Chapter 7
Platform Valuation for Product Family Design

Seung Ki Moon and Timothy W. Simpson

Abstract The valuation of a product increases flexibility in decision-making for developing new products or redesigning existing products and affects product life cycles. Strategic adaptability is essential in capitalizing on future investment opportunities and responding properly to market trends in a dynamic environment. To identify the valuation of a platform in a product family, we investigate strategic module-based platform design using market-based decision-making. The objective of this chapter is to propose a financial model to evaluate design valuation for a platform based on market mechanisms in an uncertain market environment. Real options analysis is applied to value options related to introducing new modules as a platform in a product family. In the proposed model, we use design quality that is determined by customers' preferences and performance utilities for products. To demonstrate implementation of the proposed model, we use a case study and numerical analysis involving a family of mobile products.

7.1 Introduction

Product family design allows innovative companies to create customized product roadmaps, to manage designers and component partners, and to develop the next generation of products based on platform strategies (Cronin 2010). By sharing and reusing assets such as components, processes, information, and knowledge across a

S.K. Moon (✉)
School of Mechanical and Aerospace Engineering, Nanynag Technological University, Singapore 639798, Singapore
e-mail: skmoon@ntu.edu.sg

T.W. Simpson
Mechanical and Nuclear Engineering, Penn State University, University Park, PA 16802, USA

Industrial and Manufacturing Engineering, Penn State University, University Park, PA 16802, USA

T.W. Simpson et al. (eds.), *Advances in Product Family and Product Platform Design: Methods & Applications*, DOI 10.1007/978-1-4614-7937-6_7,

family of products, companies can efficiently develop a set of differentiated economic offerings while also improving the flexibility and responsiveness of product development (Simpson 2004). Product family design is a way to achieve cost-effective mass customization by allowing highly differentiated products to be developed from a common platform while targeting products to distinct market segments (Shooter et al. 2005).

In uncertain market environments, the valuation of a product increases flexibility in decision-making for developing new products or redesigning existing products and affects product life cycles (Bollen 1999). Design has reflected the requirement changes that are caused by customers' preferences, technologies, economic situations, company's strategies, and competitive moves. Strategic adaptability is essential in capitalizing on future investment opportunities and responding properly to market trends in a dynamic environment (Smit and Trigeorgis 2004).

Market-based product design can consider various and dynamic market environments by capturing dynamic factors, such as customer needs and trends, companies' strategies, regulations, resources, and technologies in product design. To identify the valuation of a platform in a product family, we investigate strategic module-based platform design using market-based decision-making. The value of products depends on market segmentation strategies that are identified by information derived from the relationship between customer needs and functional requirements. Real options valuation provides a rigorous analysis that can be applied to develop a financial model for valuing, managing, and optimally exercising options (Longstaff and Schwartz 2001). Real options analysis is a decision-making method to evaluate design strategies that are affected by company's decision, competitors' action, and new technologies (Smit and Trigeorgis 2004).

The objective of this chapter is to propose a financial model to evaluate design valuation for a platform based on market mechanisms in an uncertain market environment. The proposed model is to facilitate product family design strategies that will maximize the expected profit under uncertain constrains, such as demand, customers' preferences, and regulations. Real options analysis is applied to value modules related to a platform in a product family. In the proposed model, we use design quality that is determined by customers' preferences and performance utilities for products.

The remainder of this chapter is organized as follows. Section 7.2 reviews related literature and background for product family design and market-based design approaches. Section 7.3 describes the proposed financial model to evaluate product family design. Section 7.4 gives a case study and numerical analysis for design valuation involving a family of mobile products. Closing remarks and future work are presented in Sect. 7.5.

7.2 Literature Review and Background

7.2.1 Product Family Design

A product family is a group of related products based on a product platform, facilitating mass customization by providing a variety of products for different market segments cost-effectively (Simpson et al. 2005). A successful product family depends on how well the trade-offs between the economic benefits and performance losses incurred from having a platform are managed. A well-defined platform reduces production costs by improving economies of scale and reducing the number of different components that are used (Simpson et al. 2005; Moon et al. 2008).

Simpson et al. (2001) introduced a method to optimize a platform by minimizing performance loss and maximizing commonality based on a scale-based product family design approach. Johannesson and Claesson (2005) described a configurable product platform design process and model using an operative product structure and a hierarchical function-mean tree to capture parameters describing design information such as rules, variants, requirements, and product configuration possibilities. Thevenot et al. (2007) developed the design of commonality and diversity method (DCDM) to provide designers with recommendations for both the functional and component levels by the inherent trade-off between commonality and diversity during product family and platform development. Moon et al. (2008) introduced a market-based negotiation mechanism to support product family design by determining an appropriate platform level that represents the number of common modules using a dynamic multi-agent system in an electronic market environment. Zacharias and Yassine (2008) proposed a mathematical model for developing and evaluating modular product families to provide maximum market coverage by integrating a conceptual design approach, a product development cost model, an economic model. Moon and McAdams (2009) introduced a method for developing a universal product family through a game theoretic approach in a dynamic market environment by extending concepts from product family design to universal design. Johnson and Kirchain (2011) used a generative cost model to investigate development lead time and costs that can have significant effects on technology choice and lead to substantial cost savings in product families. Rojas Arciniegas and Kim (2012) developed a methodology to identify a set of components containing sensitive information related to security concerns using clustering optimization, while considering component sharing and optimal architecture for a family of products.

