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ABSTRACT

This paper presents a framework for valuing managerial flexibility within the context of product standardization. The framework originates in a major standardization problem concerning digital tape recording at Philips Electronics. We use insights from financial option theory to calculate the option value of simultaneously developing two correlated product standards, and then compare this value to the option value of developing a single standard. We determine a threshold level such that for lower follow-on investment outlays development of both standards is optimal while for higher investment levels development of a single standard is optimal. This threshold is negatively related to the correlation between the value of the two standards. Finally, we show that properly incorporating uncertainty and the interdependence between the payoffs to the two standards leads to significantly different conclusions from standard NPV-analysis.

INTRODUCTION

This article is motivated by a case study concerning the standardization decision in the Video Cassette Recorder (VCR) market faced by Philips Electronics. As in many R&D-driven markets, management at Philips Electronics was confronted with the problem of optimally allocating scarce R&D resources for developing new technologies or product standards in a new market, in which mistakes would have detrimental effects on future market shares.¹ Product standardization issues are of great concern to management, because substantial future profits and potential followon products are at stake in standardization contests. Some examples are the Microsoftversus-Netscape contest to establish a dominant Internet standard, the recently ended Sony/Philips-versus-Toshiba/Time-Warner battle over a dominant standard for digital video, and the classic contest between Matsushita and Sony for a dominant standard for analog video. In the early stages of a product's life cycle, management is often faced with the dilemma of developing a single standard at the risk of later having to switch to a winning competing standard or developing two or more standards simultaneously, at the expense of incurring additional R&D costs. This dilemma becomes even more pressing when there is substantial uncertainty surrounding the support of a product standard from important intermediate parties providing complementary products or services, as for example in the software industry in the case of consumer electronics.

In the study presented here, the management at Philips had to decide between three alternative strategies: (1) to conduct R&D to develop a new manufacturing technology simultaneously for both analog and digital video; (2) to initiate R&D to develop this new technology for either analog or digital video; or (3) to refrain from any R&D regarding this technology. When the product market is characterized by high uncertainty surrounding future standards, substantial value exists in the firm's ability to postpone the final decision (to choose between both technologies) until the productlaunching stage following initial R&D. If management chooses to develop two product standards simultaneously, it effectively acquires an option to postpone the decision on the competing standards up until the final moment of product launch. This enables us to apply financial option theory to model the value of this type of managerial flexibility in product standardization. Specifically, we can use Stulz's (1982) model for the option on the maximum of two risky assets to calculate the option value of developing two standards simultaneously and compare this value to the option value of developing a single standard. Modeling this type of decision as an option enables us to avoid the pitfalls of traditional financial decision making that ignores flexibility (such as the application of standard NPV methods).

This paper attempts to reduce the gap between theory and empiricism in real options analysis concerning R&D decisions. Current contributions to real options end with the conclusion that theory runs ahead of practice without much empirical support.² Moreover, current applications of real options mainly concern investment projects dependent on natural resources. This paper represents an attempt to broaden the range of application with a consumer market application.

The rest of the paper is organized as follows. In Section 2 we review some concepts about endogenous versus exogenous product standardization and the differences between option and strategy models. Section 3 describes the product standardization case in the field of consumer electronics at Philips Electronics. Section 4 describes the model for the option on the maximum of two risky assets and presents complementary comparative statics results. Section 5 describes parameter estimation and analyzes the case with option analysis. Section 6 concludes and gives directions for further research.

ENDOGENOUS VERSUS EXOGENOUS PRODUCT STANDARDIZATION

There are two fundamentally different ways to address the economic analysis of product standardization problems. The first is the industrial organization perspective that considers product standardization as endogenous. The second perspective originates from finance theory, which regards the uncertainty underlying managerial flexibility as exogenous.

The work of Katz and Shapiro (1985) is representative of the industrial organization approach assuming that consumers value a product more highly when it is compatible with other consumers' products. They analyze the incentives for companies to switch from incompatible to standardized products, and find that a dominant firm may choose to remain incompatible with a rival because it will suffer a substantial loss in market share if it becomes compatible, since this would increase the

value to consumers of its rival's product. Farell and Saloner (1985) focus on the social costs of standardization. Because of high switching costs and coordination problems, firms are often reluctant to move to a new and better standard. They call this "excess inertia", and show that there will always exist excess inertia under imperfect information. Buyers too will be confronted with large uncertainty and high switching costs as a consequence of excess inertia or incompatibility of product sets, when competing standards are introduced to the market while the final standard is still to be set (see Klemperer, 1987, and Beggs and Klemperer, 1992).

The application of option theory, as discussed in this paper, provides a different approach to standardization; see Sanchez (1991) and Baldwin and Clark (1992) for initial discussions. The main difference between the option approach and the industrial organization perspective is that the standardization process is treated as exogenous in the option approach.³ Thus the timing of the introduction of a new standard is fixed. Firms are presumed unable to influence the outcome of a standardization contest. In contrast to the existing industrial organization literature, however, the value payoffs of new standards can be treated as uncertain and potentially correlated. This represents a major improvement for the analysis of standardization issues. Furthermore, the option approach enables us to relax the assumption made in the industrial organization literature of one existing standard and one new standard. With the option approach the parallel development of both competing standards can be analyzed.

