$\Pi = \frac{M}{2(M\sigma_n^2\rho\alpha^2 + 2\beta)}[\alpha\mu_n - \beta c(n,w)]^2$$

The certainty equivalent of profit, Π, is non-decreasing in ω, the time of overlap between the definition and integration phases. This follows from a simple application of the chain rule as Π is decreasing in the unit variable cost c(n, *w)* which in turn is decreasing in *w.* To maximize CEP, the time overlap, ω, would be driven to its upper bound of K, making the unit variable cost equal to c(n, *K)*. For brevity, we denote c(n, *K)* by $c_K(n)$ and restate Problem CEP as:

$$\text{Max } \Pi = \frac{M}{2(M\sigma_n^2\rho\alpha^2 + 2\beta)}[\alpha\mu_n - \beta c(n,w)]^2 \qquad (5)$$

[4]This expression is valid when $\alpha\mu_n \geq \beta c(n, w)$. When $\alpha\mu_n < \beta c(n, w)$, the margin p* - *c(n, w)* is negative as seen above, and the firm would make a loss. Although in some exceptional cases firms would be interested in minimizing this loss, we focus on the case when firms want to introduce profitable products.

It is noteworthy that the higher the flexibility of the PDT, the greater the certainty equivalent of profits. This can be easily verified by an application of the chain rule that Π is increasing in K since Π is decreasing in $C_K(n)$ and $C_K(n)$ is decreasing in *K*.

3.1 Characterization of the Optimal Point of Definition

Expression (5) for the certainty equivalent Π is a nonlinear expression in *n*, due to which it may have multiple local optima. To keep our focus on the insights about the optimal point of definition, we examine cases that would result in a unique optimal point of definition. As discussed at the end of this section, the properties of this unique (global) optimum can then be generalized to the neighborhood of the local optima, which may result in more general situations.

A unique optimal point of definition results when the objective Π given by expression (5) is concave with respect to *n*, which happens under the following circumstances. Frequently in product development practice, the reduction in the unit variable cost exhibits diminishing returns as more and more time is spent on integration. For a given amount of flexibility (overlap K), spending more time on integration corresponds to defining early (smaller *n*), so the diminishing results means that the unit variable cost function $c_K(n)$ is increasing convex in *n* (See Figure 2). (The increasing nature of $c_K(n)$ in *n* is obvious because greater *n* means higher unit variable cost as discussed in the previous section. The convexity of $c_K(n)$ in *n* captures the diminishing marginal returns in reducing the unit variable cost due to expediting definition). A unique optimal point of definition (concave Π) results when the development process is such that (i) the mean of customer attractiveness μ is an increasing concave function of *n*, and (ii) the variance σ^2_n is decreasing convex in *n*. These correspond to situations that we observed in practice when the new information collected from customers continues to add positive value (customer-desired changes made to the design help only increase the mean product attractiveness or decrease the variance), and the value added experiences diminishing returns as time progresses. This is due to the fact that ideas with the greatest potential for improving attractiveness/reducing variance are obtained from the customer early, and with the incorporation of this feedback in the prototypes, customer ideas are exhausted of their potential to improve attractiveness[5]. It is noteworthy that these are sufficient but not necessary conditions for a unique optimal point of definition.

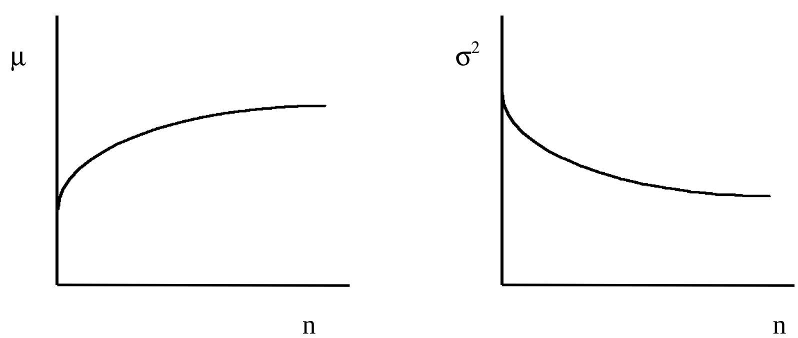

Figure 3 : Relation of μ and σ^2 of Attractiveness with n

Under these conditions, it can be seen that the objective function in Problem CEP is concave in the number of reviews *n*. The optimal point of definition, review *n*, can then be given by the following conditions (which are obtained by setting $\Pi(n - 1) \leq \Pi(n) \geq \Pi(n + 1)$):

[5]Data collected by Griffin and Hauser (1993), reported in Figure 2 of their paper, also shows that the percentage of customer needs identified is a concave function of the time spent in interviews.

$$\frac{Mr a^{2} s_{n}^{2} + 2b}{Mr a^{2} s_{n-1}^{2} + 2b}[a\, m_{n-1} - b\, c_{n-1}]^{2} \leq [a\, m_{n} - b\, c_{n}]^{2} \qquad (6)$$

$$\frac{Mr a^{2} s_{n}^{2} + 2b}{Mr a^{2} s_{n+1}^{2} + 2b}[a\, m_{n+1} - b\, c_{n+1}]^{2} \leq [a\, m_{n} - b\, c_{n}]^{2} \qquad (7)$$

Using the above expressions, we now focus on deriving properties of the optimal point of definition. It is clear that the optimum is determined by the combination of the improvement in attractiveness, increase in unit variable costs, and the reduction in variance. If variance did not play a role (that is if it remained constant throughout the development process), then the optimal point of definition occurs at the point where the marginal increase in the demand due to increase in the mean of the product attractiveness balances the marginal decrease in demand due to increase in the unit variable cost of the product: $[\alpha\mu_{n-1} - \beta c_{n-1}] \leq [\alpha\mu_n - \beta c_n] \geq [\alpha\mu_{n+1} - \beta c_{n+1}]$ (see Proposition 1). We shall refer to this point as the deterministic point of balance (DPB). When the variance comes down over time due to changes made based on feedback from the customer, its effect is to delay finalization beyond the DPB, as stated in Proposition 1.

Proposition 1 *(a) In the absence of any reduction in variance of attractiveness due to changes made based on customer feedback, a team should finalize its definition at the deterministic point of balance.*

(b) When the *customer feedback helps reduce variance at a non-zero rate, the optimal point satisfies Equations (6) and (7)* and *its effect is to delay the finalization of definition. The amount of delay depends on two factors: the amount of variance and the normalized rate of reduction in variance at the DPB. The more the rate of reduction in variance at the DPB, the more the delay*

in the point of finalization. The more the amount of variance at the DPB, the more the delay in the point of definition.

Proof of Proposition 1:

(la) If the variance remains constant throughout the development process, then Equations (6) and (7) reduce to $[\alpha\mu_{n-1}-\beta c_K(n-1)]^2 \leq [\alpha\mu_n-\beta c_K(n)]^2$ and $[\alpha\mu_{n+1}-\beta c_K(n+1)]^2 \leq [\alpha\mu_n-\beta c_K(n)]^2$, which characterizes the deterministic point of balance. For positive CEP, $\alpha\mu_{n-1}>\beta c_K(n-1)$, $\alpha\mu_n>\beta c_K(n)$, and $\alpha\mu_{n+1}>\beta c_K(n+1)$, and the squared relations reduce to the linear relations.