7.2.2 Market-Based Design Approaches

In engineering design and product development, market-based design approaches can provide the ability of investigating additional flexibility and strategic value.

Game theoretic approaches have been applied to model strategic relationships between designers for sharing design knowledge and solving design problems. Real option analysis has offered a natural framework to evaluate the valuation of product design by utilizing managerial flexibility in the valuation process (Gamba and Fusari 2009; Brach 2003).

Xiao et al. (2002) applied game theoretic approaches and design capability indices to model the relationships between engineering teams that were described as cooperative, noncooperative, and leader/follower protocols and facilitate collaborative decision-making during a product realization process. Fernandez et al. (2005) proposed a framework for establishing and managing collaborative design spaces by combining elements of cooperative and noncooperative behavior and formulating strategic and extensive games with utility theory. Kopin and Wilbur (2005) introduced a Bayesian game to model cost sharing in uncertain and incomplete information that were related to producer and consumer attributes such as nature, production costs, players and information, and preferences. Jiao et al. (2006) identified four types of real options based on European options for product family design and developed a valuation framework to evaluate the options of configuration inherent in design using financial analysis. Ford and Sobek (2005) applied real options concepts to product development processes for managing uncertainty through flexibility impacts project behavior, performance, and value. Gamba and Fusari (2009) described a stochastic dynamic framework for valuing the contribution of modularization process and modular operations in the design of systems using real options. Kumar et al. (2009) proposed a market-driven product family design methodology to determine an optimal product offering and platform level strategy based on the estimated demand model in market segmentation grids by evaluating the impact of the variability of products and development cost. Shiau and Michalek (2009) introduced an approach based on Stackelberg game to solve a product design optimization problem for profit maximization under short-run price competition. The proposed approach considered Nash and Stackelberg conditions as design constraints to reflect competitor pricing reactions. Moon et al. (2011) developed a method for designing customized families of services using game theory to model module sharing and decide strategic solutions for selecting modules in dynamic market environments. A coalitional game was employed to model potential module sharing and determine which modules used in the platform provide the most benefit. Jiao (2012) utilized a hybrid real options valuation approach to evaluate the flexibility of product platforms for improving platform planning and investment by integrating product-related options and project-related options under endogenous and exogenous uncertainties. In the next section, the proposed financial model for evaluating the valuation of platform design is discussed in detail.

7.3 A Financial Model for Platform Design Valuation

In this chapter, we propose a financial model to investigate design strategies based on the value of the platform design using real option analysis.

7.3.1 Product Family Architecture

The basic idea of modular design is to organize products as a set of distinct modules that can be designed independently and develop a variety of products through the combination and standardization of modules (Ramesh et al. 2002). We assume that a product can be decomposed into modules that provide specific functions, and functions are achieved by the combination of the modules' design variables.

Suppose that a product family consists of l products, $F = (P_1, P_2, \ldots, P_l)$ and a product, i, consists of m_i modules, $P_i = (\boldsymbol{x}_{i,1}, \boldsymbol{x}_{i,2}, \ldots, \boldsymbol{x}_{i,m_i})$, where $\boldsymbol{x}_{i,j}$ is a module j in product i and consists of a vector of length n_m, $\boldsymbol{x}_{i,j} = (x_{i,j,1}, x_{i,j,2}, \ldots, x_{i,j,n_m})$. The individual scalar components $x_{i,j,k}$ ($k = 1, 2, \ldots, n_m$) of a module $\boldsymbol{x}_{i,j}$ are called design variables. Each module can be achieved by alternative instances. Let b_j be an instance of module j ($b_j = 1, 2, \ldots, B$) and $\boldsymbol{M}$ be a module instance matrix for the instances of modules in a product family. By introducing a module instance matrix $\boldsymbol{M}$, the product family is represented as

$$\mathbf{PF} = \mathbf{MX} \tag{7.1}$$

where $\boldsymbol{M}$ is defined as

$$\boldsymbol{M}_{i,j} = \begin{cases} b_j & \text{if module } j \text{ is used in a product } i \\ 0 & \text{otherwise} \end{cases} \tag{7.2}$$

In the module instance matrix, if modules are designed by the same instance (i.e., common modules), then the number of b_j is the same. And, the large number of b_j indicates the number of alternatives in module j. Based on the proposed product family architecture, a module instance matrix can be represented as

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_{11} & \mathbf{M}_{12} \\ \mathbf{M}_{21} & \mathbf{M}_{22} \end{bmatrix} \tag{7.3}$$

where $\mathbf{M_{11}}$ and $\mathbf{M_{21}}$ are matrixes for common modules, because the common modules should be included in both products. $\mathbf{M_{12}}$ and $\mathbf{M_{22}}$ can be a matrix for unique or variant modules in a product family.

