SNF Working Paper No. 28/07

Product Development in IT and Telecommunications Information Acquisition Strategies

by

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SNF Project No. 7310
Verdsetting med realopsjonsmodeller: IKT-virksomhet.

THE ECONOMICS OF TELECOMMUNICATIONS

This report is one of a series of papers and reports on telecommunication economics published by the Institute for Research in Economics and Business Administration (SNF) as part of its telecommunication economics program. The main focus of the research program is to study the deregulation process of the telecommunication industry, and the economic and organizational consequences of changes in markets, technology and regulation. Being started in 1992, the program is now in its fourth period ending in 2005/2006. The program is financed by Telenor AS.

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, OCTOBER 2007
ISSN 1503-2140

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October 2007

Abstract

Investment projects within information technology and telecommunication industries face high uncertainty with respect to future cash flows, especially due to technological innovations and changing markets. Competition among IT and telecommunications companies leads to rapid technological innovations, and companies develop new products and product features in order to be competitive. We evaluate development of a product, to be launched when a higher telecommunications network opens at a pre-specified future date. The problem we focus on is how to develop a new product that is well adapted, both to capacity and features of the new network platform, as well as to consumer demand. We incorporate these features into the term "product quality", which we in our model formulate as a partially observed stochastic variable.

JEL Classifications: C61, D83, G31

Key words: information acquisition, R&D project, telecommunications, capital budgeting

1 Introduction

A major problem in valuation of IT and telecommunications projects is that it is difficult to assess future product and technology needs. For example, when the SMS (Short Message Service) feature was launched, the industry did not foresee the large demand of this product.

In recent years, technological innovations have led to convergence between mobile communications and Internet applications, and new network standards offer higher capabilities of merging voice and data communication, as well as higher potentiality of carrying and transmitting data at a high speed rate. Such innovations imply an ongoing high uncertainty with respect to future product features and demand for these.

In this paper we evaluate development of a new product, to be launched when a higher telecommunications generation network opens at a pre-specified future date. The new network with larger capacity facilitates enhanced mobile devices. The problem we focus on in this paper is how to develop a new product that is well adapted, both to the capacity and features of the new network platform, as well as to consumer demand. We incorporate these factors into the term "product quality", which we in our model formulate as a partially observed stochastic variable. We assume that we have two decisions to make: First, in a pre-development stage, we decide how much (costly) information about "product quality" it is optimal to choose. The next stage in the model is the product development stage, in which we make decisions with respect to investments in "product quality". We assume that investments in product quality take time, and that we may invest in product quality until the date at which the new network is opened. At this date our product is commercialized.

We find that the optimal effort to acquire information in the pre-project (the first stage) is higher the more noisy signal we have about the true quality of the product to be developed. Moreover, the more noisy signal, the lower value of the project. We obtain similar result with respect to volatility in product quality: higher volatility reduces project value. However, volatility of product quality is relatively insensitive with respect to the choice of optimal effort in the pre-project.

The problem in our paper relates to R&D projects evaluated as contingent claims on an underlying asset. A number of articles have studied such problems recently, among these, Childs and Triantis (1999), Schwartz and Moon (2000), Miltersen and Schwartz (2002) and Berk, Green, and Naik (2004).

Childs and Triantis (1999) specify a rich R&D model, which enables them to study effects of several factors, among these, learning-by-doing, collateral learning between different projects in time, interaction between the markets for resulting products, and different intensities of investment. The dynamic R&D model is numerically implemented, and optimal policies for the multiple R&D projects are analyzed.

Another related model is formulated in Berk et al. (2004). The paper formulates a multi-stage investment problem with the value of the completed R&D project as an underlying variable. Uncertainty of future project cash flows consists both of a systematic component (exogenous uncertainty due to overall economic activity) and an unsystematic component (technical uncertainty). Decision makers resolve technical uncertainty through additional investment.

Schwartz and Moon (2000) and Miltersen and Schwartz (2002) discuss models more closely related to our approach. These papers formulate research and development projects in which it takes time to make the investments of the project, similarly to Pindyck (1993). Investments costs are formulated as a continuous, stochastic process, reflecting the assumption that an IT development project takes time, has uncertain costs, and that the time it takes to complete the investment is uncertain. *Learning* is associated with investment process, as the technical uncertainty in the research and development project is reduced as they get closer to completion of the project. Schwartz and Moon (2000) formulate an investment opportunity in R&D as a contingent claim that has as an underlying variable the value of the asset obtained at the completion of the project and the expected cost to completion. Miltersen and Schwartz (2002) introduce imperfect competition into a similar problem: they analyze a duopoly situation, in which two firms compete about being the first firm to develop a product and enter a market, thereby earning monopoly profit as long as the other firm has not entered the market.

Similarly to Schwartz and Moon (2000) and Miltersen and Schwartz (2002) we formulate uncertainty in project value as a controlled continuous time stochastic process, where the control variable represents an investment rate. However, whereas our problem is to choose an optimal strategy to invest in quality, in order to target an optimal quality level at *given* time of product launch, the problems in the mentioned papers are to find an optimal investment strategy for an R&D product, under the assumption that the time it takes to finish the product is uncertain, as the remaining investment cost is given by a stochastic process. Another difference is that in the present paper the uncertain variable is only partially observable.