(lb) When the variance reduces in time, the multiplicative factors in equations (6) and (7), $(M\sigma_n^2 r\alpha^2+2\beta)/(M\sigma_{n-1}^2 r\alpha^2+2\beta)$ and $(M\sigma_n^2 r\alpha^2+2\beta)/(M\sigma_{n+1}^2 r\alpha^2+2\beta)$ influence the optimal point of definition as follows. The multiplicative factor $(M\sigma_n^2 r\alpha^2+2\beta)/(M\sigma_{n-1}^2 r\alpha^2+2\beta)$ in Equation (6) is less than 1, and the factor $(M\sigma_n^2 r\alpha^2+2\beta)/(M\sigma_{n+1}^2 r\alpha^2+2\beta)$ in Equation (7) is greater than 1. Since μ is concave increasing in *n*, and c is convex increasing *n*, condition (6) and (7) are satisfied beyond the deterministic point of balance. Therefore, the optimal point of definition is delayed. To see the effect of the amount of delay, note that the multiplicative factors in equations (6) and (7) can be expressed as

$$\frac{Mr a^2 s_n^2+2b}{Mr a^2 s_{n-1}^2+2b}=1-\frac{M(s_{n-1}^2-s_n^2)r a^2}{Mr a^2 s_{n-1}^2+2b}=1-\frac{M\left(\frac{s_{n-1}^2}{s_n^2}-1\right)r a^2}{M\frac{s_{n-1}^2}{s_n^2}r a^2+\frac{2b}{s_n^2}}$$

$$\frac{Mr a^2 s_n^2+2b}{Mr a^2 s_{n+1}^2+2b}=1-\frac{M(s_n^2-s_{n+1}^2)r a^2}{Mr a^2 s_{n+1}^2+2b}=1+\frac{M\left(1-\frac{s_{n+1}^2}{s_n^2}\right)r a^2}{M\frac{s_{n+1}^2}{s_n^2}r a^2+\frac{2b}{s_n^2}}$$

If the normalized rate of reduction in variance at the DPB, shown by $(\sigma_{n-1}^2)/(\sigma_n^2) - 1$, and by $1-(\sigma_{n+1}^2)/(\sigma_n^2)$ is low (high), the multiplicative factors are close to (significantly different from) 1, and the optimal point of balance is closer to (farther from) the deterministic point of balance. Low (high) absolute values of σ_n^2 tend to locate the optimal point of definition nearest to (farther from) the deterministic point of balance. Therefore, the amount of delay is directly proportional to both the normalized rate of reduction in variance at the DPB and the absolute amount of variance at the DPB.

Thus the effect of variance in attractiveness, felt only when the firm is risk-averse, is to further delay the optimal point of definition. A high normalized rate of variance reduction at the DPB implies that the customer information is adding value (reducing uncertainty), while a high absolute value of variance at the DPB implies that there is a benefit to further variance reduction, so there is benefit to spending more time in defining the product in both these cases. Note that the above conclusions are based on the fact that the objective Π is concave resulting in a unique optimum. But even if it is not concave (resulting in multiple local optima), in the neighborhood of the local, interior optima, we should find that (i) the marginal increase in the demand due to an increase in the attractiveness balances the marginal decrease in demand due to an increase in the unit variable cost of the product, and (ii) the effect of variance reduction is to delay the local optimum.

The above analysis has considered the case when the unit cost function $c(n,w)$ is deterministic, i.e. the uncertainty facing the product development process is primarily customer preference uncertainty. It is interesting to note that analysis similar to the above can be carried out for the case when the uncertainty arises primarily from the unit variable cost function. Such a situation occurs if the technical risks far outweigh the market risk. When the unit variable cost can be described as a random variable with a normal distribution and the product attractiveness to the customer is not uncertain (can be modeled deterministically), the point of definition occurs *before the DPB* in the presence of reduction in the variance of the unit cost function. For the sake of brevity, a detailed statement and proof of this result are provided in the appendix in Corollary 1. When both the product attractiveness and the unit variable cost are random variables, it is not possible to obtain closed-form results for the certainty equivalent of profit. However, we can qualitatively reason that reduction in the variance of the unit cost function will *counter* any delay in the optimal point of definition beyond the DPB due to the effect of reduction in variance of product attractiveness.

How does a firm's definition approach vary if it is not risk averse? Using our model, this question can be easily answered because when a firm is risk neutral, it has the implicit utility function U(x) = x. A risk neutral firm will therefore seek to maximize the expected value of the profits, which is given by $\Pi = M[am_n\text{-}bp][p\text{-}c_n]$. Under these conditions, the optimal point of definition under risk neutrality is given by the equations: $[\alpha\mu_{n-1} - \beta c_{n-1}] \leq [\alpha\mu n\text{-}\beta c_n] \geq [\alpha\mu_{n+1}\text{-}\beta c_{n+1}]$ (A detailed proof of the above result is provided in the appendix.) From the previous section, we know that this is the condition that characterizes the DPB. Thus a firm that is risk neutral must define its specifications at the deterministic point of balance.

Finally, it is interesting to note that a higher degree of flexibility (greater K) will help a firm defer commitment to specifications. This is because increased flexibility helps the team overlap the phases more in time and increase the time spent on integration, thereby reducing the unit variable cost $c_K(n)$. The decreasing nature of $c_K(n)$ in K will make it optimal for the firm to define later by delaying the DPB, as can be easily seen from the above expressions (6) and (7).

3.2 Implications of Dynamic Demand For Product Definition

In this section, we consider the implications for firms considering dynamic pricing and faced with dynamic demand. Following Eliashberg and Jeuland (1986), we use the model of dynamic demand given in Equation (8), where $N(t)$ is the cumulative number of sales of the product at time t.

$$\dot{N}(t) = [M - N(t)][a\Phi - bp(t)] \qquad (8)$$

For tractability, we use the continuous equivalent of the model of definition for a risk-neutral firm presented in the previous section (by converting discrete variable n into the continuous variable of time), denote the mean of the attractiveness by Φ, and assume the existence of the derivatives of the expected profit function with respect to the price and the point of definition t_{def}. The DPB is characterized by $\alpha(d\Phi(t_{def})/dt_{def})=\beta(dc(t_{def})/dt_{def})$. The expected profit of the firm (Π_E) then, is given by Equation (9).

$$\Pi_E = \int_0^{T_h} [p - c(t_{def})]\dot{N}(t)dt \qquad (9)$$

Here, T_h is the expected length of the horizon of the sales of the product. To optimize the timing of definition finalization decision, we follow the same procedure as above, i.e. find the profit-maximizing price, substitute it in the profit function, and determine the optimal timing of finalization.

Lemma 1 *The optimal point of definition for a risk-neutral firm considering dynamic demand and pricing policies is the same* as *that for a risk-neutral firm under equivalent static demand and prices, i.e. the deterministic point of balance.*

This result follows because the dynamic nature of demand and price change are post-launch effects while definition is a pre-launch process. Hence, under dynamic demand and pricing, the optimal definition approach does not change from the one described in previous sections.