7.3.2 Company's Profit Model and Platform Strategy Cost

We use sales profits to evaluate company's profit. We assume that the price of a product is determined by the company based on product quality. The product quality can be represented as functions desired by customers. Then, the profit of product i, π_i, can be formulated based on sales price, product cost, and demand as follows:

$$\pi_i = (S_i - C_i)D_i \tag{7.4}$$

where S_i is the sales price of product i, C_i is the product cost of product i, and D_i is the sales quantity of product i. In product family design, product cost depends on platform strategies and design quality. Generally, product cost can be determined by total expected product volume, material cost, direct labor, production resource usage, tooling and capitalization costs, system cost (overhead or indirect costs), and development costs (Magrab 1997). Based on the proposed product architecture as mentioned in Sect. 7.3.1, product cost for product i is represented by

$$C_i = \boldsymbol{M_i L_i^{'} X_i^{'}} \tag{7.5}$$

where $\boldsymbol{M}_i$ is a module instance matrix for product i, $\boldsymbol{L}_i$ is a vector of module costs for product i, and $\boldsymbol{X}_i$ is module design variables in product i. The module instance matrix is generated by a feasible set of products and includes a platform strategy to satisfy product requirements in a product family. In product family level, product cost using a platform strategy, s_y, can be represented as

$$C(s_y) = \boldsymbol{M}(s_y)\boldsymbol{LX} \tag{7.6}$$

where $\boldsymbol{M}(s_y)$ is a module instance matrix when s_y is used for product family design. The different platform strategies are constructed by combining the different modules into common and variant modules.

To develop platform strategies based on common modules, we introduce an expected strategy cost that represents additional costs for developing a new platform for a product family. Such costs could come from redesigning components, creating convenient interfaces, or having some components essentially overdesigned for the most of the product family such that it works sufficiently for one specific product. Let A be a set of strategies for increasing the platform level, and let $c_p(s_y)$ be the expected platform strategy cost for strategy $s_y(y = 1, 2, \ldots, A)$. Then, the expected platform strategy cost can be calculated as follows (Moon et al. 2008):

$$c_p(s_y) = \eta \times \frac{\sum_{i \in I} C_i^a}{f(I) \times r} \tag{7.7}$$

where C_i^a is the additional design cost of product i associated with the new platform, η is a factor for overhead cost, and $f(I)$ is a strategy weight function as follows:

$$f(I) = \begin{cases} 1, & \text{if a module is unique} \\ I, & \text{otherwise} \end{cases} \tag{7.8}$$

and r is a volume penalty factor related to product sales quantity. Hence, the expected total product family cost, EC, for the product family using platform strategy, s_y, can be calculated by

$$EC(s_y) = \sum_{i \in I} C_i + c_p(s_y) \tag{7.9}$$

where C_i is the product cost of product i. For a given set of products, the value of $c_p(s_y)$ varies depending on the strategy for platform design. The expected platform strategy cost function will be used to determine a platform for a product family and can be developed by various cost functions based on products' characteristics and/or company's strategy in product family development. The next section introduces a financial model for evaluating platform design valuation using real options.

7.3.3 A Financial Model

We propose a financial model to evaluate the valuation of product family design using real options analysis in an uncertain market environment. A company tries to maximize profit by identifying module valuation when new platform design for a product family will be introduced into markets. In the proposed financial model, demand can be represented as the source of uncertainty and volatility in a market. We assume that the demand follows a Geometric Wiener Process and has drift, μ, for the demand changing (Kamrad and Ritchken 1991). The drift is defined as

$$\mu = r - \frac{\sigma^2}{2} \tag{7.10}$$

where r is the riskless rate and σ is the instantaneous volatility. Let u be the rate of moving up, d be the rate of moving down, and $ud = 1$. The demand can move up, move down, or state constant at time t. The probabilities of movements for the demand at time t can be obtained as follows (Kamrad and Ritchken 1991):

$$p_1 = \frac{1}{2\lambda^2} + \frac{\mu\sqrt{\Delta t}}{2\lambda\sigma} \tag{7.11}$$

$$p_2 = 1 - \frac{1}{\lambda^2} \tag{7.12}$$

$$p_3 = \frac{1}{2\lambda^2} - \frac{\mu\sqrt{\Delta t}}{2\lambda\sigma} \tag{7.13}$$

where Δt is the length of each time interval and $\lambda \geq 1$. If $\lambda = 1$, $p_2 = 0$, and the movements of the demand become a binominal model (Cox et al. 1979).

We consider a profit model for a single product. We assume that the demand, D_t, during time interval, t, is a variable in company's profit function. Let S be the sales price and C be the production cost. We assume that the sales price and the production cost are determined by the company. The production cost is represented as row materials, labors, logistics, assemblies, financial issues, and regulation. Profit, V_{sp}, for a product in time interval t can be defined as

$$V_{sp}(t) = (S - C)D(t) \tag{7.14}$$

Otherwise, we consider a platform that is applied to a product. Let d_i be the rate of changing demand related to design quality for the product and v be the rate of variable production cost savings if the platform is applied to a product family. The demand of the product is affected by design quality related to customers' preferences. Let A_p be the additional cost of introducing a platform per time interval. The additional cost is represented as the research and implementation costs of the new design. The profit per time interval t for the family product can be calculated as

$$V_{fp}(t) = S(1 + d_i)D(t) - (1 - v)(1 + d_i)CD(t) - A_p \tag{7.15}$$

Then, the net benefit from the platform design, N_t, for introducing a platform during time interval t can be represented as the maximum of the difference between 0 and two profit Eqs. (7.13) and (7.14):

$$N_t = \max(0, d_iSD_t + (v - d_i + vd_i)CD_t - A_p) \tag{7.16}$$

Interpreting Eq. (7.15), positive values of the net benefit represent an advantage of the family design over single product design. If the net benefit is zero, the company selects a single product to maximize the profit. The net benefit is affected by the volatility rate, the changing demand rate, the saving cost of family design, and the additional cost. To evaluate the valuation of platform design with respect to customers' preferences and family design, sensitive analysis will be performed. In this research, we use a lattice approach to solve the problem (Brach 2003). When $\lambda = 1$, the valuation of a platform can be calculated by the value of call option based on the net benefit as follows:

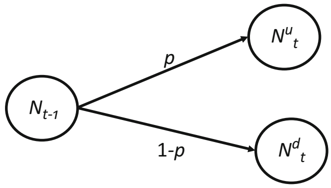

Fig. 7.1 Call option valuation in the binomial tree

$$F(t, N_t) = \frac{pN_t^u + (1-p)N_t^d}{(1+r_f^t)^{\Delta t}} \tag{7.17}$$

Where p is a risk natural probability and r_f^t is a risk-free interest rate at time t, N_t^u is the net benefit of achieving the best case scenario with probability p at time t, and N_t^d is the net benefit of achieving the worst case scenario with probability $(1 - p)$ at time t. Figure 7.1 shows the binomial tree for assessing the call option.

7.3.4 Design Quality

In product design, customers' preference may vary based on specific functional requirements. Functional preference information can help develop market segmentation for a product family by identifying an initial platform based on core common functions. The division of a market into homogenous groups of consumers' preference is known as market segmentation (Meyer and Lehnerd 1997). Because a market segment provides guidelines for determining and directing customer requirements, it can be used to identify the criteria for designing a product family more accurately (Longstaff and Schwartz 2001). The basic development strategy within any product family is to leverage the product platform across products that target multiple market segments. In the initial phase, customers are classified into groups based on their characteristics and preferences. Products are also clustered as groups based on potential suitability for the customers. To evaluate and measure performance of a product, we propose a quality metric that is positively related to product quality, customer preference, and price. In this chapter, we introduce two quality levels to determine the performance of a product (1) marginal quality and (2) full quality. The marginal quality is defined as the level of quality that satisfies minimum functional requirements for customers to perform a job through a product. Customers have zero preference if the service quality of the product is below the marginal quality. The full quality is represented as the level of quality that satisfies maximum functional requirements for customers to pay the price for purchasing a product. The marginal and full qualities are determined by functions depending on customers' preferences in market segments. Figure 7.2 shows two design quality functions of a product for different customers' groups. In between marginal and full qualities, customers have various preferences related to product's quality.

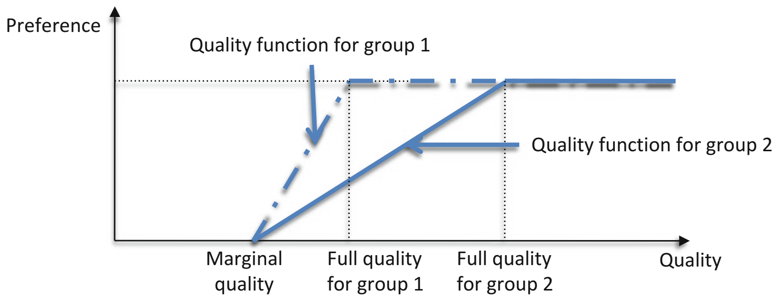

Fig. 7.2 Relationship between preference and quality for a product

We assume that the quality of a product is represented by customers' preference. To determine the value of customers' reference related to the product quality, Q_p, we assume that customers in the market are categorized into two homogenous customers, normal and specific groups. The value of the preference, $U(Q_p)$, can be represented by a utility function as follows:

$$U(Q_p) = \begin{cases} 0, & \textit{if } Q_p \le Q_M \\ \frac{f_{n,q}(Q_p)+f_{s,q}(Q_s)}{2}, & \textit{if } Q_M < Q_p \le Q_F^N \\ \frac{1+f_{s,q}(Q_p)}{2}, & \textit{if } Q_F^N < Q_p \le Q_F^S \\ 1, & \textit{if } Q_F^S < Q_p \end{cases} \tag{7.18}$$

where Q_M is the marginal quality of a product, Q_F^N is the full quality of a product for a normal customer group, Q_F^S is the full quality of a product for a specific customer group, $f_{n,q}$ is a normal quality function, and $f_{s,q}$ is a specific quality function. The specific quality represents the interaction of product functions: it is a measure that indicates what requirements are needed to make product functions for the specific customer group. In this chapter, the design quality allows us to explore how a particular product platform can best be used to develop a family that provides high qualities to customer groups through the estimation of demand.

In general, market demands can be affected by the quality and price of a product (Krishnan and Zhu 2006). To determine the expected demands for introducing new design at a specific time, we can use the expected preference value and demographics (potential customers) in market segmentation grids that are covered by a product (Moon and McAdams 2009). Based on the expected demand, we can estimate the expected increasing demand rate of a specific product for applying to the proposed financial model. In the next section, the proposed financial model is applied to determine the valuation of a platform strategy using a case study involving a family of mobile products.

