THE OPTIONS VIEW OF PRODUCTS: FLEXIBILITY, MODULARITY, AND SYSTEMIC EFFECTS

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Abstract

This paper aims to lay a theoretical foundation on how individuals value durable products. In this paper we emphasize *ownership* and analyze why customers want to own products and the value they give to ownership. Specifically, we argue that the ownership of a product represents a bundle of options. At any given point in time, the owner of a product has the option to choose whether she wants to use the product or not. In addition, this paper extends the current literature on product value by taking explicitly into account several important characteristics of modern products, namely modularity, and systemic as well as network effects. This approach has the significant benefit that it allows consideration of uncertainty about the future use of the product. The model shows that the value of a product is sensitive to the changes in uncertainty, especially when the variable costs are high compared to the utility. This uncertainty about future utility depends on the uncertainty about future needs and wants, about the quality of the product, and about the availability and quality of future upgrades. However, the value is also dependent on the uncertainty about the future variable costs.

1 Introduction

This paper aims to lay a theoretical foundation on how individuals value durable products. Traditionally, the theory of customer behavior has been concerned with how customers use products and services (Kotler, 1988, Schiffman & Kanuk, 1987). Thus, the emphasis has been on the *use* of the product. It has searched for reasons why customers use products in general and how they choose which products to use. In this paper we shift the emphasis to *ownership* and analyze why customers want to own products and the value they give to ownership. Specifically, we argue that the ownership of a product represents a bundle of options. At any given point in time, the owner of a product has the option to choose whether she wants to use the product or not. In this paper, we will present a framework to analyze the value of ownership and the factors that affect it. The theory of option pricing is originally developed by Black and Scholes (1973) and Merton (1973). Option valuation has later been applied in addition to model the value of investments in real assets (e.g., Dixit & Pindyck, 1994, Trigeorgis, 1996).

In addition, this paper extends the current literature on product value by taking explicitly into account several important characteristics of modern products, namely modularity, and systemic as well as network effects. For our purposes, we restrict the word product to encompass only durable products for which ownership makes sense.

The paper is organized as follows. Section 2 discusses an individual's motivational base for using a product and the satisfaction given by the usage.

Section 3 discusses how the structure of complex products affects their value. Section 4 focuses on the effects of uncertainty about the product and its characteristics on the value of the product. Section 5 develops a mathematical model based on the analysis in preceding chapters to quantify the value of product, and Section 6 concludes.

2 Needs, Wants, and Satisfaction given by a Product

In this section, we discuss the basic concepts of customer behavior. Based on these concepts, we develop a framework for perceived customer value in the following sections. We start by discussing needs, wants, and motivation, and products as satisfiers of these.

A useful distinction can be drawn between needs, wants, and demands. A human *need* is a state of deprivation of some basic satisfaction. Needs are not created by the society or marketers; they exist in the very texture of human biology and the human condition. There exist several different views on these subjects, but in this paper we will only concentrate on the ones presented by Kotler (1988) and Schiffman and Kanuk (1987).

Wants are desires for specific satisfiers of these deeper needs. Human wants are continually shaped and reshaped by social forces and institutions such as churches, schools, families, and business corporations.

Motivation can be described as the driving force within individuals that impels them to action. This driving force is produced by a state of tension, which exists as the result of an unfulfilled need or want. Individuals strive, both consciously and subconsciously, to reduce this tension through behavior that they anticipate will fulfill their needs or wants, and thus relieve them of the stress they feel.

Goals are the sought-after results of motivated behavior. For instance, a person may have a need for something and might have identified specific ways to fulfill this need. These ways are the wants of the person. The person is then motivated to act towards the goal of obtaining a specific product among the ones she has identified, i.e. one of her wants, to fulfill the need in question.

There are several essential aspects of needs and goals that are should be noted (Schiffman & Kanuk, 1987):

- **Needs are never fully satisfied.** For example, a person needs food and companionship repeatedly.
- **Needs, wants, and goals vary over time.** New needs emerge as old needs are satisfied. It is commonly assumed that needs exist in a hierarchy: new, higher order needs appear as older, lower order needs are satisfied. In addition, success and failure influence goals. Individuals who successfully achieve their goals usually set new and higher goals for themselves; i.e. they raise their levels of aspiration. On the other hand, failure may drive people to strive for lower goals; i.e. they substitute new, lower goals for the unachieved older goals. Wants are also affected by changes in the environment: culture and fashion change, people move from one environment to another, etc.
- **Multiplicity of needs.** People usually strive to fulfill several needs at the same time. Even a single product may fulfill several needs. Usually, however, one

need is stronger than others and drives the person's behavior towards fulfilling that specific need.

- **Needs and goals vary among individuals.** People with different needs may seek fulfillment through selection of the same goals, and people with the same needs may seek fulfillment through different goals.

A fundamental viewpoint in our analysis is that people use products to satisfy their wants, and thus to help them reach their goals. We assume that there exists a measure, called utility, of how much the use of a product would help an individual to reach her goals. The emphasis here is on the word 'would' since we take utility as an *ex ante* measure. The utility thus not only depends on satisfying a need, but also on her specific wants which are shaped by the environment. Some ways of satisfying needs may be socially preferably to others.