Reduction in the unit variable cost after launch due to learning effects enables the firm to delay definition further because decreasing cost before launch is not as important as when there is no learning and no post-launch cost reduction. This is formally stated and proved in the proposition below.

Proposition 2 *When the firm expects experience effects to lower the unit variable cost after the product launch, it should delay the definition beyond the deterministic point of balance thereby improving the attractiveness of the product. The faster the learning and the post-launch decrease in unit* variable *cost, the greater the firm's expected profits.*

Proof of Proposition 2 and Lemma 1: The problem is a dynamic control problem and can be optimized using Pontryagin's maximum principle. We model the learning effects using an exponential learning curve following established practice in the literature. For tractability, we again adopt a continuous model. The problem is defined as follows:

$$\text{Max} \qquad \Pi_E = \int_0^{T_h} [p - c(t_{def})] \dot{N}(t) dt$$

$$\text{s.t.} \qquad \dot{N}(t) = [M - N(t)][a\Phi - bp(t)]$$

$$\mathrm{c(t)} = \mathrm{c}_0 e^{-bN(t)}$$

$$\mathrm{N(0)} = 0 \qquad \mathrm{N(T_h)} = N_1$$

where b is the learning constant, and c_0 is the unit variable cost at the point of launch and N_1 is the given level of penetration achieved by the firm. The Hamiltonian of the above control problem, for a costate variable of λ is given by

H=(p-c+ l)dN/dt. Setting *dH/dp=0*, and setting *dH/dN=-d l /dt*, we have

$$p^* = \frac{a}{2b}\Phi + \frac{1}{2}(c - l)$$

$$(p - c + l)(a\Phi - bp) - b\dot{N}c = \dot{l}$$

Using the above conditions, the expected profit-maximizing price is found to be $p^* = (a/b)F - 1/(h-t/2)$. This expression for price can be substituted back to find the rate of penetration *dN(t)/dt*. Π_E is then evaluated using *N(t)*, and the first order condition gives us the optimal point of balance. A detailed derivation of Equation (10) is provided in the appendix.

$$a \frac{d\Phi}{d\,t_{def}} = [\frac{1 - e^{-bN_1}}{b\,N_1}]b \frac{d\,c_0}{d\,t_{def}} \qquad (10)$$

If there is no learning effect in the unit variable cost, then in the limit as b goes to zero, the term $(1-e^{-bN1})/(bN_1)$ is equal to 1, which proves Lemma 2. This gives us the same result as Proposition 1, i.e. the optimal point of definition is at the deterministic point of balance which is characterized by $a(dF(t_{def})/dt_{def})=b(dc(t_{def})/dt_{def})$**.**

The term $(1-e^{-bN1})/(bN_1)$ is strictly less than 1 for non-zero values of b. This follows trivially if bN_1 is greater than or equal to 1. *If* bN_1 is less than or equal to 1, using the series expansion for e^{-bN1} , the term $(1-e^{-bN1})/(bN_1)$ reduces to $1 - (bN_1/2!)+(b^2N_1^{\ 2})/3!$ -+……… A pairwise comparison of adjacent positive and negative terms show the negative terms dominate the positive terms, and hence the term $(1-e^{-bN1})/(bN_1)$ is less than 1. This implies that the value of $a\ dF(t_{def})/dt_{def}$ is lower than the value of bdc_0/dt_{def} at the optimal point, which occurs after the deterministic point of balance. Hence the optimal point of definition has shifted to the right due to learning effects. As the value of b increases, the term $(1-e^{-bN1})/(bN_1)$ decreases, and hence from Equation (20), the value of Π increases, showing for the same value of the point of definition, the expected profits are higher.

Next, we consider the effect of competition on product definition.

4 Effect of Competition on Definition in A Duopoly

In order to better understand how competition affects the optimal product definition approach of a firm, we consider a model of a duopoly situation in which two firms are offering substitutable products, and one firm (the leader) has announced a product launch date before the other (the follower). We extend the formulation of the previous section by adding a term for demand substitution due to the presence of the other firm, and derive Nash equilibrium conditions to characterize the optimal definition approach under competition. This helps us compare the definition strategies of the leader and the follower with that of the monopolistic situation of Sections 2 and 3.

For this duopolistic model, we assume our conceptualization of the product development process presented in Section 2 holds; both firms are risk averse and continue to refine their product specifications by simultaneously pursuing product realization, interacting with customers, and using the customer feedback to update their product specifications and design. Let the launch date of the leader be T_1, and the launch of the follower be at time $T_2 \geq T_1$. In order to analyze the Nash equilibrium, it is necessary that the launch dates of both firms be known to each other. We seek to understand how the presence and launch date of a competing firm will affect the definition approach of the leader and the follower.

It is easily seen that the leader will enjoy a monopolist position for the time period $T_2 - T_1$. Once the follower enters, the two firms will compete based on their product's attractiveness and price. We model that this competition lasts till the end of the horizon which occurs at $\tau_h + T_1$, where τ_h is the length of the lifecycle of the current product generation. (For firms in the high technology industry, the lifecycle of a generation is often determined by the rate of development of core technologies, such as the microprocessor.) For simplicity, we assume both firms have the same level of flexibility K, demand is uniform in the entire planning horizon, and customers buy the product, as in the case of the monopolist, based on the difference between attractiveness and price. The presence of a competing firm means that some customers migrate to the competing product due to its greater attractiveness or lower price. For tractability, we assume the continuous version of the model presented in Section 3. Denoting the leader and the follower by the subscripts 1 and 2 respectively, we have the demand functions for the two firms in the duopoly phase given by Equations (11) and (12):

$$D_1 = Ma[a\ \Phi_1 - b\ p_1 + g\,(\Phi_1 - \Phi_2) + d\,(p_2 - p_1)] \qquad (11)$$
$$D_2 = Ma[a\ \Phi_2 - b\ p_2 + g\,(\Phi_2 - \Phi_1) + d\,(p_1 - p_2)] \qquad (12)$$

where δ is the effect of the differential in price between the two products, γ is the effect of the differential in attractiveness between the two products, and *a* is the fraction of the remaining potential market at the end of the monopoly period. γ and δ in the above expression are substitution coefficients that capture the effect of a competitive product with different price and product attractiveness. A higher level of γ would have more customers substituting one product for the other due to the gap in product attractiveness between the products, as would a higher level of *d* for the product price. With the above expression for demand, the certainty equivalent of profit Π_2 of the follower is given by:

$$\Pi_2 = Ma(p_2 - c_2)[a\ m_2 - b\ p_2 + g\,(m_2 - m_1) + d\,(p_1 - p_2) - \frac{Ma}{2}(p_2 - c_2)\,s_2^2\,r\,(a+g)^2]$$

The leader's certainty equivalent of profit Π_1, is a convex combination of terms corresponding to the monopolist and a term similar to the follower.