When just one new and improved standard is being developed, firms can switch from the existing standard to the new standard. The decision about developing the technology for the new standard depends on the option value of switching to the new standard in the future. The value of this option depends on the expected profit value of the new standard and the expected profit value of the old standard. In the case that the expected profit value of the new standard currently exceeds the profit value of the old standard, the option value is high and developing the technology for the new standard appears worthwhile. When the expected profits of the new standard are much lower than the expected profits of the old standard, firms will not adopt the new standard. Since there is no obligation to replace the standard (i.e., exercising the option), the option value is practically zero. In the case that the expected profits of both the old and the new standard are about the same, the uncertainty surrounding both expected profit values plays a crucial role. Since downward risk is limited by the right not to exercise the option, but upward potential is unbounded, the option value increases with the relative uncertainty surrounding both standards. Due to this asymmetry, the value of the option might well offset the costs of developing the option even if the expected value of the new standard is currently lower than the expected value of the old standard. The option of exchanging one asset for another is examined in more detail by Margrabe (1978).⁴

When two new competing standards are emerging, however, firms face the decision of either developing technology for both standards and choosing the one which will eventually dominate, or developing the technology for just one of the two standards (i.e., the one that has the highest net option value). In order to analyze this dilemma, we rely on Stulz's (1982) model for the value of an option on the maximum of two risky assets. This provides a framework to value the flexibility gained in developing two product standards that may differ in their product characteristics, instead of one.⁵ By using an incremental or staged approach to investment, we can see that additional value can be gained by initiating development, thereby creating the option of choosing between the two product standards at a later date. The value achieved by the ability to choose between the two proto-types, just before market introduction, might be sufficient to cover the costs involved in the initial stages of developing both. If the company develops just one prototype, and the market proves unfavorable for this particular product standard, the company is forced to take a license on the competing and prevailing product standard. However, these licensing costs can be avoided if the company keeps the option open.

We now turn to a discussion of endogenous versus exogenous product standardization in strategy models. The strategic aspects of product standardization can be analyzed from either the competitive-positioning perspective (Porter, 1985) or from the resource-based view of strategic thinking (Collis and Montgomery, 1995). The competitive-positioning approach emphasizes the effect of exogenous factors on the determination of a firm's strategy. A company must adjust to its competitive environment, which serves as a starting point for strategy formulation. A successful strategy, one that creates excess expected returns, focuses on gaining and defending a sustainable competitive advantage. The resource-based view adopts a more endogenous perspective by emphasizing a firm's influence on its environment. This approach assumes that a company is able to develop unique and superior organizational capabilities that allow it to create some major competitive advantage and change the company's environment. From this viewpoint, a successful strategy is one that uses unique competencies to shape the environment to the company's vision. A company's environment is the result of strategic thinking, and not simply the starting point of strategic thinking. Hamel and Prahalad (1994) highlight the challenge not only to proceed from existing core competencies, but to stretch and leverage these competencies to establish a successful future for the company.

The specific market conditions will of course be decisive regarding the influence a firm has over its environment. This holds not only for different firms within a specific market, but also for a particular firm with different products within the same market. Philips Electronics, for example, presently holds an option on launching a product standard in digital video with its Multimedia Compact Disc (MMCD), co-developed with Sony. Given the patent position of the Philips/Sony team and the strong competition from a consortium by Toshiba/Time-Warner with their Digital Video Disc (DVD), this development may well be regarded as an endogenous process. It can be analyzed by means of a game-theoretic perspective using insights from industrial organization theory and the patent race literature.⁶

In contrast, the option on product launch of digital *tape* recording, which we analyze in this paper, has an exogenous character. Philips did not have a dominant patent position in digital tape recording at the beginning of this decade. Furthermore, Matshusita has a dominant share of the analog video market after its victory over the standardization battle with its VHS system, developed by Matsushita's subsidiary JVC, leaving Philips with its V 2000 and Sony with its Betamax system -both technologically superior systems- far behind (Rosenbloom and Cusumano, 1987). Given the weaker position of Philips in the analog video market and the absence of a strong patent position in digital tape recording at the time, we suggest that at the time of the decision to develop the manufacturing technology, it was advantageous for Philips to consider development of two competing product standards simultaneously, thereby effectively postponing the final decision on market launch to a later date. Moreover, we argue that the creation of this option to switch to the standard that will

eventually succeed can be analyzed from an exogenous perspective, given that at the time Philips had to "wait-and-see" how conditions for the digital tape recording market would develop and given that the company had minor influence on the outcome of the standardization process.