We will measure utility in monetary terms in order to be able to compare satisfaction over time and across different products. Hence, if the use of a product would give X 'utils', the user would be indifferent between accepting X dollars and using the product.

We analyze products at the level of 'functions', that is the different ways a given product can be used. Each function helps the user in a different way to reach her goals and satisfy her wants, but also a given function could help the user to get closer to multiple goals. The choice of using a product is determined by the user's assessment of the product's capability to satisfy the current wants and help her towards her goals. Since her needs and goals change over time, the assessed benefit of products changes also. Thus, different products and functions are used at different times depending on what wants and goals are strongest, and hence also the usage of a given product or function varies over time.

One point about the definition of functions should be noted: the reference to the user choosing to use the functions. For instance, a standard fax machine has two functions, but, according to our definition, they are not sending and receiving, but sending and *being ready to receive*. The user cannot choose, in general, at any given point to receive a fax but she can choose to have the fax machine ready to receive in case someone else wants to send her a fax.

We define the *value* of a product as an individual's assessment of the product's capability to satisfy her wants and help her towards her goals, not only now but also in the future, over the lifetime of the product. It thus fundamentally depends on her knowledge, beliefs, and expectations of the product and its functions, but also on her beliefs about her future wants and goals. Hence, by the nature of the definition, each individual has her own assessment of the value of a given product.

These definitions are broad enough to encompass many different kinds of attributes people normally associate with the value of a product. For instance, the value of a car not only depends on an individual's assessment of the benefits of driving (one function) but also on her estimate of its ability to boost her ego (another function). The latter function might be continuously in use and its utility would heavily depend on the society's values and fashions. Alternatively, a painting with only aesthetic value is used to satisfy a want for beauty when it is put on a wall.

In addition to benefits, there is always also a *cost* in using a given function. In some cases, this could be a direct cost like having to pay for the usage or the inconvenience of the usage. But it can also be indirect. Every time an individual uses a function, she has to pay a variable cost, which depends heavily on the characteristics of the function in question. Some functions can be used concurrently with others implying a low cost, whereas some might require the full attention of the user implying very high cost. For instance, the fax machine referred to earlier has a very low cost unless the owner wants to use the same telephone line for other purposes and thus turn off the answering mode in the fax machine.

Our reference to measurable utility *levels* might not seem justifiable, since utility in reality is always a comparison between alternatives, a relational attribute. At a given point in time, one could prefer watching TV to reading a newspaper and even state an assessment of the difference, but would find it very hard to state the absolute utility level from watching TV. But this is actually the essence of our construction, since the decision to use a product at a given point in time depends not on the absolute level of utility but on the difference between using that product and alternative ways to spend the costs associated with using that product, i.e. direct monetary costs, time, etc.

It should be further noted that our model does not assume full rationality, in the standard economic sense, on behalf of the owners. While it seems that we assume owners will make tedious calculations about future wants and opportunities to use a product, it might happen that the owners discount future utility in a way to make it practically meaningless, and focus only on current wants in an impulsive manner. Also, the wants that they use in the calculation and the expectations about future wants are not assumed to be correct on the average.

3 Modularity, Systemic Effects, and Network Externalities

Most functions portray some kind of interaction with other functions or depend on other people using the same function. This applies especially to complex products like computers but also to simple ones like nuts and bolts. The function of a bolt is to fasten something but that function has practically no value without a nut. A computer's value depends heavily on the availability of programs but also on other people using the same programs and thus enabling data transfer. We divide these effects on value into systemic and network effects. The first refers to the case when two or more different functions available to the same user interact with each other and where the value of one depends on the others. The latter refers to the case when a function's value depends on other people using the same or a compatible function. These notions are not completely independent and we will later discuss their interdependence.

3.1 Systemic Effects and Modularity

Modular products are composed of parts, modules, that have clearly defined boundaries and interfaces with the other modules in the system. Modular structure gives many advantages over a rigid structure in design and manufacturing (Baldwin & Clark, 1992), but we will focus on the effects of modularity on the use of a product, i.e., on modularity in use.

The main value added of a modular system for the owner is due to upgradability. Modules can be interchanged with new modules with better performance or lower costs, or completely new modules can be added to the system. The owner may purchase a simple product at first and later upgrade it. A prime example is the PC, which consists of several modules, memory, storage, display, etc. The owner can later decide to upgrade the hard disk to bigger and faster, increase memory capacity, add a CD-ROM, a modem, a printer, or other peripherals. Part of the value of a PC comes from the option to upgrade the system.

Thus, the value of a modular product is not only depended on the value of the option to use the current configuration when the owner wishes, but also on the option to upgrade the configuration, i.e., a compound option on the use of the upgraded system. The value of this compound option depends on several variables. First, the probability of the availability of the additional modules is important, and the time when they become available. Second, the cost of the upgrades and the added benefits are important. But the total value of the upgrade option is also increased by increasing the number of different options, i.e., by making the modules smaller so that smaller changes are possible. For some configurations, their whole value could be just in the upgrade option. For instance, a computer without software has only value in running software that could be purchased later, an upgrade option.