$$\Pi_2 = M(1-a)(p_1^m - c_1)[a\ m_1 - b\ p_1^m - \frac{M(1-a)}{2}(p_1^m - c_1)\,s_1^2\,r\,a^2] +$$
$$Ma(p_1 - c_1)[a\ m_1 - b\ p_1 + g\,(m_1 - m_2) + d\,(p_2 - p_1) - \frac{Ma}{2}(p_1 - c_1)\,s_1^2\,r\,(a+g)^2]$$

where the price in the monopoly phase is given by p_1^m. This expression for CEP-maximizing price during the monopoly phase would be the same as derived in section 3.1. Subsequent to the entry of the follower, the CEP-maximizing price of the leader would drop. The expression for the CEP-maximizing prices for both the leader and the follower in the duopoly phase, obtained by deriving the set of Nash equilibria for the two firms, is presented in the appendix in Result 1. (These lengthy expressions are left out from the body of the paper for the sake of brevity, but they yield intuitions similar to the case of the monopolist : the CEP maximizing price of a firm is higher if at the point of definition (a) its product's mean attractiveness is higher, and variance and unit variable costs are lower, and/or (b) competitive product's mean attractiveness is lower, and variance and unit variable costs are higher.) These prices can be substituted back to obtain the optimal definition points for the two firms - the expressions are presented in the appendix to keep the focus on the insights. The optimal point of definition for the leader and the follower are different, as is to be expected due to their different launch times, but they possess a similar pattern as discussed in the following proposition.

Proposition 3 *In the presence of competition, the optimal product definition approach for both the leader and the follower depends on how the ratio of substitution to sensitivity coefficients of the product attractiveness* (γ/α) *and price (d/b) compare with each other:*

Case 1: If $\gamma/\alpha = d/b$*, then the optimal product definition approach for both the leader and the follower is independent of the other firm (not influenced by the presence of competition and is similar to that of a monopolist with the corresponding launch date.*

Case 2: If γ/α < d/b, then both the leader and the follower define earlier than a monopolist with the same launch date.

Case 3: If γ/α > d/b, then both the leader and the follower define later than a monopolist with the same launch date.

The proposition is proved in the appendix, we present the intuition here. In Case 1**,** because of the *symmetric* nature of the competition on product attractiveness and unit variable cost, both firms define their products in the same way as a monopolist with their respective launch dates. However in absolute terms, the follower's point of definition is beyond that of the leader. To compensate for the delay in definition and launch, the follower will adopt a second-but-better strategy by offering a product that is better in both attractiveness (μ will be higher and σ^2 will be lower) and the unit variable cost (c will be lower) when both the leader and the follower experience the same functions of c, μ, and σ^2. When $\gamma/\alpha \leq \sigma/\beta$, product substitution is based more on price than on performance, and both firms would finalize the definition earlier to have a lower unit variable cost as a result of more extensive testing and integration. When $\gamma/\alpha \geq \sigma/\beta$, the competition (substitution) is based more on product attractiveness than on price, so both firms define the product as late as possible to increase the mean attractiveness and reduce the variance in the product's attractiveness. In Case 2 (3) in Proposition 3, the follower will have a more significant advantage over the leader in the unit variable cost (attractiveness) because of more time available for product development until the launch date.

The definition timing of the leader, however, differs from the follower in that it is moderated by the level of penetration intended to be achieved in the monopoly period.

Interestingly, when product substitution is based more on price (performance) than on performance (price), for a higher intended level of penetration, the leader will delay (expedite) its definition. This can be seen from the fact that the higher the market penetration (1 - *a*), the later the optimal point of definition in the expression for the timing of optimal point of definition in a price sensitive market (see Corollary 2 in the appendix).

When both the firms are risk neutral, the expected profits will not be penalized by the variance term as was the case in the previous section. The demand functions for the firms in the duopoly phase would be similar to the previous section without the variance term (for instance, $D_1=Ma[aF_1-bp_1+g(F_1-F_2)+d(p_2-p_1)]$, where F_1 and F_2 denote the mean of the attractiveness for the two firms. The expressions for the expected profits, expected profit-maximizing prices, and optimal point of definition for both the leader and the follower in the risk-neutral case are very similar (and somewhat simpler) to that of the risk averse case. Once again, the optimal product definition approach for both the leader and the follower depends on how the ratio of substitution to sensitivity coefficients of the product attractiveness (γ/α) and unit variable cost (δ/β) compare with each other. Based on whether γ/α equals, exceeds or falls below δ/β, both leader and follower finalize their definition at the same time, later or earlier than a monopolist with corresponding launch dates. The penalizing effect of a non-zero variance in the case of risk aversion tends to delay definition compared to the risk-neutral case.

Next, we present a conceptual framework that captures the insights from our model.

5 A Conceptual Homework For the Model Insights

The model we presented above is focused on the optimal definition approach in highly dynamic environments. Given the short lifecycles of products in such environments, a firm does not enjoy the luxury of launching a product first and then reducing the unit variable cost after launch - price premiums can be enjoyed only for a short while, and to be profitable, unit costs must be low from the moment of launch. This would drive the team to spend more time in the; integration phase optimizing the product's design. However, uncertainty surrounding customer preferences favors delayed definition, leaving less time for integration and reduction in unit variable cost.

As observed in section 3, when variance does not play a role (i.e. it is either absent or does not reduce with time), a firm defines its specifications at the point where the effect of improvement in attractiveness on profit balances the effect of increase in unit variable cost. This point, DPB, occurs earlier or later in the process depending on the integration needs of the specification in question, the flexibility of the PDT, and the performance/price sensitivity of the market (see Figure 4).

	High Integration Need Specifications		**Low Integration Need Specifications**	
	Inflexible Process	*Flexible Process*	*Inflexible Process*	*Flexible Process*
Price Sensitive (Greater a)	Early and Sharp Definition	Early Definition with Time Overlap	Early to Mid-Course Definition	Mid-Course Definition with Time Overlap
Performance Sensitive (Greater b)	Early to Mid-Course Definition	Mid-Course Definition with Time Overlap	Mid-Course to Late Definition	Late Definition with Time Overlap

Figure 4 : Insights into Deterministic Point of Balance

The integration needs of the specification being defined has a significant influence on the increase in unit variable cost due to delay in definition. Specifications with high integration needs in general require more time for integration and delays in their definition can lead to a much greater increase in unit variable cost in relation to specifications with lower integration needs. The unit variable cost curve for specifications with high integration needs will generally be steeper and lie above those with low integration needs (see Figure 2), which would mean that the optimal point of definition (DPB) is reached earlier in time for specifications with high integration needs.

The flexibility of the PDT is also a key determinant of the point of balance. When the team is more flexible, its ability to anticipate and/or easily absorb changes in specifications allows for a greater time period of overlap K and the unit variable cost curve experiences a slower rate of growth, due to which the optimal point of definition occurs later in the process. Similarly, the optimal point is delayed if the market is more performance sensitive than price sensitive in order to achieve an improvement in product attractiveness.

The combination of these three factors - the integration need of the specifications, the flexibility of the PDT, and the performance/price sensitivity of the market determines the optimal definition approach in the absence of reduction in the variance of attractiveness (see Figure 4). Early definition is optimal only when uncertainty does not play a role/the firm is not risk averse, the development team is inflexible, the integration needs of the specification are high, and the market is price sensitive. For specifications with low integration needs, it is not necessary to define so early, so the optimal point would occur early to midway during the process. When the PDT is flexible, it can begin the integration phase before definition is complete, and this additional time available for integration can be used to delay definition of specifications with both high and low integration needs.