7.4 Case Study

To demonstrate and validate the proposed model, a family of mobile products consisting of N73, N76, N78-1, and N79-1 is investigated from the Nokia N70 phone family as shown in Fig. 7.3. The Nokia N70 series family products provide a good example of common and variant functions for vision accessibilities as shown in Table 7.1. These products offer the opportunity to create a product family with the vision features as common functions that constitute the product platform. Since the accessible features of the mobile product family are considered as functions for modules or components, the products can be applied to case studies related to universal product family design (Moon and McAdams 2009).

The objective in this case study is to determine the valuation of a new platform strategy in uncertain market environments. The platform design strategy is represented by accessible modules to support persons with vision limitations due to ageing and disabilities. This case study focuses on introducing a new product platform through the addition of accessible modules. Benefit of the proposed product platform is based on the maximum valuation of the proposed additional modules. We also perform sensitivity analysis for the valuation of the platform design strategy with respect to different parameters that reflect the proposed financial model.

Fig. 7.3 Nokia N70 series products (Nokia 2008)

Table 7.1 Vision accessible features for four products (http://www.nokiaaccessibility.com)

Vision features		N73	N76	N78-1	N79-1
F1	Tactile key markers	Yes	No	Yes	Yes
F2	Standard key layouts	Yes	Yes	Yes	Yes
F3	Key feedback—tactile	Yes	Yes	Yes	Yes
F4	Key feedback—audible	Yes	Yes	Yes	Yes
F5	Audible identification of keys—when pressed	No	No	No	No
F6	Audible identification of keys—feedback	Yes	Yes	Yes	Yes
F7	Adjustable font style	No	Yes	Yes	No
F8	Adjustable character size	No	Yes	Yes	Yes
F9	Display characteristics (color display)	Yes	Yes	Yes	Yes

Fig. 7.4 Market segmentation grids for the four products

7.4.1 Market Analysis and Platform Strategy

Figure 7.4 shows current market segmentation grids for the mobile products with respect to vision features and market prices. The products have different vision accessibility features and market prices depending on market segments. For example, N73 covers no vision impairment and low price market. In Table 7.2, we can consider F2, F3, F4, F6, and F9 as common modules for the phone family. And, F1, F7, and F8 are considered as variant modules.

In this chapter, the company wants to maximize profits by introducing a new platform as accessible modules for the family of mobile products. We facilitate function configuration for developing platform design strategies by identifying relationships between functions and market segments at a conceptual design phase. Using Feature and Component Matrix, we can determine the relationship between vision features and components as shown in Table 7.2. We consider that a cell phone consists of 11 components (Holtta-Otto and De Weck 2007). Among the components, we assume that a main board includes a program for supporting all features.

To develop a new platform consisting of common modules and variant modules, we need to determine valuation of the variant modules (F1, F7, and F8). The valuation of modules can help decide which modules are included to a new platform for increasing benefits and accessible features in product family design. Table 7.3 shows configuration strategies that consist of the variant modules for the phone product family. To determine the expected strategy cost as mentioned in Sect. 7.3.2, we considered the number of components that are related to vision features and use a unit additional cost, C^a, for each component. For example, since the tactile key marker is related to two components, upper case and keypad, the additional cost of the tactile key marker is 2 C^a. We assume that a factor of overhead cost and a

Table 7.2 Feature and component matrix for the products

Vision features	Power converter	Power cable	Upper case	Lower case	Speaker	Display unit	Keypad	Microphone	Antenna	Main board	Battery	Component #
F1			×				×					2
F2			×				×			×		3
F3			×				×			×		3
F4			×		×		×			×		4
F5			×		×		×			×		4
F6			×		×		×			×		4
F7			×			×	×			×		4
F8			×			×	×			×		4
F9			×			×	×			×		4

Table 7.3 The expected additional strategy cost for the platform strategies

	Additional component design cost					
Strategy	N73	N76	N78-1	N79-1	Total	Expected additional strategy cost
S1-F1F7	4C[a]	2C[a]	–	4C[a]	10C[a]	5C[a]
S2-F1F8	4C[a]	2C[a]	–	–	6C[a]	3C[a]
S3-F7F8	8C[a]	–	–	4C[a]	12C[a]	6C[a]
S4-F1F7F8	8C[a]	2C[a]	–	4C[a]	14C[a]	7C[a]

Table 7.4 Comparison to current market segments and the expected market segments

Platform strategy	N73	N76	N78-1	N79-1
Current	No	Mild	Moderate	Mild
S1	No, mild	Mild	Moderate	Mild, moderate
S2	No, mild	Mild	Moderate	Mild
S3	No, mild, moderate	Mild	Moderate	Mild, moderate
S4	No, mild, moderate	Mild, moderate	Moderate	Mild, moderate

volume penalty factor are 2 and 1, respectively. The expected strategy cost for the product family can be calculated by Eq. (7.7). Table 7.3 shows the results of the expected strategy cost for the platform strategies.

In the vision impairment point of view, Table 7.4 shows a comparison of current market segments and the expected market segments for new platform design strategies. For example, if N73 includes additional features, F1 and F7, as a platform strategy (S1), its expected market segments will cover no and mild segments for the vision impairment.