Essential elements for an assessment of the competitive position in a product standardization case include: the number of competitors, the market shares of the major competitors (or industry concentration), core competencies and patent positions. Important elements affecting the market opportunity include: the expected profitability and growth of the market; expected entry barriers, substitution effects, and the estimated diffusion or adoption rate of the new technology standard. We will not discuss these elements in-depth but refer to general textbooks on marketing and strategy for expository matters, e.g., Urban and Hauser (1993). These elements provide a conceptual framework for the assessment of expected cash flows resulting from the development of the competing product standards.

THE PHILIPS PRODUCT STANDARDIZATION CASE: BETTING ON TWO HORSES?

The prevailing standard in the VCR-market is the $\frac{1}{2}$ " A SD standard. Standard Definition (SD) refers to the quality of the resolution of the image, $\frac{1}{2}$ " refers to the width of the tape, and 'A' means that analog technologies are used to record the images on tape. There are also camcorders in the market that use 8 mm tape, but this tape is not used by conventional table-top players or the smaller and handier personal video players. Philips produces video players of all three types, but only players that handle $\frac{1}{2}$ " tape. It is generally believed, in accordance with the miniaturization trend, that 8 mm tape will become the standard tape for all players in this market. Therefore, Philips was considering the production of all three types of players to handle 8 mm tape.

Philips has the choice between two standards, analog (8A SD) and digital (8D SD), when developing 8 mm products for the video market. Both applications will be based on the same manufacturing technology. The analog application is based upon magnetic forces, while in the digital application images are built up from numbers, giving a higher level of sharpness and improved quality. Also, the digital application

is less sensitive to interference. There is no loss of image quality, and the sound quality equals that of the compact disc (CD). The digital application requires a different kind of tape than the analog application. Both applications can be used for the manufacturing of the three types of players: table top, personal video and camcorders. The decision facing Philips is whether to extend current research to develop and engineer video players using analog technologies (8A SD), or to start new R&D for the digital manufacturing technology (8D SD). Going with the latter entails the risk that consumers are not yet "ready" for digital technology in video players, or that software makers are not willing to develop 8 mm digital software, while the first choice entails the risk of being left behind while the competition conquers the digital market.

It is clearly desirable for the company to develop the technology that will eventually become the global standard. Both production processes require the same follow-on investment (the exercise price of the option to select the most profitable) since both applications are based on the same manufacturing technology. However, they differ in the values of expected cash flows and volatility. On one hand, analog technologies are better established as production methods and are therefore perceived as being less risky in comparison to the digital technology, which has not yet matured. On the other hand, miniaturization and digitalization are viewed by consumers as elements of better product performance. Thus, growth in the digital video market is expected to exceed growth in the analog video market. However, the manufacturing costs of digital video are higher as more expensive tape is needed.

R&D of the digital technology entails more costs than R&D of the analog technology, hence, the costs of developing the digital option alone exceed the costs of the separate analog option. However, the expected sales of the digital application substantially exceed the expected sales of the analog application. Basically, the problem boils down to the decision to develop both technologies simultaneously, to develop just the digital technology or to abandon research and development for this video technology. The costs of the option are the extra costs involved in the full development of the digital technology compared to the extended development of the analog technology. The option to develop both should be pursued if the net value of the option, i.e., the option value to develop both minus the cost of creating this option, exceeds the net value of the option to develop just the 8A SD or the 8D SD. If the

option to develop both is created, the decision of which standard to adopt will be postponed until the time when uncertainty in the market is resolved.

It is intuitively clear that there are two opposite factors influencing the correlation between the present value of sales from the two applications. On one hand, a booming digital VCR market will be at the expense of the analog VCR market, suggesting a negative correlation. On the other hand, both applications aim at the same market, suggesting a positive correlation. This correlation is one of the key parameters in evaluating the option to develop both standards.

OPTION PRICING ON THE MAXIMUM OF TWO RISKY ASSETS AND COMPARATIVE STATICS

Consider a firm like Philips considering two product standards. Only one of these standards will be produced eventually. Suppose manufacturing can start in τ years, and the total investment (capital and marketing expenditures) for introduction is the same for both standards; in option terms, this means they have the same exercise price. If the firm starts R&D for the manufacturing technology and prototypes for both standards, it creates the option to produce the product with the highest value after τ years, or to abandon production of both products if neither will make a profit. We view this as a European call option on the maximum of two risky assets.

Following Stulz (1982), let $V(S_1, S_2, X, \tau)$ be the value of a European call option with pay-off at maturity of $V = \max\{\max(S_1, S_2) - X, 0\}$. The underlying assets, S_1 and S_2 , denote the present values of expected cash flows from the two products, discounted at the firm's cost of capital. Both S_1 and S_2 are assumed to follow a geometric Brownian motion during the R&D stage. The appendix gives the analytic solution for V developed by Stulz (1982) adjusted for continuous dividend yields on S_1 and S_2 . The equivalent dividend yield of S_i , denoted by δ_i , represents the difference between the total equilibrium rate of return on the asset and the growth rate of the asset. σ_1^2 and σ_2^2 denote the variances of the stochastic processes for S_1 and S_2 , respectively. The common exercise price of the option, X, represents the investment in necessary capital and marketing expenditures before market introduction. The riskfree rate of interest is constant and denoted by r. Finally, ρ denotes the correlation between the movements in the values of the two standards.