Modular products could be considered a subset of a larger group of systemic products. We define systemic products to be all whose value depends in some way on other products without necessarily being modules in the same system. This includes, for example, substitute products. The value of owning both WordPerfect and Microsoft Word is less than the sum of the values of owning one of them. This is because one already gives nearly all the functionality that they give together. Systemic products also include products whose value depends on some underlying infrastructure, as the value of cars depends on the availability of gasoline (Katz & Shapiro, 1994).

3.2 Network Effects

Network effects arise when the value of a product depends on how many other people are using that same function or a compatible one, almost always the more the better. A good example is a fax machine. If no one else has one, a fax machine has little if any value, and its value goes up with the number of other people owning one. This is also the case when the functions are required to be compatible but not the same. As we defined earlier, a fax machine has two functions: sending and being ready to receive. The value of the send-function depends on how many others are at that point using the ready to receive function. We call these effects *positive* network effects, since network effects can also be negative. For instance, many products related to status, like jewelry, depend negatively on the number of other people using the same product. When we talk about network effects, we mean positive network unless otherwise specified.

Positive network effects mean that there exist increasing returns to scale. The more a company is able to sell its products, the more value these products have for the customers, and thus the more they might be willing to pay (e.g., Kelly, 1997). This is troubling to neoclassical economics since it does not yield the kind of nice equilibria that is expected in the theory of general equilibrium (e.g., Arthur, 1989, 1994). It also is not compatible with the neoclassical idea that value comes from scarcity, which is closer to negative network effects (Arthur, 1989, 1994).

Network effects can arise in many different ways. The opportunity to transfer data, as discussed above with fax machines, is clearly one, and is very important in the current network era. The act of communication will always require some kind of compatibility for the messages to be delivered and understood. The more technical equipment is used for this, the more important network effects will become. The need to communicate thus creates a want to use equipment that is compatible with what others use and thus increases the value of such products and functions.

However, network effects, as we have defined them here, might also arise in ways that are more conventional. The need to be accepted by others, for instance, creates a want to wear similar clothing. The more blue dress shirts become popular in the investment-banking world, the more people will find them acceptable in addition to the standard white dress shirts, and start wearing them. This example also illustrates a fundamental idea: it matters who the others using the same kind of product are. This is also true to a lesser extent for fax machines: it barely matters if people one will never communicate with have fax machines, but it matters a lot if one's business partners and friends have one.

Like we mentioned earlier, network effects and systemic effects are interdependent. The more popular a product is the more one could expect there to be complementary products or new modules available. For instance, the growing popularity of Windows-based computers has clearly affected the number and quality of programs available for them. Similarly, as credit cards became more popular, more stores started accepting them. These induce a clear positive-feedback loop, since as the number of Windows-based computers grows, more software is developed for them thus making the computers more valuable which probably induces new people to buy one.

Network effects are quite easily incorporated into our model by making the level of utility obtainable from the use of a function to depend on the number of other people using the same or a compatible function. This effect is based on the expected number of people with compatible functions *at the time of the use*. So, not only does the current number of users matter but also the expected growth or decline in the number of users. Network effects by themselves seldom affect the costs of using a function.

Incorporating the interdependence between network and systemic effects is more troublesome. Not only do network effects affect the value of individual upgrade options but they also affect the possibility of new upgrade options becoming available in the future. The value of individual upgrade options grows with the number of people expected to be using compatible functions in the future.

4 Uncertainty and Option Value

All of the discussion above hinges critically on the assumption that the owner does not have full information about the future use of the product. In this section, we will consider how uncertainty comes about, how it affects the value, and how prospective owners form their opinions and assumptions about a product.

There are four fundamental sources underlying the uncertainty in the value of a product. First, future needs and wants are not known in advance, except for possible the most basic ones. While she may always need food, shelter, and companionship, the specific ways with which to satisfy them, i.e., her wants, certainly change over time. Second, the capability of the product to satisfy those needs and wants is not known in advance. This is especially true before the prospective owner has been able to try out the product, but in addition, she can never be sure how well the product keeps functioning in the future. Third, the availability and quality of upgrades is uncertain as well as the number of people using the product in the future and thus the network effects. All of the above relate to the utility of using the product. But the variable costs are also uncertain. The price of gasoline could go up, or new and better products could become available to satisfy the same needs and wants.

The sellers of a product can affect the impressions a prospective owner develops for each of the uncertainties listed above. They can develop new needs and wants by innovative marketing, but also signal about the quality of the product in question to satisfy these needs and wants. For instance, mobile phones used to be a status symbol when relatively few people had them. Now, they have become more or less necessary commodities that have little status value but a very high value in actual communication. Also, what in computer technology is called "promiseware", i.e., what companies say will be available in the near future, not only affects the competitive situation but also the value the prospective owners give to the option to upgrade the product. The price charged for the product is also an important signal about the capability of the product to satisfy needs and wants. If the product costs significantly less than the prospective owner values it at, based on a first estimate, she might reconsider her impression of the quality of the product and become suspicious of its value. This could explain several examples in the software industry about products that have actually sold much better when their price is raised.