The market's increasing sensitivity to performance would delay the definition even if the integration needs of the specifications are high and the PDT is inflexible, resulting in the optimal point falling early to mid-way during the process. For specifications with low integration needs, the definition can occur midway to even late in the process, thereby improving the product's attractiveness using customer input. The PDT's flexibility can again be useful to spend more time on integration while the definition is being pursued. While specifications with high integration needs may still have to be defined midway through the process, those with low integration needs can be finalized considerably late in the process taking advantage of the flexibility and period of overlap to meet the need for better attractiveness/performance.

The role of uncertainty in specifications is to further delay the point of definition beyond the DPB for a risk-averse firm. As the analysis in section 3 shows, the combination of high value of variance and high rate of (normalized) variance reduction at the point of balance means that more time be spent in defining the product (see.case I of Figure 5). Similarly, in case 2, when both the rate of variance reduction and the value of variance at the DPB are low, the firm should finalize definition as close to the DPB as possible, because the information collected is not adding much value and there is not much variance to be reduced through information collection. In case 3 (when the rate of variance reduction at the DPB is high but the level of variance is low at the DPB) as well as in case 4 (when the rate of variance reduction at the DPB is low but the level of variance is high at the DPB), the firm should delay definition somewhat beyond DPB to further benefit from variance reduction. The amount of delay in cases 3 and 4 would fall between that of cases 1 and 2.

	High Absolute Value of Variance at DPB	**Low Absolute Value of Variance at DPB**
High Normalized Rate of Variance Reduction at DPB	(1) Significantly Delayed	(3) Somewhat Delayed, Between 1 and 2
Low Normalized Rate of Variance Reduction at DPB	(4) Somewhat Delayed, Between 1 and 2	(2) Slightly Delayed

Figure 5 : Optimal Point of Definition Under Uncertainty and Risk Aversion

In the presence of competition, a firm's definition approach will depend on whether the product substitution is based more on performance or price (or more rigorously if the ratio of the substitution to sensitivity coefficient for product attractiveness is greater or less than that for price). When the market substitutes products more based on price, both the leader and the follower define earlier than a monopolist with the corresponding launch time, and the leader also defines relatively later (leaves less time for integration after finalization of specifications) than the follower (see Figure 6). On the contrary when the product substitution is based more on performance, the leader and follower define later than a monopolist with the corresponding launch time, and the leader defines relatively early (leaves more time for integration after finalization) than the follower.

	Substitution Based on Performance	**Substitution Based on Price**
Leader	Definition Later than Monopolist, Relatively Earlier than Follower	Definition Earlier than Monopolist, Relatively Later than Follower
Follower	Definition Later than Monopolist, Relatively Later than Leader	Definition Earlier than Monopolist, Relatively Earlier than Leader

Figure 2.6 : Effect of Competition on Definition

5.1 Illustration: Computer System Development

The situation facing our study company, a personal computer (PC) design and assembly firm, is a classic example of a highly dynamic environment due to the following reasons. In this market, the price drops and performance doubles every 18 months, and technologies and products become obsolete every 18-24 months. Consequently, the customer information collected and used to develop these products has a short life-span. Some observers have termed this a fruit-fly industry, in reference to the highly turbulent environment in which firms obsolete their own products to prevent competitors from doing so. Our attention will be focused on the development of a high performance server, a growing market segment that has also been experiencing increasing competition due to the relatively higher margins compared to the desktop segment of the PC industry. The firm's process illustrates the phase review approach described in this paper in action - its development process consists of five phases spaced about two months apart from each other. (While there were fine differences in the details of the process used by the various different PDT's in the company, the overall structure of the process was very similar because the top management of the company, in the spirit of TQM, placed a lot of emphasis on using standardized processes to obtain predictable results.)

Our study of the process at this company showed that the process was quite flexible due to (i) its lean organization that was in close communication with suppliers and actively anticipated changes, and (ii) widespread use of computer-aided design, rapid prototyping, and object oriented programming in the development of software. To illustrate the need for real-time definition, we focus our attention on two of the many specifications of the server product studied. The firm, a reasonably established player in the server market was committed to sustaining, and if possible gaining, market share in this lucrative market segment. This, combined with the fact that the product being developed was a derivative product, made the firm's risk aversion high to the possibility of launching a product that was technically advanced but unattractive in the eyes of the customer. The server market segment may be described as reasonably price sensitive (it is more price sensitive than the mainframe and workstation segments, but less so than the desktop segment).

The two specifications we focus on to illustrate the need for real-time definition are (i) the hard disk capacity to be used with the product (which will be procured from preferred suppliers), and (ii) the choice of the operating systems the product will support (Windows NT, Novell Netware, etc.). It must be noted that the hard disk choice strongly impacts the design of many other mechanical components, whose tooling and dies have long lead times for procurement and pilot testing. So, despite the flexible development process at the company, this specification would come under the *high integration need category*. With regards the choice of an O/S, the study company faced substantial uncertainty about the viability/ desirability of supporting the Novell Netware operating system (due to the increasing dominance of Windows NT). The firm was waiting on Novell to release a new version of Netware, and the attractiveness of this feature to its customers depended on the capabilities of the new version of Netware. The O/S choice (whether to support Novell Netware or not), however, only affected the software component of the product which, although still challenging, did not face the substantially high lead times experienced by toolings and dies. It would therefore be a specification with relatively low integration needs.

Our study of the company's process serves to illustrate many of the insights derived from the model. In this price-sensitive market, the high integration need specification must be defined early, while the low-integration need specifications may enjoy mid-course definition due to the flexible process (as seen in Figure 4). In the studied process, the firm (which possessed an appreciation of the definition tradeoffs) finalized the hard disk specification in the very first phase of the process, while the option of supporting Netware was not finalized until the third phase of the five phase development process. To avoid any delays in launch, the firm continued to overlap the software development phase with the process of deliberation to finalize the choice of the O/S supported by the firm. The uncertainty facing the O/S feature was handled by designing the code in such a way that it can be easily adapted to Netware, if the decision was made to support Netware. While it is unnecessary as well as undesirable to finalize the choice of O/S feature very early (when there is substantial market uncertainty), it is important to reach agreement on the hard disk capacities to be supported early because of their high integration needs. This illustrates the need for customizing the product definition approach to the market the in-house capabilities, and the technical specifications being considered as seen environment, in the model and the conceptual framework presented above.

6 Contributions, Limitations, and Further Work

Managing product definition in highly dynamic environments is a complex managerial task. The conventional view of definition is that it is a one shot event, while what emerges from this paper is that it is a gradual and deliberate process in which important choices about the product specifications are made with a more thorough understanding of customer preferences. Our first contribution in this paper has been to pose and answer the following question: Why is early product definition, recommended as a good practice in the literature, not always the desirable approach in high velocity environments? Uncertainty surrounding a product's specifications, the firm's risk aversion, and the ability to benefit from customer input during the definition process are the three major reasons why early definition of product specifications is not always optimal. In contrast to existing literature which has stressed only the virtues of early definition (and that too in informal terms), we have argued that there are really tradeoffs underlying the definition process (improvement in attractiveness and market risk reduction versus lesser time available for integration and increase in unit variable cost due to delayed definition), and these tradeoffs can be profitably balanced by managers in real-time during the definition process.