We now examine decision rules for different levels of the follow-on investment (common exercise price) and show that, under some assumptions on the upfront costs of developing both standards, there exists a cutoff level of investment, X^* , for which the net value of developing two standards equals the net value of developing a single standard. The net value of developing both standards is higher (lower) for follow-on investments that are lower (higher) than X^* . We also analyze the influence of the correlation between S_1 and S_2 on V and on X^* .

Let C_{12} , C_1 and C_2 denote the costs of developing both standards simultaneously, the first standard alone or the second standard alone, respectively. We assume that $0 < C_{12} - C_1 < H(S_1,S_2,\tau)$ for i = 1,2, where $H(S_1,S_2,\tau)$ denotes the value of the option to exchange the standard that has the highest expected payoff (say S_2) for the other standard (S_1). Thus, the payoff of H at maturity equals $Max(S_1 - S_2,0)$. The assumption that $C_{12} > C_i$ is made since otherwise the net value of developing two standards (V - C_{12}) would always exceed the net value of developing a single standard ($c_i - C_i$). In that case, the decision rule is straightforward: develop both standards if V > C_{12} , and abandon development whenever V < C_{12} . With the assumption that $C_{12} - C_i$ < H, we ensure that there is some probability that the value of the standard that is expected to be subordinated exceeds the value of the standard expected to be dominant. If this assumption is violated, we show that it is never optimal to develop two standards, but rather to develop the standard with the highest expected payoff whenever the net option value exceeds zero.

Define,

$$f_i(X) = [V(S_1, S_2, X, \tau) - C_{12}] - [c(S_i, X, \tau) - C_i]$$
(1)

where $c(S_i, X, \tau)$ denotes the value of the call option with underlying value S_i , exercise price X, and time to maturity τ (Black and Scholes, 1973, and Merton, 1973). In order to show that there always exists a level of investment, X*, such that for X < X* the net value of developing both standards (V - C₁₂) is highest, and for X > X* the net value of developing a single standard (c_i - C_i) is highest, we apply the intermediate value property.⁷ Since $f_i(X)$ is continuous, $f_2(X) = H(S_1, S_2, \tau) - C_{12} + C_2 > 0$ and $f_1(X) > f_2(X) > 0$ for X $\rightarrow 0$, and $f_i(X) = C_i - C_{12} < 0$ for X $\rightarrow \infty$, there always exists an X_i^* for i = 1,2 such that $f_i(X_i^*) = 0$. It remains to be shown that the function $f_i(X)$ is monotonic decreasing. Following Stulz (1982), V can be written as $c(H(S_1, S_2, \tau) + S_2, X, \tau)$. Since $H(S_1, S_2, \tau) + S_2$ is the value of receiving the larger of S_1 and S_2 at maturity, we must have that $H(S_1, S_2, \tau) + S_2 \ge S_i$ for i = 1, 2. Since

$$\frac{\partial^2 c(S_i, X, \tau)}{\partial S_i \partial X} = \frac{-\varphi \left(d_i + \sigma_i \sqrt{\tau} \right) e^{-\delta_i \tau}}{X \sigma \sqrt{\tau}} < 0$$
⁽²⁾

where ϕ denotes the density function of the standard normal distribution, and d_i is as defined in the appendix, it must hold that

$$\frac{\partial f_i(X)}{\partial X} = \frac{\partial c(H(S_1, S_2, \tau) + S_2, X, \tau) - \partial c(S_i, X, \tau)}{\partial X} < 0$$
(3)

Therefore, $f_i(X) > 0$ for $X > X_i^*$ and $f_i(X) < 0$ for $X < X_i^*$. This also proves that it is never optimal to develop two standards if $C_{12} - C_i > H$. Thus, we finally arrive at the following decision rule: for $0 < X < Min[X_1^*, X_2^*]$ develop both standards whenever $V(S_1, S_2, X, \tau) > C_{12}$ and refrain from development whenever $V(S_1, S_2, X, \tau) \le C_{12}$. For $X > Min[X_1^*, X_2^*]$ develop the standard with the highest expected payoff $(c(S_i, X, \tau) - C_i)$ whenever $c(S_i, X, \tau) > C_i$, and refrain from development whenever $c(S_i, X, \tau) \le C_i$.

Stulz (1982) analyzes the impact of the correlation on the option value, V, and shows that this impact is always negative. That is, the value of the option is lowest when the two risky assets have a correlation coefficient of one. Intuitively, as ρ increases, the probability that the payoff of S_1 will be "close" to the payoff of S_2 increases, and the value of switching from one to the other or receiving the best of the two is lower. Similarly, if ρ decreases, it becomes more likely that the value of one of the assets is high, while the value of the other is low, so the option to switch or select the best is higher.