All the impressions that a prospective owner forms about a product are social constructions. That is, they do not have any scientific basis but are rather formed in continuous social interaction with other people and the sellers of the product in question. Social norms, legitimacy, group identity all affect them. All of these are important topics that warrant further investigation, but they are beyond the scope of this paper.

5 Mathematical Model

5.1 Introduction

In this section, we develop a mathematical model for the value of durable products to take into account the option-like nature of products. In our model of the option value of a product, we need to make some assumptions about the nature of the product and the utility obtainable from the use of the product. This utility is highly dependent on the product in question, i.e. it depends on the functions and attributes of the product, and the characteristics of the owner.

5.2 Assumptions

We consider a market where instruments and real products are traded continuously within a time horizon $[0, T]$. The market consists of a set of agents, M, and the number of elements in M is n_m. The set of real products is denoted by I and the number of elements in I is n_i.

In describing the probabilistic structure of the markets, we will refer to an underlying probability space (Ω, F, P). Here Ω is a set, F is a σ-algebra of subsets of Ω, and P is a probability measure on F. The following assumptions characterize our product markets.

ASSUMPTION 1: *The stochastic variables of the market follow an Itô stochastic differential equation*

(1) $$dx(t) = x(t)\alpha(t)dt + x(t)\mathbf{e}(t)d\mathbf{z}(t),$$

where α*:* $[0, T] \to \mathbf{R}$ *and* $\mathbf{e}:[0,T] \to \mathbf{R}^n$ *are given bounded functions and* $\boldsymbol{z}(t)$ *is an n -dimensional Brownian motion on the probability space* (Ω, F, P)*, along with the standard filtration* $\{F_t: t \in [0, T]\}$.

Assumption 1 implies that there are n independent Brownian motions in the markets.

ASSUMPTION 2: *There is stochastic variable cost in using the products in I for all agents in M.*

We will denote by $K_{m,i}(t) = \int_0^t k_{m,i}(y)dy$ the cumulative variable cost for using product $i \in I$ for customer $m \in M$ at time $t \in [0, T]$.

5.3 Value of the Products

Here, we consider the pricing equations for products. The underlying value of the product at time $t \in [0, T]$ means the minimum certain amount of money that the customer could spend in an alternative way to be able to get the same amount of utility as from using the product. This means that the measure of utility we are talking about is in reality a measure of the actual, 'abstract' utility's certainty equivalent which is the certain amount of money that could be used to generate the same 'abstract' utility level. That is, the amount of utility we measure is the *certain* amount of money the customer could use to get the same utility level as she would get from the use of the product.

We consider here the simplest case, a product with one function and no network or systemic effects.

At each instant in time, the owner has to decide whether she will use the product or not. This is the fundamental option nature of the product. We will denote by $S_{m,i}(t) = \int_0^t s_{m,i}(y)dy$ the cumulative utility process underlying the product *i* at time *t*, i.e. the (monetary) amount of utility the customer could obtain at time *t* by using product *i*. We assume that the process of $s_{m,i}(t)$ is given by Assumption 1. That is

(2) $$s_{m,i}(T) = s_{m,i}(t)\exp\left\{\int_t^T \left[\alpha_{s_{m,i}}(y) - \frac{1}{2}\mathbf{e}_{s_{m,i}}(y)\mathbf{e}_{s_{m,i}}(y)'\right]dy + \int_t^T \mathbf{e}_{s_{m,i}}(y)d\mathbf{z}(y)\right\}$$

and correspondingly with variable costs

(3) $$k_{m,i}(T) = k_{m,i}(t)\exp\left\{\int_t^T \left[\alpha_{k_{m,i}}(y) - \frac{1}{2}\mathbf{e}_{k_{m,i}}(y)\mathbf{e}_{k_{m,i}}(y)'\right]dy + \int_t^T \mathbf{e}_{k_{m,i}}(y)d\mathbf{z}(y)\right\}$$

It should be noted that these are *rates*, i.e., the utility and cost per unit time. Equations (2) and (3) imply that the uncertainty in the utility and variable processes is generated from the *n* Brownian motions. Further, $s_{m,i}$ and $k_{m,i}$ can be correlated, partially correlated, or independent of each other.

Hence, the option to use the product $i \in I$ one time unit at time $t \in [0, T]$ for consumer $m \in M$ is worth $\max[s_{m,i}(t) - k_{m,i}(t), 0]$ at the time of expiration. Similarly, using the product for an infinitesimal time dt has value $\max[s_{m,i}(t) - k_{m,i}(t), 0]dt$. That is, the consumer uses the product during the interval from t to $t + dt$, if the utility from usage outweighs the cost of usage. The value of usage in the future is assumed to follow the expectation of this value, conditional on current information. Now we make the following assumption.