To develop insights about the real time decision process, we presented a model that captures the above-mentioned definition tradeoffs. In this model, the definition is refined in real-time using customer information resulting in improvements in the product's attractiveness and sales potential. Risk aversion of the firm is modeled using the certainty equivalent of the firm's profit. Using this model, we found that early definition is optimal only in a limited set of situations: when the market conditions do not experience significant uncertainty/the firm is not risk-averse, its development team is inflexible, the specifications have high integration needs, and the market is price (not performance) sensitive. If any of these conditions do not hold and the firm forces an early definition, the firm would earn less than optimal profits. A firm that forces an early definition when uncertainty is high also earns considerably less margins (refer expression (4) in section 3). A firm cannot delay its definition forever, however, because of the increase in unit variable costs due to delays. Unless the customer information continues to greatly improve the attractiveness or reduce uncertainty, a firm should commit to its specifications as quickly as possible to leave enough time for integration. We also presented a simple model of the effect of competition on the definition decision in section 4, which indicated that under competition a firm should expedite (delay) definition if customers substitute based on price (performance).

New product definition process has received relatively little attention from researchers in terms of formal models which may be one reason why the definition phase tradeoffs have not received close scrutiny. In this early/ ground-breaking phase of this inquiry, we have made some modeling assumptions which must be relaxed in future research. For instance, we treated the launch date as a hard constraint in our model. This is a reasonable assumption for many firms in the high-technology industry, in our experience, because the launch is dictated by external factors such as large trade shows before which firms launch products. When this assumption does not hold but the opportunity cost of delayed launch is known, we can use sensitivity analysis to determine the impact of the launch date on the certainty equivalent of profit or expected profit, to extend our model. It was also assumed that the attractiveness data obtained from the customers follows a normal distribution. However, this is used only to derive an expression for the certainty equivalent of profit which can also be obtained without difficulty for other distributions of attractiveness. The analysis of the model in section 3.1 was for the case of a unique optimal point of definition, but we found that the properties of the optimum (such as balance between attractiveness and cost, and delay due to variance reduction) are also valid in the vicinity of interior, local optima. Also, costs associated with changing product definition in realization have not been included because from our experience the cost of making changes to virtual and soft prototypes (made during realization out of materials such as foam, fiber, glass, and inexpensive metals and plastic) is relatively small compared to the cost of changes to tooling and fixtures in the integration phase. While the model in this paper did not include a term for development costs, it may be seen qualitatively that the effect of a development cost term, which is monotone increasing in the time of definition, would be to further expedite definition.

Several aspects discussed in this paper merit further research attention. First, we analyzed the product definition timing decision for a structured development process (with periodic "phase reviews"). While other scholars have taken a similar approach to model the development process (Ha and Porteus 1995), industrial experience shows that the degree to which a structured process is followed varies not only from company to company, but also within the same company. The analysis in section 2 show that the results of this paper hold for the limiting case of continuous reviews, but it must be analyzed as to what effect informal decision making has on the definition timing. Second, this paper examined product definition under customer preference uncertainty, and the effect of technological uncertainty on the definition approach must be considered in further work. With uncertainty about core technologies, it may be difficult to prototype the product and collect customer feedback as described in this paper, so characterizing the definition approach under uncertainty about technology and product architectures would require a different modeling approach. Convex costs and concave attractiveness functions, that yield a unique optimum point of definition, correspond to the case of diminishing returns from pursuing integration and collecting customer information (for which evidence is found in the literature). It must be investigated as to what effect other functional forms of costs (that include costs of making changes to tooling that are contingent on the nature of design changes) have on the definition approach. More broadly, we have restricted our attention to projects that develop individual products. An extension of this study should consider product line and generation development initiatives (Kekre and Srinivasan, 1990). The definition phase for each product then has to decide which features to incorporate in each of the current products, and which features to defer for a future generation.

7 Conclusions and Implications For Practice

With the understanding from the model and analysis of the product definition phase, we can make the following concluding remarks with implications for practice. First, if a firm is either not risk-averse or if the customer preferences are not time variant and the firm can determine them quickly with certainty, the firm should resort to early definition. This approach is easier for a team to manage in most cases, as it does not involve changes in the middle of the process, and also leaves enough time for integration. However, the work of Von Hippel (1992) shows that customers find it inherently difficult to specify their needs at the outset of a product development process without prototypes of concepts. Under these circumstances, early definition faces the difficulty of committing to specifications with incomplete information about customer preferences. Real-time definition makes incorporating the feedback from customers and refining the product possible, thereby improving its attractiveness to the customer-base and its sales potential. Further, in dynamic environments information collected can become obsolete quickly, and uncertainty surrounding the specifications coupled with a firm's risk aversion can make early definition undesirable. New technologies or products influence customer preferences, rendering specifications defined early obsolete. Real-time definition, by delaying commitment when necessary, can help a firm respond quickly to changes in customer preferences. However, this requires that the firm make its finalization decision more deliberately, and be flexible in its development process so that the integration phase need not wait until definition is complete, and changes in specifications will not create the need for much more integration. For such an approach to work, the team must use customer-provided feedback to reduce variance of attractiveness, and not cause a phenomenon called creeping featurism which may lead to increasing uncertainty and confusion in the development process.

To illustrate real-time definition, we provided a full-length example from one of our study companies. Recent field study work offers evidence that other firms too might be using such an approach of delaying commitment to their advantage. In what they call the Second Toyota Paradox**,** Ward et al. (1995) describe in detail how delaying finalization helps Toyota develop better cars. Iansiti (1995) presents several practical examples from his field studies on how developing products in "turbulent environments" requires different approaches to definition and development including making product decisions closer to launch. A recent empirical study of product development performance in the computer industry by Loch et al. (1996) also shows that flexibility provided by changes in specifications positively affects the innovation rate and performance.

In summary, this paper makes a contribution to the product development literature by drawing attention to the process of product definition, and developing a model of the trade-offs underlying it. Our recommendation to managers is that instead of force-fitting one particular definition approach (such as early definition) for all projects, they be more deliberate and make decisions about the definition process in real-time, by assessing the market uncertainty, value of customer information, and the difficulty in making changes to the product. The framework presented in section 5 provides some guidance in this regard. Real-time definition appears to be a more comprehensive approach because it does not assume that one definition approach fits all NPD processes, but instead requires customization to the market conditions. The flexibility offered by such an approach seems to be essential to adapt to highly dynamic environments in many industries.