For the product standardization problem, this means that the value of the option is highest when the values of the two standards move in different directions under the same circumstances. However, this is not very likely in this case since both standards are different versions of the same product. Both applications aim at the same market, and therefore market changes affect both underlying values in a similar way, suggesting a positive correlation. Nonetheless, since both applications are

substitutes within the same market, this substitution effect suggests a negative correlation between the two values. When management can choose between parallel development of several standards, the option impact is highest when two standards are chosen with the lowest correlation.

Finally, we determine the impact of correlation, ρ , on the cutoffs X_i^* . Since the value of the option on the maximum of both standards decreases as correlation increases, while the value of the option on a single standard is unaffected by changes in the correlation, we expect the partial derivative of X_i^* with respect to ρ to be negative. Taking $X = X_i^*$ in equation (1) we have that

$$V(S_1, S_2, X_i^*, \tau) - C_{12} = c(S_i, X_i^*, \tau) - C_i$$
(4)

Differentiating with respect to ρ and rearranging gives

$$\frac{\partial X_i^*}{\partial \rho} \left(\frac{\partial V - \partial c}{\partial X_i^*} \right) = -\frac{\partial V}{\partial \rho}$$
(5)

Since the right-hand side of equation (5) is positive and, from equation (3), the term in brackets is negative, it follows that X_i^* decreases as ρ increases. Hence, the range of follow-on investments, for which parallel development is optimal, shrinks.

PARAMETER ESTIMATION AND OPTION ANALYSIS

In this section we determine the cutoff investment (X*) in the manufacturing of video players below which it is economically preferable to create the option to develop both standards simultaneously. Sixteen in-depth interviews with various managers within Philips' R&D and marketing departments were conducted to collect information about the input parameters for our model, including the uncertainty surrounding the value of expected cash flows for each standard and the correlation between these values. Within R&D, we interviewed managers at different hierarchical levels, including seven research team members, the project leader, the group leader, and two directors. Within marketing too, we interviewed managers at different hierarchical levels, including levels, including product management (3), and two directors.

Although the number of interviews with both functional departments is unequal and the interviews are not proportionally distributed among the hierarchical levels, we gave ourself the latitude not to discriminate between the different answers. Given prior experience with product failures, senior managers may be inclined to be more conservative about market opportunities than research team members who are rather unexperienced with market introductions.⁸ It appeared that there was a major dispersion in the answers to the questions about market opportunities. There was little dispersion in the answers to the questions about the cost of investment, the costs of R&D, and the time to completion of the products.

More specific, each interview addressed questions regarding future prices, quantities, costs, the rate of acceptance for both 8A SD and 8D SD, as well as capital expenditures, marketing expenditures and upfront costs (salaries, equipment, etc.) for developing each of the three options. We assume that each manager provides numbers from the same probability distribution. From the data collected from each interview we calculated the present value of expected cash flows for both standards. For each standard, these numbers represent 16 random drawings from a distribution of the underlying value. In order to test the hypothesis of a lognormal distribution for S_1 and S₂, the Bera-Jarque (e.g. Judge et al. 1987) test is applied.⁹ This test is based on how far estimates of the third and fourth moments deviate from the expected values of the moments under normality. Under the null hypothesis that $ln(S_1)$ and $ln(S_2)$ are normally distributed the statistic has an asymptotic $\chi^2(2)$ distribution. Normality cannot be rejected for the analog standard as well as the digital standard at the α =5% significance, since χ^2 =3.78 for the analog standard and χ^2 =5.68 for the digital standard which are lower than the critical value of 5.99 for a chi-square distribution with two degrees of freedom.

It is well-known that when S_1 and S_2 are two correlated geometric Brownian motions during the R&D stage, the joint distribution of $\ln(S_1)$ and $\ln(S_2)$ is bivariate normal with standard deviations of $\sigma_1 \sqrt{\tau}$ and $\sigma_2 \sqrt{\tau}$, respectively, with correlation coefficient ρ ; see for example Hull (1997). Therefore, we can use our data in order to estimate the parameters in the Stulz (1982) model. We performed maximum likelihood estimation to obtain the standard deviations and correlation of the sample, using the following likelihood function

$$L(\sigma_1, \sigma_2, \rho) = \prod_{i=1}^{N} (2\pi |\Sigma|)^{-\frac{1}{2}} \exp\left(-\frac{1}{2}\left(\overline{S}_i - \overline{\mu}\right)\Sigma^{-1}\left(\overline{S}_i - \overline{\mu}\right)\right)$$
(6)

where

$$\overline{S}_{i} = \begin{pmatrix} \ln(S_{1,i}) \\ \ln(S_{2,i}) \end{pmatrix}, \quad \overline{\mu} = \begin{pmatrix} E(\ln(S_{1,i})) \\ E(\ln(S_{2,i})) \end{pmatrix}, \quad \Sigma = \begin{pmatrix} \sigma_{1}^{2}\tau & \rho\sigma_{1}\sigma_{2}\tau \\ \rho\sigma_{1}\sigma_{2}\tau & \sigma_{2}^{2}\tau \end{pmatrix}$$
(7)