ASSUMPTION 3: *There is a discount rate for the process* $E\{\max[s_{m,i}(T) - k_{m,i}(T), 0] \mid F_t\}$ *for all* $m \in M$, $i \in I$, *and* $t \in [0, T]$.

We will denote the discount rate by $r_{m,i}$ and it reflects the agent's attitude towards risk in the process $E\{\max[s_{m,i}(T) - k_{m,i}(T), 0] \mid F_t\}$. Now we state the following theorem that gives the price of a product.

THEOREM 1: *The time t T -maturity price of the product*

(4) $$C_{m,i}(t,T) = \int_t^T \exp[(t-y)r_{m,i}] E\{\max[s_{m,i}(y) - k_{m,i}(y), 0] \mid F_t\} dy$$

$$\text{for all} \quad m \in M, \quad i \in I, \quad t \in [0,T]$$

PROOF: Given Assumption 3, we get equation (4) by integrating over the lifetime of the product. *Q.E.D.*

By using the models of Black (1976) and Margrabe (1978) we get

$$(5) \qquad c_{m,i}(t,T) = \exp\left[(t-T)r_{m,i}\right]\left[s_{m,i}(T)N(d_1) - k_{m,i}(T)N(d_2)\right],$$

where

$$d_1 = \frac{\ln\left[\hat{s}_{m,i}(T) \big/ \hat{k}_{m,i}(T)\right] + \frac{1}{2}\sigma^2(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = d_1 - \sigma\sqrt{T-t}$$

$$\sigma = \frac{\sqrt{\int_0^T \mathbf{e}_{s_{m,i}}(y)^2 dy + \int_0^T \mathbf{e}_{k_{m,i}}(y)^2 dy - 2\int_0^T \mathbf{e}_{s_{m,i}}(y)\mathbf{e}_{k_{m,i}}(y)' dy}}{T-t}$$

$$\hat{s}_{m,i}(T) = E\left[s_{m,i}(T) \mid F_t\right]$$

$$\hat{k}_{m,i}(T) = E\left[k_{m,i}(T) \mid F_t\right]$$

$$C_{m,i}(t,T) = \int_t^T c_{m,i}(t,y)dy$$

5.4 Sensitivity Analysis

In this section, we consider the effects of different inputs in the pricing model. We study how these inputs affect to the value of a product when other variables are assumed to remain constant.

First, we analyze variables that affect the expected value of the underlying asset. These variables are the current value of the underlying utility and the drift term of the utility process. Both these variables have positive effect on the expected value. This can also be seen from equation (5). Figure 1 illustrates how the increase in the expected utility changes the value of the product.

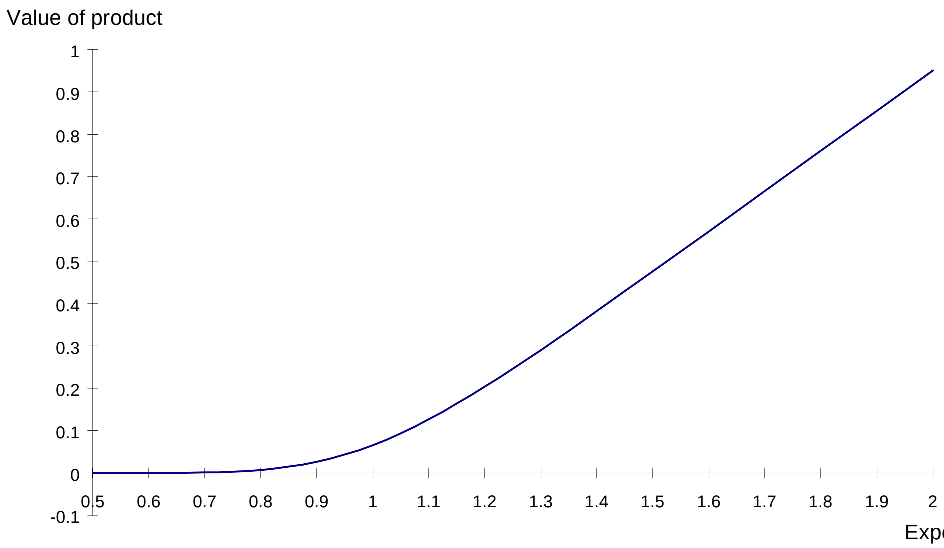

Figure 1. *The effect of expected utility value on the value of the product*

The expected value of variable costs has an opposite effect on the product price. The variables that affect to the expected value are the current value of variable costs and the drift term of the variable costs process. Figure 2 illustrates the situation.