7.4.2 Identify Design Quality

Based on the platform design strategies, the expected design qualities for the products can be calculated by the value of preference as mentioned in Sect. 7.3.3. We assume that the design quality of a product is depended on the number of vision features in the product. We consider customers with vision impairment as the specific group. Figure 7.5 shows the functions of design quality for two customer groups. The marginal quality was determined by the number of common vision features. The full quality of the normal group was determined by the design quality of N73, while the full quality of the specific group was the maximum number of vision features.

Table 7.5 shows the expected design qualities of the products with respect to vision features. The expected preference values of the products for the platform strategies are calculated by Eq. (7.18). For example, the expected design quality

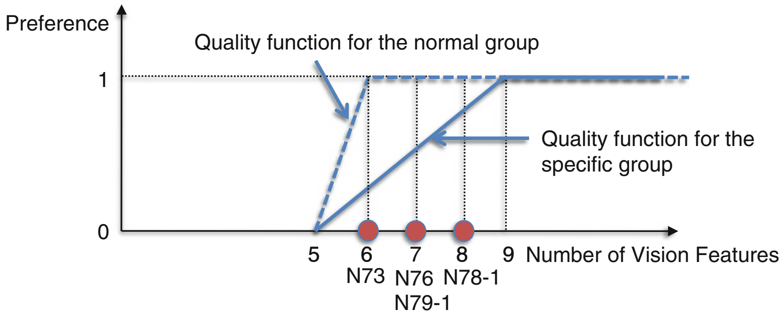

Fig. 7.5 Preference and design quality for the products

Table 7.5 The expected design qualities of the products

Strategy	N73	N76	N78-1	N79-1
Current	0.625	0.75	0.875	0.75
S1	0.75	0.875	0.875	0.875
S2	0.75	0.875	0.875	0.75
S3	0.875	0.75	0.875	0.875
S4	0.875	0.875	0.875	0.875

of N73 in S1 is 0.75, because the number of vision features for N73 is 7 (F1, F2, F3, F4, F6, F7, and F9) and the expected preference value of 7 vision features is 0.75 (0.5 for the specific group and 1 for the normal group). Therefore, we can expect that demand for the mobile products with accessible features will be depended on the number of persons with vision limitations due to age and disabilities.

7.4.3 Numerical Analysis

To evaluate the valuation of the vision features, S4 was selected for applying to numerical analysis based on the proposed financial model. We assume that the expected demands for the products are determined by the result of market analysis and the amount of total demands for the cell phone products is 400,000. We assume that the total time horizon for the problem is 10 years and the time interval is 1 year. According to the market analysis in Sects. 7.4.1 and 7.4.2, we assume that the expected demand of the mobile product with accessible features is increased. Suppose that the problem parameters at the current time ($t = 0$) in the case study are as follows:

S	=\$400 (average sales price for mobile products)
C	=\$320 (average production cost for mobile products)
D_0	=400,000 (demand at $t = 0$)
A_p	=\$7 per a product (additional cost when C^a is \$1)
r	=5 % (riskless rate)
σ	=10 % (volatility)
u	=1.0226 (the rate of move up)
d	=0.9729 (the rate of move down)
d_i	=3 % (the rate of the expected increasing demand rate)
v	=2 % (the rate of cost saving for product family)
r_f^t	=5 % (the rate of a risk-free interest at time t)

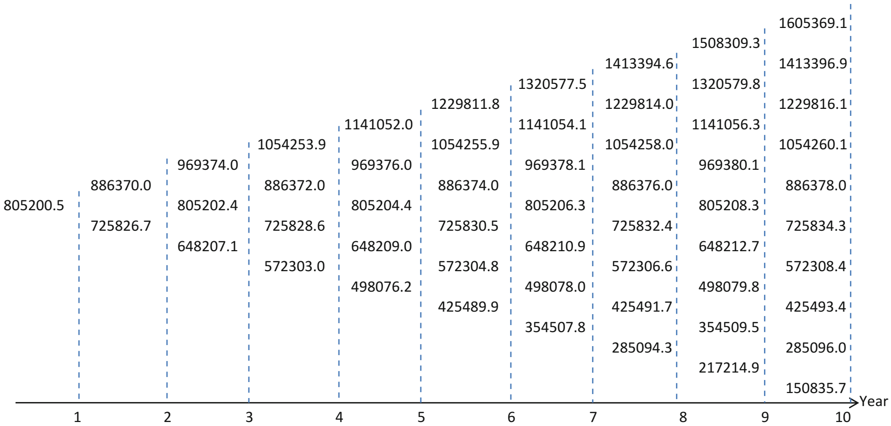

Fig. 7.6 Option value for additional accessible modules in the binomial lattice

We assume that $\lambda = 1$. Then, the probabilities of movements for the demand can be calculated by Eqs. (7.10) and (7.12). Therefore, $p_1 = 0.5712$ (move up) and $p_3 = 0.4288$ (move down). Using a lattice approach, the valuation of real option for vision accessible modules is estimated to be \$805200.5. This value is represented as the expected worth of introducing additional accessible modules as a platform for the family of the mobile phones for 10 years. A binomial lattice with 10 time steps and 66 nodes is generated to estimate the valuation of the module as shown in Fig. 7.6. Since the valuation of F1, F7, and F8 are depended on the redesign cost, C^a, additional vision features for a new platform can be selected by design constraints related to development cost for the features.