The net cash flows, discounted to the present, for the analog (S_1) and digital (S_2) manufacturing process are set equal to the sample means, respectively F281m and F411m;¹⁰ see Table 1. The risk-free rate is set equal to the rate of a riskless bond with approximately the same maturity as the option, that is r = 6%. The time from the moment of creation of the option until the expected expiration date (τ) is approximately 3.5 years. The present value of the costs for developing just 8A SD (C₁) or just 8D SD (C₂) are F40m and F52m, respectively, while the present value of the common costs of developing both (C₁₂) are estimated to be F68m. Due to synergistic advantages, the costs of developing both are lower than the sum of the costs of developing each on an individual basis. The equivalent dividend yields are assumed to be zero.

Estimates of uncertainties and the correlation, and corresponding standard errors are given in Table 2. As expected, the standard deviation of the digital process (S_2) exceeds the standard deviation of the analog one (S_1) . The estimated value of their correlation coefficient, $\rho = 0.21$, means that both technologies are influenced in the same direction by the rate of acceptance and market penetration. A lower correlation coefficient would have resulted in a higher option value. Standard deviations of each parameter were calculated in order to perform reasonable sensitivity analysis. We find that the option value is very sensitive to estimation errors in the uncertainties of S_1 and S_2 , as opposed to errors in their correlation, while the range of follow-on investments is very sensitive to estimation errors in the correlation as opposed to errors in the uncertainties.

Insert Table 1 about here

Insert Table 2 about here

Given these parameter value estimates, we calculated the option values of each alternative. We illustrate in Figure 1 the net option value, i.e., the option value of each decision minus the costs of creating that option, versus the investment sum required for full-scale development. The horizontal line represents a net value of zero. The optimal decision is to develop the set of standards that yields the highest net option value at a given level of investment. This set is empty when there is no positive net option value at this level of investment.

Insert Figure 1 about here

The option to develop both standards should be created when investment in marketing and capital expenditures ranges from 0 to approximately F380m. At this cutoff level, $X_2*=F380m$, the net value of the option to develop both standards and the value of the option to develop just the 8D SD standard are equal. When X exceeds X_2* , it is shown in Figure 1 that the option of developing 8A SD has a low value. In that case, the option on the maximum value of both standards is dominated by the value of 8D SD. Since the costs of developing both standards are higher than the costs of just developing 8D SD while the option values of both decisions are nearly equal, the net value of developing both standards is lower than developing just the 8D SD for X above F380m. When X exceeds F740m, none of the available net option values is positive. At this high level of required follow-on investment, development of each standard must be abandoned.

Since maximum likelihood estimates are asymptotically normal, 95%confidence intervals of σ_1 , σ_2 and ρ can be derived as [0.15,0.27], [0.24,0.44], and [0.03,0.39], respectively. With these confidence intervals, we performed sensitivity analysis to determine whether the errors in the estimated variables have a significant impact on the derived results. Since the major decision is about developing 8D SD or both 8A SD and 8D SD, σ_1 is left out of consideration. Figure 2 confirms that σ_2 has a significant impact on the option value. This implies that the decision to develop 8D SD may be easily altered. The decision whether to develop both standards or just the digital standard is not very sensitive to σ_2 , since the confidence range for X_2^* is approximately [F360m, F390m].

Insert Figure 2 about here

Figure 3 confirms that ρ has a negative impact on the option value and X_2^* . The option on a single standard of course does not depend on ρ . The value of the option to develop both standards appears not to be very sensitive to the correlation. However, Figure 3 illustrates that ρ has a large impact on the decision whether to develop both standards or just 8D SD. As discussed in section 4, correlation has a large impact on the option value. Therefore, it is intuitively clear that the decision ranges are largely affected by correlation. Consistent with the previous analysis, the cutoff investment level X_2^* decreases as ρ increases. The confidence interval for X_2^* is equal to [F330m, F420m].

Insert Figure 3 about here

Of course, the topical question is to what extent option analysis changes the decision rules obtainable by a straightforward NPV-analysis. Table 3 shows that disregarding uncertainty and the interdependence between the value payoffs of the two standards leads to significantly different conclusions. The conventional NPV for each standard equals the value of introducing that product standard minus its investment and development costs, i.e., $S_i - X - C_i$.

For an investment in marketing and manufacturing of F370m, following the NPV-rule management at Philips would not invest in developing a product standard for digital tape recording. On the contrary, with option analysis, it was shown that keeping its options open and developing both product standards simultaneously is optimal for an investment level up to F380m.