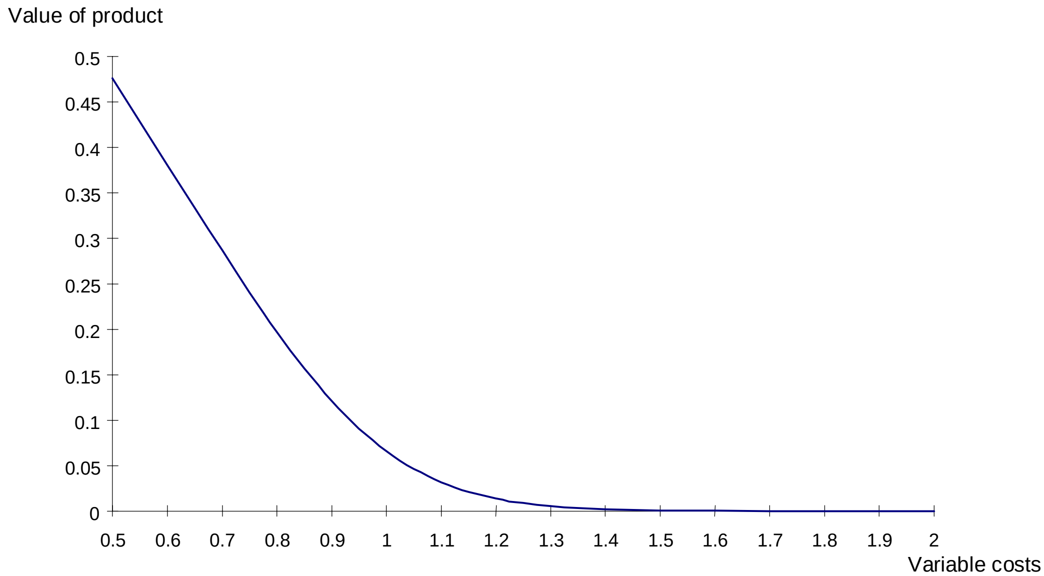

Figure 2. *The effect of variable costs on the value of the product*

From Figures 1 and 2 we see that when the expected value of the consumption utility is higher than the variable costs (1.0) then the increase in the expected utility has strong impact on the value of the product.

Next we study the effect of the volatility parameter, σ, in equation (5) on the value of product. Normally, if the volatility parameter increases then also the discount rate increases. However, here we assume that only the volatility parameter changes. We consider two situations. Firstly, Figure 3 illustrates the case when the expected utility value is lower than the expected value of variable costs.

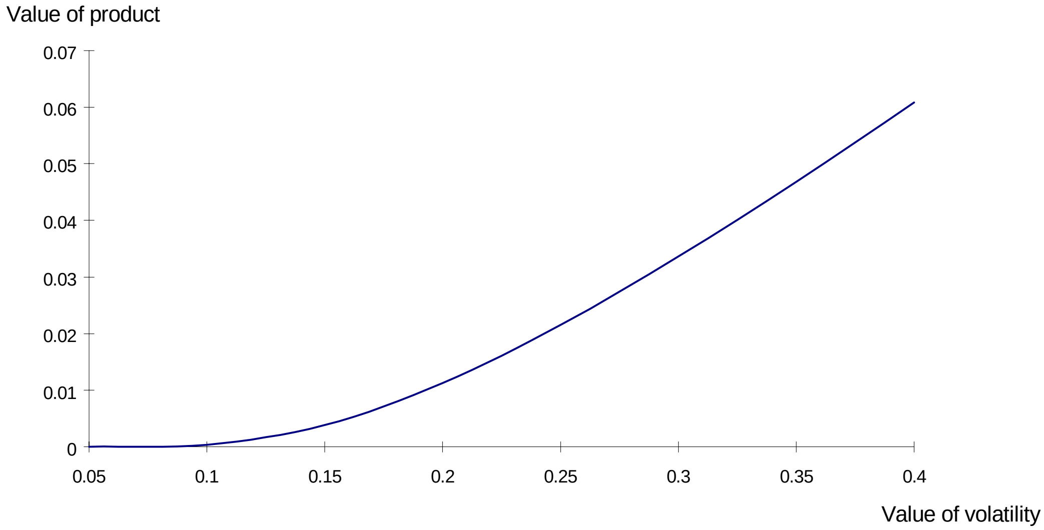

Figure 3. The effect of volatility on the value of the product when the expected value of utility process is lower than the expected value of variable costs.

Figure 4 illustrates the situation when the expected value of consumption utility is higher than the expected value of variable costs. From figures 3 and 4 we see that value of the product is more sensitive to the changes in the volatility when the expected value of utility process is lower than the expected value of variable costs. That is, when the product has high variable costs the increase in the utility volatility increases effectively the value of the product.