We performed sensitivity analysis to investigate the behavior of the estimated option value against chaining system parameters such as the rate of cost saving for product family, the volatility of demand, and the rate of the expected increasing demand. Figure 7.7 shows the effect of the rate of cost saving for product family on

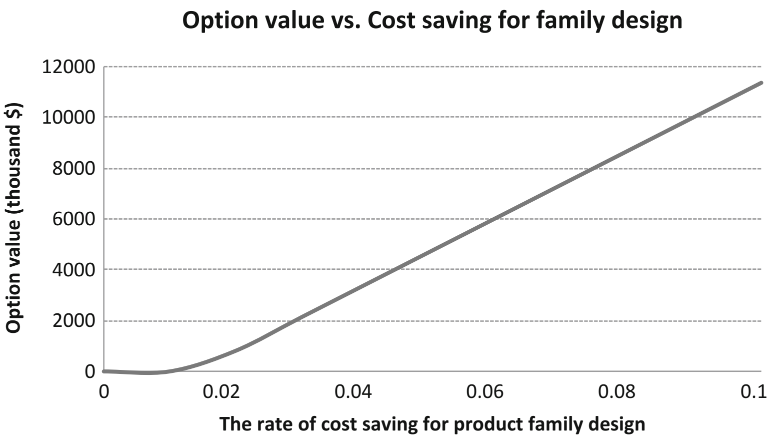

Fig. 7.7 The estimated option value versus the rate of cost saving for family design

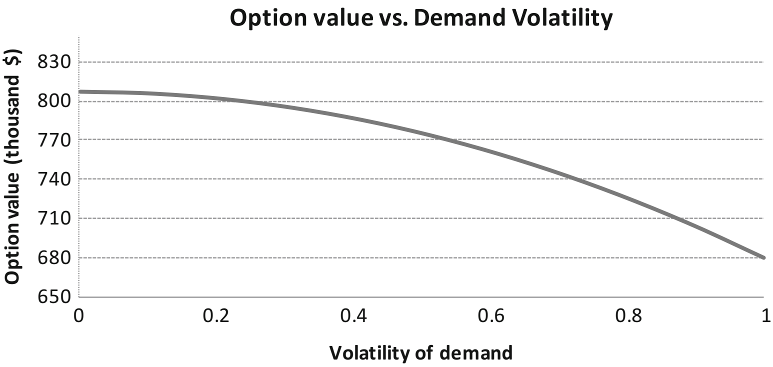

Fig. 7.8 The estimated option value versus volatility of demand

the estimated option value. While the rate of the cost saving increases, the option value increases linearly. Figure 7.8 shows the estimated option value against the volatility of demand. The estimated option value is dropped with an increasing rate while the volatility increases. Figure 7.9 presents the estimated option value versus the rate of the increasing demand that occurs with customers' preferences and demographic trend. Design quality gives positive effects on the option value.

Through the case study, we demonstrate that the proposed valuation model for a module could be used to determine a design strategy for maximizing profits by valuing the module in the family of products. The proposed model can provide a quantitative method to facilitate family design in an uncertain market environment.

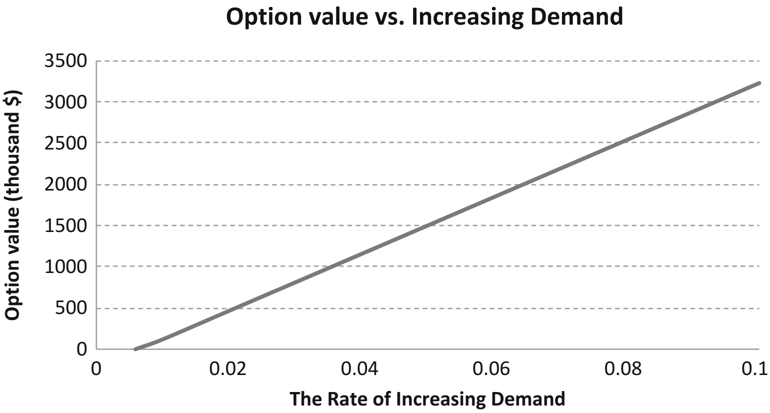

Fig. 7.9 The estimated option value versus the rate of increasing demand

7.5 Closing Remarks and Future Work

In this research, we presented a valuation financial model to evaluate design value based on real options analysis in an uncertain market environment. Real options analysis was applied to evaluate the expected worth of introducing new modules as a platform in a product family. Modular product architecture was used to allow a range of trade-offs in determining the specific configuration for a platform at a conceptual design phase. To evaluate and measure design quality of a product, we proposed a preference function using customers' preferences and performance utilities for products.

The proposed financial model can facilitate design strategies that will maximize the expected profit under uncertain constrains, such as demands, demographic trends, and regulations. In a case study, we have applied the proposed model to determine the valuation of accessible modules for a platform in a family of mobile products in an uncertain market environment. We also performed sensitivity analysis to investigate the behavior of the estimated option value against changing system parameters such as the volatility of demand, the rate of the expected increasing demand, and the rate of cost saving for product family.