Insert Table 3 here

SUMMARY AND CONCLUSIONS

In this paper, we provided a framework for valuing managerial flexibility in product standardization settings with simultaneous development opportunities by means of option analysis. Valuable flexibility arises from developing two standards with the option to make a final decision on product launch once the actual global product standard is known in the future. The product standardization decision is an extremely important issue for many firms developing and engineering new products in complex, dynamic and uncertain markets. Options analysis confirms that creating the option on two standards becomes more attractive when the correlation between the payoffs of the two standards is lower. Disregarding uncertainty and the interdependence between the payoffs to the two standards may lead to significantly different conclusions based on NPV-analysis.

Our options analysis was motivated by a study at Philips Electronics to assess the flexibility value of a standardization issue in the VCR market. Philips had the choice between two standards, analog and digital, for new 8 mm products for the video recorder market, with the same amount of follow-on investment, but with different expected cash flows and risk. We estimated that the two product standards have a low positive correlation. Since the extra costs of developing improved analog and digital video simultaneously are relatively low, we find that creation of the option to develop both standards is attractive for relatively low investments. As the required investment increases, development of just the digital technology yields the highest net value. Reasonable errors in the estimated variables have some impact on these decisions ranges, but do not substantially change the overall results.

For possible extensions, we note that the model used in this paper assumes that the capital and marketing expenditures required for a successful market launch are equal and certain for both applications. As both applications rely on the same manufacturing technology, production facilities require approximately the same capital expenditures. Furthermore, it is reasonable to assume that Philips holds a 'wait-and-see' position, given the absence of market dominance or patent dominance in digital tape recording. Therefore, the marketing expenditures necessary for a product launch of the standard finally chosen may fairly be assumed to be equal. Also, since there appeared to be little dispersion in the answer to the question about the cost of investment, it is fair to assume consensus about the cost of investment. For general applications, these assumptions will likely not hold in practice and different and/or uncertain exercise prices for the different standards will have to be used.

Another point of interest for further research is relaxing the assumption that the standardization issue on digital tape recording has an exogenous character. We have argued that this assumption holds for the market conditions confronting Philips in the particular standardization situation described. However, given today's standardization contests, management also needs to be supported with models that amalgamate option analysis with game-theoretic or endogenous perspectives, since in many situations companies are, at least to some extent, able to influence the outcome of a product standardization contest (e.g. Smit and Ankum, 1993; Smit and Trigeorgis, 1993; Lambrecht and Perraudin, 1997, and Kulatilaka and Perotti, 1998).

A further extension would be considering an American option in order to include early exercise of the option instead of a European option, as assumed in the Stulz model. A first step in this direction is taken by Gerber and Shiu (1996) who analyze the American option on the maximum of two risky assets under the condition of a zero exercise price. Related to this extension is to incorporate an uncertain maturity in the Stulz model, since the lead-time of R&D is often uncertain. Moreover, after the R&D stage, a company has the option to postpone market introduction. Including this option leads to a compound option (Geske 1979) in a multistage setting. Finally, we note that correlation between the project values of both standards is likely time-varying. Since the initial development of both standards are finalized, we expect this correlation to decrease over time. We leave these topics for further research.

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FIGURE 1



Figure 1 : Net value of the option to develop the analog (A) technology only (dotted line), to develop the digital (D) technology only (dashed line), and to develop both (A+D) technologies simultaneously (solid line). The dotted vertical line represents the investment cutoff level X_2^* .

FIGURE 2



Figure 2: Net value of the option to develop digital technology and to develop digital as well as analog technology for $\sigma_2 = 0.24$ (dotted line), $\sigma_2 = 0.34$ (dashed line), and $\sigma_2 = 0.44$ (solid line). For each pair of lines, the line with the higher (absolute) slope represents the value of the option to develop both technologies. The dotted vertical lines represent the investment cutoff levels X₂* for each standard deviation.

FIGURE 3



Figure 3 : Net value of the option to develop the digital as well as the analog technology for correlation $\rho = 0.03$ (dotted line), $\rho = 0.21$ (dashed line), and $\rho = 0.39$ (solid line with lower slope). The solid line with the higher slope represents the value of the option to develop digital technology. The dotted vertical lines represent the investment cutoff levels X_2^* for each correlation.

TABLE 1

| S_1 | F 281m | | |
|----------------|-----------|--|--|
| S ₂ | F 411m | | |
| r | 0.06 | | |
| δ_1 | 0 | | |
| δ_2 | 0 | | |
| τ | 3.5 years | | |
| C_1 | F 40m | | |
| C_2 | F 52m | | |
| C_{12} | F 68m | | |

Parameter value estimates for the Philips' product standardization case

Note: S_1 and S_2 are the underlying values of the analog and the digital product standard, respectively; r is the riskfree rate of return; δ_1 and δ_2 are the dividend yields of the analog and digital project, respectively; τ is the time to maturity of the option; C_1 , C_2 , and C_{12} are the costs of developing the analog standard alone, the digital standard alone, and the analog and digital standard simultaneously, respectively.

TABLE 2

Estimates of the standard deviations of each product standard alone and their correlation (with standard errors in parentheses)

| $\sigma_{_{1}}$ | 0.21 (0.03) |
|-----------------|-------------|
| σ_2 | 0.34 (0.05) |
| | 0.21 (0.09) |
| μ | 0.21 (0.07) |

Note: σ_1 and σ_2 represent the standard deviations of the analog project and the digital project, respectively; ρ is the correlation between the project values of the analog standard and digital standard.