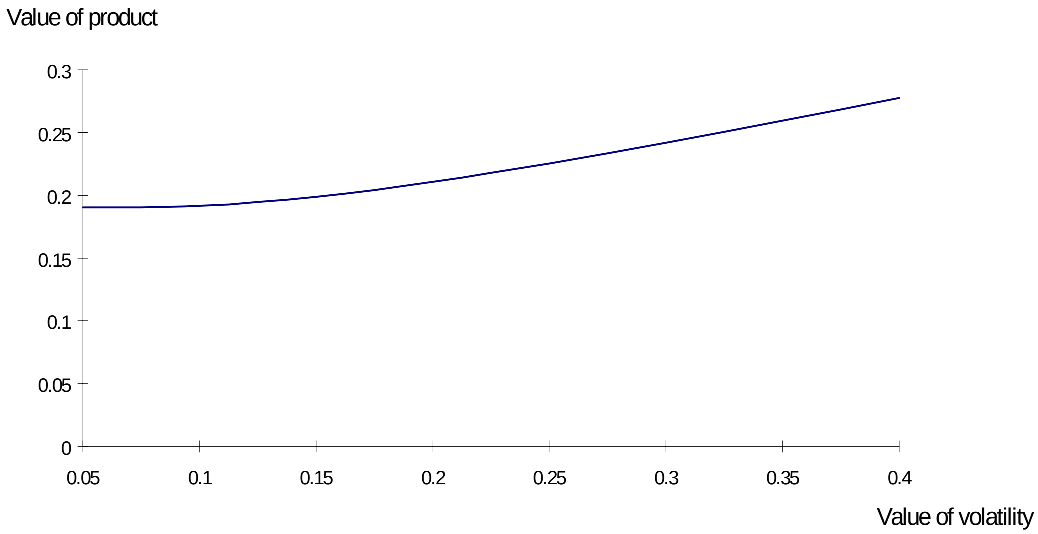

Figure 4. *The effect of volatility on the value of the product when the expected value of consumption utility is higher than the expected value of variable costs.*

Finally, we study how the changes in the discount rate affects to the value of the product. Equation (5) implies that the rate has negative effect on the product price. Figure 5 illustrates the situation.

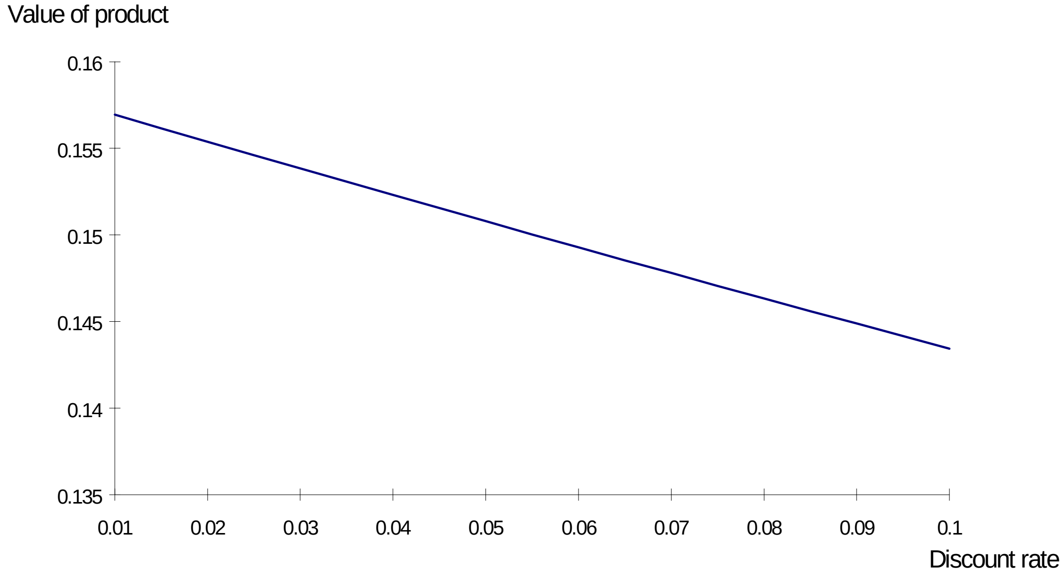

Figure 5. The effect of discount rate on the value of the product

5.5 Network Effects

In this section, we extend the model to cover network effects. For products displaying network effects, the value of usage depends on how many other people have a compatible product. For example, the value of a fax machine increases as the number of people having fax machines increases. We denote by $f(t)$ the number of people having a compatible product at time $t \in [0, T]$. We make here the assumption that the owner of the product can estimate accurately the function f. We also assume that the way this affects the utility process is through the drift term, by making the drift term dependent of the derivative of f. That is, the instantaneous increase in the utility rate depends on the instantaneous change in the number of people owning a compatible product. Then the utility process becomes:

$$(6) \qquad s_{m,i}(T) = s_{m,i}(t)\exp\left\{\int_t^T \left[\alpha_{s_{m,i}}(f'(y), y) - \frac{1}{2}\mathbf{e}_{s_{m,i}}(y)\mathbf{e}_{s_{m,i}}(y)'\right]dy + \int_t^T \mathbf{e}_{s_{m,i}}(y)d\mathbf{z}(y)\right\}$$

The value of the product is then obtained as in Theorem 1 but with the new $s_{m,i}$ given above.

This way to incorporate network effects leaves considerable room for assuming different functional forms for $f(t)$ and for the dependence of the drift term on $f(t)$. There is no general definition of these functions that could capture the idiosyncrasies of different products.

5.6 Modularity

In this section, we consider product modularity. That is, we investigate the case when the product consists of separate modules that can be changed. In this section, we illustrate two different ways to model the product modularity. The first model considers mixed Brownian motion and Poisson jumps, and the second model assumes that the product consists of module options.