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Appendix

Proof of Certainty Equivalent for Π:

The certainty equivalent of anticipated profit of *P*, Π, can be derived from the following expression:

$$1-e^{-r\Pi}=\int_{-\infty}^{\infty}[1-e^{-rM(a\Phi(n)-bp)(p-c(n,w))}]\,f(\Phi(n))d\Phi(n) \qquad (13)$$

where $$\int_{-\infty}^{\infty} f(\Phi(n))d\Phi(n)=1$$

f(Φ(n)) is the pdf of a normal variable with mean μ_n and variance σ_n^2. The above relationship reduces to

$$e^{-r\Pi} = \int_{-\infty}^{\infty} e^{-rM(a\Phi(n)-bp)(p-c(n,w))} \frac{1}{\sqrt{2\Pi}\, s_n} e^{-\frac{(\Phi(n)-m_n)^2}{2s_n^2}} d\Phi(n) \qquad (14)$$

Consider the exponent of the term within the integral, $-rM\alpha\Phi(n)(p-c(n,\omega))+rM\beta p(p-c(n,\omega))-(\Phi(n)-\mu_n)^2/(2\sigma_n^2)$. After some algebraic manipulation, this term can be rewritten as:

$$-\frac{[\Phi(n)-\{m_n - M s_n^2 r a(p-c(n,w))\}]^2}{2s_n^2} - \frac{m_n^2 - \{m_n - M s_n^2 r a(p-c(n,w))\}^2}{2s_n^2} + rMbp(p-c(n,w))$$

Then Equation (14) can be rewritten as :

$$e^{-r\Pi} = e^{-\frac{m_n^2 - \bar{m}_n^2}{2s_n^2} + rMbp(p-c(n,w))} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\Pi}\, s_n} e^{-\frac{(\Phi(n)-\bar{m}_n)^2}{2s_n^2}} d\Phi(n) \qquad (15)$$

$$\bar{m}_n = m_n - M s_n^2 r a(p-c(n,w))$$

The term under the integral sign is equal to 1. Setting the indices on the LHS and the RHS of the Equation (15) equal, we obtain the certainty equivalent Π to be

$$\Pi = M[p - c(n,w)][a\, m_n - \frac{M}{2} s_n^2 r a^2 (p - c(n,w)) - bp]$$

Statement of Corollary 1 :

Let c(n, w) be normally distributed with mean κ and variance χ^2, and the product attractiveness be denoted by Φ(n). The product attractiveness is assumed to be deterministic. The certainty equivalent of P(n) can be obtained in a similar manner to section 3.1. If $\overline{\Pi}$ denotes the certainty equivalent of P(n), we have

$$1-e^{-r\overline{\Pi}} = \int_{-\infty}^{\infty}[1-e^{-rM(a\Phi(n)-bp)(p-c(n,w))}]f(c(n,w))dc(n,w) \qquad (16)$$

where f (c(n, ω)) is the pdf of a normal variable with mean κ and variance χ^2. This equation can be solved in a similar manner to the previous case to obtain the value of $\overline{\Pi}$.

$$\overline{\Pi} = \mathrm{M}[a\ \Phi_{\mathrm{n}} - bp][\mathrm{p} - k_{\mathrm{n}} - \frac{M}{2}c_n^2 r(a\ \Phi_{\mathrm{n}} - bp)]$$

The optimal price is given by $p^c = \frac{1}{M\ c_n^2 rb+2}k_n + \frac{M\ c_n^2 rb+1}{b(M\ c_n^2 rb+2)}a\ \Phi_n$

The optimal price can be substituted back to restate the certainty equivalent as follows.

$$\overline{\Pi} = \frac{M}{2b}\frac{(a\ \Phi_n - b\ k_n)^2}{M\ c_n^2 rb+2}$$

We now make similar assumptions to the assumptions made in section 3.1. We assume that Φ_n is increasing in *n*, κ_n is decreasing and convex in the time for integration, and therefore, increasing and convex in the time of definition. We also assume that χ_n^2 is decreasing and convex in the time of integration, and therefore, increasing and convex in the time of definition. The rationale behind these assumptions is similar to the intuition behind the assumptions made in section 3.1.

Corollary I *(a) If the variance in the unit variable cost is constant throughout the development process, then the team should finalize its definition at the deterministic point of balance.*

(b) When the time spent in integration reduces the variance in the unit variable cost at a nonzero rate, the optimal point of definition is before the deterministic point of balance. The amount the definition should be expedited is directly proportional to both the absolute amount of variance and the normalized rate of reduction in variance in the unit cost at the DPB.

The deterministic point of balance in this case is characterized by :

$a\,\Phi_{n-1} - b\,k_{n-1} \leq a\,\Phi_n - b\,k_n \geq a\,\Phi_{n+1} - b\,k_{n+1}$. The proof is parallel to the proof of Proposition 1.

Proof of Optimal Point of Balance for a Risk-neutral Firm :

A risk-neutral firm has the implicit utility function of U(x)=x. To find the certainty equivalent of profits for a risk-neutral firm, we use $U(\Pi) = \Pi = \int_{-\infty}^{\infty} Pf(\Phi(n))d\Phi(n)$ which is the expected value of P. The value of II is then given by $\Pi = M[a\,m_n - bp][p - c_n]$. The first order condition for optimality of the price gives the optimal price to be $p^* = \frac{a\,m_n}{2b} + \frac{c_n}{2}$. Substituting the optimal price into the expected profits yields $\Pi(n) = M\,\frac{(a\,m_n - b\,c_n)^2}{2b}$. The first order conditions of $\Pi(n-1) \leq \Pi(n) \geq \Pi(n+1)$ shows that the optimal value of n is given by the deterministic point of balance (DPB).

Proof of Equation (10) :

Substituting the value of p* back into $\dot{N}(t)$, the diffusion of the product can be described as

$N(t) = M - \bar{h}(h - t/2)^2$ where $\bar{h}$ and h are constants of integration. From the boundary

conditions, the values of h and $\bar{h}$ are found to be $h = \frac{T_h}{2[1 - \sqrt{1 - \frac{N_1}{M}}}$ and $\bar{h} = M / h^2$.

The objective function Π_E can then be rewritten as $\int_{-\infty}^{\infty} p\dot{N}dt - c_0 \int_0^{T_h} e^{-bN}\dot{N}dt$ where $\dot{N} = \bar{h}(h - t/2)$.

Evaluating the above integral gives us

$$\Pi_E = \frac{\bar{h}T_h}{b}[a\Phi(h - \frac{T_h}{4}) - 1] - c_0(\frac{1 - e^{-bN_1}}{b}) \qquad (20)$$

The value of $\bar{h}T_h(h - T_h/4)$ is found to be N_l. The first order optimality condition, after simplification, can be stated as Equation(10).