TABLE 3

| | NPV-analysis | Option-analysis |
|--------------------------|---------------|-----------------|
| Develop both standards | 0 < X < 241 | 0 < X < 380 |
| Develop digital standard | 241 < X < 359 | 380 < X < 740 |
| Develop no standard | 359 < X | 740 < X |

Difference in development ranges between NPV-analysis and option analysis

Note: X is the exercise price of the option.

APPENDIX

Stulz (1982) shows that

$$V(S_1, S_2, X, \tau) = c(S_1, X, \tau) + c(S_2, X, \tau) - M(S_1, S_2, X, \tau)$$
(A1)

where $c(S_i, X, t)$ is a European call option on asset S_i with exercise price X and time to expiration τ and $M(S_1, S_2, X, \tau)$ is the value of a European call option on the minimum of S_1 and S_2 . Adjusting for equivalent dividend yields on both assets, $M(S_1, S_2, X, \tau)$ equals

$$S_{1}e^{-\delta_{1}\tau}N_{2}(d_{1}+\sigma_{1}\sqrt{\tau},(\ln(S_{2}/S_{1})+\delta_{1}-\delta_{2}-\frac{1}{2}\sigma^{2}\tau)/\sigma\sqrt{\tau},(\rho\sigma_{2}-\sigma_{1})/\sigma) + S_{2}e^{-\delta_{2}\tau}N_{2}(d_{2}+\sigma_{2}\sqrt{\tau},(\ln(S_{1}/S_{2})-\delta_{1}+\delta_{2}-\frac{1}{2}\sigma^{2}\tau)/\sigma\sqrt{\tau},(\rho\sigma_{1}-\sigma_{2})/\sigma)$$
(A2)
- $Xe^{-r\tau}N_{2}(d_{1},d_{2},\rho)$

and

$$c(S_i, X, \tau) = S_i e^{-\delta_i \tau} N_1(d_i + \sigma_i \sqrt{\tau}) - X e^{-r\tau} N_1(d_i) \qquad i = 1,2$$
(A3)

where $N_2(d_1,d_2,\rho)$ is the bivariate cumulative standard normal distribution with upper limits of integration d_1 and d_2 and coefficient of correlation, ρ . $N_1(\gamma)$ is the cumulative standard normal distribution with upper limit of integration γ , and

$$d_{i} = (\ln(S_{i} / X) + (r - \delta_{i} - \frac{1}{2}\sigma_{i}^{2})\tau) / \sigma_{i}\sqrt{\tau}$$

$$\sigma^{2} = \sigma_{1}^{2} + \sigma_{2}^{2} - 2\rho\sigma_{1}\sigma_{2}$$
(A4)

ENDNOTES<

¹ For related option valuation of R&D in the consumer electronics industry, see Lint and Pennings (1998) and Pennings and Lint (1997).

² See, for example, the overview by Trigeorgis (1993), or the recent survey of investment under uncertainty by Dixit and Pindyck (1994).

³ Initial contributions incorporating endogenous competitive aspects in option analysis are given in Kulatilaka and Perotti (1998), and Lambrecht and Perraudin (1997). These studies concentrate on single projects, whereas our study focuses on two assets from an exogenous perspective.

⁴ This analysis assumes that firms are already active in the relevant market. This assumption can easily be relaxed. The decision about entering the market with the new standard depends on the profits of the new standard and the costs associated with market introduction, such as investments in plant, equipment, human resources and distribution channels. This decision can be thought of as a decision about exchanging investments that are required for successful market introduction (the exercise price) for the profits from market introduction. Thus, the option value of introducing the new standard can also be modeled using the option model to exchange one risky asset for another.

⁵ Johnson (1987) and Sanchez (1991) provide complementary models for a firm that is able to choose between more than two product standards.

⁶ For contributions to this field see: Gal-Or (1985); Conner (1988); Von Hippel (1988); Carpenter and Nakamoto (1990), and Brandenburger and Nalebuff (1995).
⁷ See any textbook in calculus, e.g. Spivak (1980).

⁸ Urban and Hauser (1993) state that after R&D between 35 and 50% of many new products are identified as failures and will never be introduced in the marketplace.

⁹ The Bera-Jarque statistic is given by $T\left(\frac{\mu_3^2}{6\sigma^6} + \frac{(\mu_4 - 3\sigma^4)^2}{24\sigma^8}\right)$ where

 $\mu_{i} = \frac{1}{T} \sum_{t=1}^{T} \left(y_{t} - \frac{1}{T} \sum_{t=1}^{T} y_{t} \right)^{i}, \sigma^{2} = \mu_{2}, \text{ T is the number of observations (T=16), and y_{t} are}$

the observations (logarithms of the underlying value).

 10 F1 = US\$0.5.