Since the proposed financial model is focused on modular product families, module configuration issues will be considered as real options analysis for introducing interfaces between modules in product family design. To improve the proposed model, we need to develop a method to better reflect the benefit of family design, social issues, and government regulation. Additionally, since the production cost are sensitive to the valuation of options, future research efforts will be focused on improving production cost models in an uncertain market environment. Also, the proposed method will be compared to other decision-making methods for determining a design strategy in a product family.

References

Bollen NPB (1999) Real options and product life cycles. Manag Sci 45(5):670–684

Brach MA (2003) Real options in practice. Wiley, Hoboken, NJ

Cox J, Ross S, Rubinstein M (1979) Option pricing: a simplified approach. J Financ Econ 3 (2):229–263

Cronin MJ (2010) Smart products, smarter services: strategies for embedded control. Cambridge University Press, New York, NY

Fernandez MG, Panchal JH, Allen JK, Mistree F (2005) Concise interactions and effective management of shared design spaces – moving beyond strategic collaboration towards co-design. In: Proceedings of ASME international design engineering technical conference & computers and information in engineering conference, 24–25 Sept, Long Beach, CA, Paper No. DETC2005-85381

Ford DN, Sobek DKI (2005) Adapting real options to new product development by modeling the second toyota paradox. IEEE Trans Eng Manag 52(3):175–185

Gamba A, Fusari N (2009) Valuing modularity as a real option. Manag Sci 55(11):1877–1896

Holtta-Otto K, De Weck O (2007) Degree of modularity in engineering systems and products with technical and business constraints. Concurr Eng Res Appl 15(2):113–126

Jiao J (2012) Product platform flexibility planning by hybrid real options analysis. IIE Trans 44 (6):431–445

Jiao J, Lim CM, Kumar A (2006) Real options identification and valuation for the financial analysis of product family design. Proc Inst Mech Eng B: J Eng Manuf 220(6):929–939

Johannesson H, Claesson A (2005) Systematic product platform design: a combined function-means and parametric modeling approach. J Eng Des 16(1):25–43

Johnson MD, Kirchain RE (2011) The importance of product development cycle time and cost in the development of product families. J Eng Des 22(2):87–112

Kamrad B, Ritchken P (1991) Multinomial approximating models for options with K state variables. Manag Sci 37(12):1640–1652

Kopin V, Wilbur D (2005) Bayesian serial cost sharing. Math Soc Sci 49(2):201–220

Krishnan V, Zhu W (2006) Designing a family of development-intensive products. Manag Sci 52 (6):813–825

Kumar D, Chen W, Simpson TW (2009) A market-driven approach to product family design. Int J Prod Res 47(1):71–104

Longstaff F, Schwartz E (2001) Valuing american options by simulation: simple least-squares approach. Rev Financ Stud 14(1):113–147

Magrab EB (1997) Integrated product and process design and development: the product realization process. CRC, Boca Raton, NY

Meyer MH, Lehnerd AP (1997) The power of product platforms: building value and cost leadership. The Free Press, New York, NY

Moon SK, Mcadams DA (2009) A design method for developing a universal product family in a dynamic market environment. In: Proceedings of the design engineering technical conferences and computers and information in engineering conference, Aug 30–Sept 2, San Diego, CA. ASME, Paper No.: DETC2009-86784

Moon SK, Park J, Simpson TW, Kumara SRT (2008) A dynamic multi-agent system based on a negotiation mechanism for product family design. IEEE Trans Autom Sci Eng 5(2):234–244

Moon SK, Shu J, Simpson TW, Kumara SRT (2011) A module-based service model for mass customization: service family design. IIE Trans 43(3):153–163

Nokia (2008) http://www.nokiausa.com

Ramesh B, Tiwana A, Mohan K (2002) Supporting information product and service families with traceability. Lect Notes Comput Sci 2290:353–363

Rojas Arciniegas AJ, Kim HM (2012) Incorporating security considerations into optimal product architecture and component sharing decision in product family design. Eng Optim 44(1):55–74

Shiau CN, Michalek JJ (2009) Optimal product design under price competition. J Mech Des 131 (7):071003:1–071003:10

Shooter SB, Simpson TW, Kumara SRT, Stone RB, Terpenny JP (2005) Toward an information management infrastructure for product family planning and platform customization. Int J Mass Custom 1(1):134–155

Simpson TW (2004) Product platform design and customization: status and promise. Artif Intell Eng Des Anal Manuf 18(1):3–20

Simpson TW, Maier JRA, Mistree F (2001) Product platform design: method and application. Res Eng Des 13(1):2–22

Simpson TW, Siddique Z, Jiao J (2005) Product platform and product family design: methods and applications. Springer, New York, NY

Smit HTJ, Trigeorgis L (2004) Strategic investment: real options and games. Princeton University Press, Princeton, NJ

Thevenot HJ, Alizon F, Simpson TW, Shooter SB (2007) An index-based method to manage the tradeoff between diversity and commonality during product family design. Concurr Eng: Res Appl 15(2):127–139

Xiao A, Zeng S, Allen JK, Rosen DW, Mistree F (2002) Collaborating multidisciplinary decision making using game theory and design capability indices. In: Proceedings of the 9th AIAA/ISSMO symposium on multidisciplinary analysis and optimization, 4–6 Sept, Atlanta, GA

Zacharias NA, Yassine AA (2008) Optimal platform investment for product family design. J Intell Manuf 19(2):131–148