Result 1 *The optimal price of the leader in the monopoly period will be the same as the monopolist in the monopoly period. The optimal prices of the firms in the duopoly stage are given by*

$$p_1^* = \frac{2\bar{b}_2}{4\bar{b}_1\bar{b}_2 - d^2}[A + \frac{d}{2\bar{b}_2}B];\ p_2^* = \frac{2\bar{b}_1}{4\bar{b}_1\bar{b}_2 - d^2}[B + \frac{d}{2\bar{b}_1}A]$$

where $\bar{b}_1$ and $\bar{b}_2$ are given by

$\bar{b}_1 = b + d + \frac{Ma}{2} r s_1^2 (a+g)^2;\ \bar{b}_2 = b + d + \frac{Ma}{2} r s_2^2 (a+g)^2$ and A and B *are* given *by*

$$A = a\ m_1 + g(m_1 - m_2) + \{\bar{b}_1 + \frac{Ma}{2} r(a+g)^2 s_1^2\}c_1;\ B = a\ m_2 + g(m_2 - m_1) + \{\bar{b}_2 + \frac{Ma}{2} r(a+g)^2 s_2^2\}c_2$$

Proof : The CEP-maximizing prices for the firms in the duopoly phase satisfy

$\Pi_1(p_1, p_2^*) \le \Pi_1(p_1^*, p_2^*)$ and $\Pi_1(p_1^*, p_2) \le \Pi_1(p_1^*, p_2^*)$. Since the CEP's are continuous in the

prices, the solution to $\frac{d\,\Pi_i}{d\,p_i} = 0$, i = 1, 2 is the set of Nash-equilibrium prices for the firms.

Solving the above equations simultaneously yields the above prices. 0

Proof of Proposition 3

By substituting the Nash equilibrium prices into the CEP function, we get for the follower

$$a\,m_2 - b\,p_2^* + g\,(m_2 - m_1) + d\,(p_2^* - p_1^*) - \frac{Ma}{2} r(a+g)^2 s_2^2 (p_2^* - c_2) = \{b + d + \frac{Ma}{2} r(a+g)^2 s_2^2\}(p_2^* - c_2)$$

Substituting the LHS of the above equation in the CEP for the follower, Π_2, we get

$\Pi_2 = Ma\,\bar{b}_2 (p_2^* - c_2)^2$. Substituting the value of p_2^* in the above expression, we get

$\Pi_2 = \frac{\bar{b}_2}{(4\bar{b}_1\bar{b}_2 - d^2)^2}[\{2\bar{b}_1(a+g) - dg\}m_2 - \{2\bar{b}_1(b+d) - d^2\}c_2 + z\,]^2$, where z is given by

$[d\,(a+g) - 2\,\bar{b}_1 g\,]m_1 + [d\,\{\bar{b}_1 + \frac{Ma}{2} 2\,(a+g)^2 s_1^2\}c_1]$. The first-order optimality condition gives us

the characterization of the optimal point of definition.

$$\frac{2[\{2\bar{b}_1(a+g) - dg\}\frac{d\,m_2}{dt_{def_2}} - \{2\bar{b}_1(b+d) - d^2\}\frac{d\,c_2}{dt_{def_2}}}{2[\{2\bar{b}_1(a+g) - dg\}m_2 - \{2\bar{b}_1(b+d) - d^2\}c_2 + 2\,\bar{b}_1 z} = \frac{Mar\,(a+g)^2(4\bar{b}_1\bar{b}_2 + d^2)\frac{d\,s_2^2}{dt_{def_2}}}{2\,\bar{b}_2(4\bar{b}_1\bar{b}_2 - d^2)}$$

If the value of $\frac{d\,s_2^2}{d\,t_{def_2}}$ is zero, the characterizing equation is

$$[2(a+g)\,\bar{b}_1 - gd]\frac{d\,m_2}{d\,t_{def_2}} = [2(b+d)\,\bar{b}_1 - d^2]\frac{dc(t_{def_2})}{d\,t_{def_2}} \qquad (24)$$

Case I

If $g/a = d/b = k$ then Equation (24) reduces to

$$a[2\bar{b}_1(1+k) - b\,k^2]\frac{d\,m_2}{d\,t_{def_2}} = b[2\bar{b}_1(1+k) - b\,k^2]\frac{dc(t_{def_2})}{d\,t_{def_2}}$$

which reduces to the characterization of the deterministic point of balance viz.

$a\dfrac{d\,m_2}{d\,t_{def_2}} = b\dfrac{dc(t_{def_2})}{d\,t_{def_2}}$, which is the same condition for definition as the monopolist.

Case 2

If $g/a = k_1$ and $d/b = k_2$ and $k_1<k_2$, then Equation (24) reduces to

$$a[2\bar{b}_1(1+k_1) - b\,k_1k_2]\frac{d\,m_2}{d\,t_{def_2}} = b[2\bar{b}_1(1+k_2) - b\,k_2^2]\frac{dc(t_{def_2})}{d\,t_{def_2}}$$

$2\bar{b}_1(1+k_1) - b\,k_1k_2 < 2\bar{b}_1(1+k_2) - b\,k_2^2$, because $2\bar{b}_1(1+k_2) - 2\bar{b}_1(1+k_1) - b(k_2^2 - k_1k_2 =$ $(k_2-k_1)(2\bar{b}_1 - d) > 0$

By simple algebra, if $k_1<k_2$,

Therefore, at the optimal point of definition, we get the result $a\dfrac{d\,m_2}{d\,t_{def_2}} > b\dfrac{dc(t_{def_2})}{d\,t_{def_2}}$, which implies that the optimal time of definition is earlier compared to the monopolist, as μ has to increase faster at the optimal point of definition, and μ is concave.

Case 3

If $g/a = k_1$ and $d/b = k_2$ and $k_1>k_2$, then Equation (24) reduces to

$$a[2\bar{b}_1(1+k_1) - b\,k_1k_2]\frac{d\,m_2}{d\,t_{def_2}} = b[2\bar{b}_1(1+k_2) - b\,k_2^2]\frac{dc(t_{def_2})}{d\,t_{def_2}}$$

By simple algebra, if $k_1<k_2$,

$$2\,\overline{b}_1(1+k_1)-b\;k_1k_2>2\,\overline{b}_1(1+k_2)-b\;k_2^2,\ \text{because}\ 2\,\overline{b}_1(1+k_2)-2\,\overline{b}_1(1+k_1)-b\,(k_2^2-k_1k_2=(k_2-k_1)(2\,\overline{b}_1-d\,)<0$$

Therefore, at the optimal point of definition, we get the result $a\,\dfrac{d\,m_2}{d\,t_{def_2}}<b\,\dfrac{dc(t_{def_2})}{d\,t_{def_2}}$, which implies that the optimal time of definition is delayed compared to the monopolist because μ has to increase slower at the optimal point of definition and μ has been assumed to be concave. The effect of reduction in variance is to delay the point of definition as before. This can be observed from the fact that $(ds_2^{\,2}/dt_{def})$ is negative, and hence the point of balance is beyond the points of balance in each of the cases, as after the point of balance, $bc(t_{def})$ increases faster than $\alpha\mu(t_{def})$.

The leader's CEP is a convex combination of terms similar to the CEPs of the follower and the monopolist. Therefore, the leader's optimal time of definition will lie between the follower and the monopolist. In the three cases analyzed in the lemma, the results for the leader's optimal time of definition follow analogously.

Corollary 2 *The point of definition for the leader depends on the level of penetration intended to be achieved in the monopoly period. For a higher intended level of penetration, the leader will define its product earlier in Case 2 in Proposition 3, and delay the definition in Case 3 in Proposition 3.*

Proof of Corollary 2: The proof of Corollary 2 follows from Proposition 3 and the fact that the higher the market penetration *(1-a)*, the more the point of definition will shift towards the definition of the monopolist.