Under the situation of modularity it is not any more realistic to assume that the uncertainty in the product utility process is generated only from Brownian motions because after the changing of a part of the product the product may become more valuable to the consumer. Now we change Assumption 1, and assume that the utility process follows the mixed Brownian motion and jump process

$$(7)\qquad ds_{m,i}(t) = s_{m,i}(t)\alpha_{s_{m,i}}(t)dt + s_{m,i}(t)\mathbf{e}_{s_{m,i}}(t)d\mathbf{z}(t) + s_{m,i}(t)\phi_{s_{m,i}}(t)dq_{m,i}(t)$$

where $dq_{m,i}$ is the increment of a Poisson process with mean arrival rate $\lambda_{m,i}$, and $d\mathbf{z}(t)$ and $dq_{m,i}$ are independent. We will assume that if a replacement of a part of the product $i \in I$ occurs $s_{m,i}$ increases by some fixed percentage $\phi_{s_{m,i}}$ with probability 1. That is, the fixed percentage $\phi_{s_{m,i}}$ is the increased utility due to the replacement. Equation (7) implies that $s_{m,i}$ will fluctuate as geometric Brownian motion, but over each time interval dt there is a small probability $\lambda_{m,i}dt$ that it will increase by to (1 + $\phi_{s_{m,i}}$) times its original value, and it will fluctuate until another replacement occurs.

Correspondingly, with variable costs the process becomes

$$(8)\qquad dk_{m,i}(t) = k_{m,i}(t)\alpha_{k_{m,i}}(t)dt + k_{m,i}(t)\mathbf{e}_{k_{m,i}}(t)d\mathbf{z}(t) + k_{m,i}(t)\phi_{k_{m,i}}(t)dq_{m,i}(t)$$

According to equations (7) and (8) we model the modularity case by assuming that the replacement of a module affects only to the instantaneous utility process and to the variable cost process. Thus, we implicitly assume that the replacement causes only variable costs. Usually this does not fit the reality but if the fixed replacement cost is small, equations (7) and (8) give a simple model for product modularity. Using Theorem 1 and the above equations the value of the product can be solved numerically. From Theorem 1 we see that if $\phi_{s_{m,i}}(t)$ is bigger than $\phi_{k_{m,i}}(t)$ for all $t \in [0, T]$ then the value of the product increases.

The other way to incorporate with the problem is to assume that each module of the product is a separate product. Now we can assume that I is the space of the product modules, i.e., it is the space of old and new modules to the product. Then $s_{m,i}$ and $k_{m,i}$ correspond the utility and variable processes of the module $i \in I$ for consumer $m \in M$. Of course, the processes of different modules can be highly correlated.

The agent problem is to solve

$$(9) \qquad C_m(t,T) = \sup_{\mathbf{h}_m(t)\in A} \sum_{i\in I} \int_t^T h_{m,i}(t,y) c_{m,i}(t,y) dy \,,$$

where C_m is the value of the product, $\mathbf{h}_m : [0,T] \to \lfloor h_{m,1}(t,\cdot) \ldots h_{m,n_i}(t,\cdot) \rfloor$ is the vector of module holdings, $h_{m,i}(t,\cdot)$ is a right-continuous function with left-hand limit and $c_{m,i}$ solves equation (8) for all $i \in I$, and A is such a space of possible module holding vectors that $C(t,T) < \infty$ and it guarantees that the holdings are such that they construct a whole product.

The optimization problem solves the value of the product to the consumer $m \in M$. Equation (9) implies that the consumer selects the most suitable modules to his product portfolio, i.e., she uses her upgradability options if necessary.

6 Conclusions

In this paper, we have developed a new model to understand the value of durable products. The model is based on the assumption that owners see their products as bundles of options. At each instant, the owner has the option to use the product, if the underlying utility of using the product is higher than the variable cost of usage. This approach has the significant benefit that it allows consideration of uncertainty about the future use of the product. The model shows that the value of a product is sensitive to the changes in uncertainty, especially when the variable costs are high compared to the utility. This uncertainty about future utility depends on the uncertainty about future needs and wants, about the quality of the product, and about the availability and quality of future upgrades. But the value is also dependent on the uncertainty about the future variable costs.

Using the model, we can develop a better understanding of how also modularity and network effects affect the value of products. The approach of this paper is very important especially for high-tech products with short life cycles, because it allows an understanding of the "economies of substitution" (Garud & Kumaraswamy, 1993, 1995) in modular products and also allows an understanding of the effects on value of the considerable uncertainty about future technological developments.

This approach points out to several interesting avenues for future research. First, a better understanding of the factors determining the utility and variable cost process is clearly warranted. The social aspects of how individuals come to have an impression about the product, its benefits, and its value should be studied extensively. Second, this also points to a useful approach to study the diffusion of new products. Social interaction and sellers' actions are very important in these situations since the uncertainty about the product is very high due to few opportunities to try out the product or observe its use. Third, this model allows studying of different strategies in pricing and marketing new products. These strategies depend on the characteristics of the product, mainly the variable cost pattern.

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