The model in our paper is a special case of the model in Lund (2004), in which a stochastic optimal control problem with controllable information acquisition is analyzed. Economic applications of similar models are Detemple (1986), Dothan and Feldman (1986), Gennotte (1986), and Brennan (1997), who characterize portfolio problems under the assumption that a decision maker does not observe the true state of the economy, but knows the stochastic process governing the variables that describe the true state of the economy. The decision maker observes the true state of the economy with noise. This observable variable is governed by a stochastic process that is influenced by the true state of the economy, as well as random shocks. As in our model, these papers separate the optimization problem into a filtering problem, in which the updated value of current state is the estimated, and an investment problem in which the updated estimates are used as true variables in a classical stochastic control problem, as in Fleming and Rishel (1975) and Øksendal (1998). In the model presented below we extend the filtering problem to include a control, by which we choose the precision of the observable noisy variable.

In the present paper we focus on the development of a product, and take the network standard as given. However, an important perspective on the telecommunications industry is the interrelation of network standards and products, as well as regulation issues. Such problems are discussed in Katz and Shapiro (1994), Perotti and Rossetto (2000), Alleman and Rappoport (2002), and Panayi and Trigeorgis (1998), among others.

2 Model formulation

We assume that a telecommunications company is to launch a new product (for example a mobile terminal) when a higher generations network is opened for public access. The network is opened at a future, given date, represented by T.

The investment project consists of three stages. The first stage is a pre-project phase, in which effort is made to acquire information about new technological innovations and about which product features will be in demand in the future. The second stage is a product development phase, in which the company aims to develop a product of a certain quality. The quality of the product depends on observability of quality, and costs of developing and producing products of a certain quality. In the third stage the product is produced and sold.

2.1 Product quality

The quality, K, of the new product is formulated as a stochastic process,

$$dK_t = I_t dt + \sigma_0 dW_t, \quad y = K_0, \tag{1}$$

where I_t is a control variable, σ_0 is the volatility parameter of the process, W_t is a Brownian motion, and y is the value of product quality at an initial time 0. The more effort put into the development through the control variable I, the higher quality of the product at time T. The cost at time t of improving product quality is given by $2FI_t + AI_t^2$, where F and A are positive constants. The quadratic term of the cost function reflects that the cost of intensifying effort is costly.

The exact quality of a new product is difficult to assess. Product quality is partly a technical question, but also a relative notion. What is the market demand for the new features in the new product, and what are the quality of competing products? It is therefore natural to assume that precise observation of the quality level is impossible. Consequently, we assume that product quality K_t can only be observed with noise: the product developer observes the process

$$dZ_t = HK_t dt + \sigma_1 dU_t, \tag{2}$$

where σ_1 is a constant representing noise, and U_t is a Brownian motion independent of W and K. The positive constant H is a control variable, by which we in the pre-project stage choose an information level. Note that the higher H is, the more information does the company have about product quality in the development phase. The initial state of the process K, y, is assumed to be Gaussian with known expectation μ and variance a^2. We define $\mathcal{Z}_t = \sigma(z_v; v \leq t)$ as the filtration generated by the observations up to time t.

For simplicity we assume that the company is risk neutral (alternatively, that uncertainty is diversifiable). The cost of acquiring information in the pre-project stage is given by a (positive and convexly increasing) cost function $M(H)$.

2.2 The value of the completed product

At future time T the infrastructure is opened, and as of this time our product is produced and sold. Moreover, at time T all uncertainty is resolved, and we observe the quality $k \equiv K_T$. We assume that the product is to be sold in a competitive market, i.e., the firm is a price taker with respect to supply. However, the price of the product depends on the quality of the product, through the function

$$P(k,t) = pke^{-\theta(t-T)}, \tag{3}$$

where p and θ are positive constants, and time is denoted by $t > T$. Thus, the price of product increases linearly in quality k. Over time, substitutes are developed, at a higher quality, and thus the willingness to pay for a certain quality falls. This is reflected in the price function in equation (3), through the term $e^{-\theta(t-T)}$.

The firm's cost of producing q units per year is given by

$$C(q,k) = ckq^2 + fk^2,$$

where c and f are positive constants. Observe that costs grow quadratically in quality.

The firm's profit at time $t > T$ equals

$$\pi(q,k,t) = P(k,t)q - C(q,k).$$

We find the optimal quantity produced at time t by the first-order condition of the profit, π, with respect to quantity, q. This leads to

$$q^*(t) = \frac{pe^{-\theta(t-T)}}{2c}.$$

The demand of the product decreases over time, through the "discounting factor" $e^{-\theta(T-t)}$, implying reduced demand for our product.

The optimal profit function at time $t > T$ is thus given by

$$\pi^*(k,t) = \frac{kp^2 e^{-2\theta(t-T)}}{4c} - fk^2.$$

Because of the decreasing demand for the product, the profit from the product is reduced over time. Moreover, observe that profit is a quadratic function of the quality level k, which means that there exist an optimal level of π^* with respect to k. Define r as a constant risk-free interest rate per year. By integration of the profit function with respect to time,

$$v(k) = \int_T^{\infty} e^{-rt}\pi^*(k,t)dt,$$

we find that the firm's time T value of producing the product is given by

$$v(k) = e^{-rT}\left(\frac{p^2k}{4c(r+2\theta)} - \frac{fk^2}{r}\right).$$

2.3 The optimization problem

By convention, we choose time zero as the beginning of the development phase. The value of the project is then given by

$$V(0,\mu,a^2) = \sup_{H\in\mathbb{R}^+, I\in\mathcal{B}} E\left[-M(H) - \int_0^T e^{-rt}\left(AI_t^2 + 2FI_t\right)dt + v(K_T)|\mathcal{Z}_0\right], \quad (4)$$

where $\mathcal{B}$ is the space of $\mathcal{Z}_t$ adapted processes. The three terms inside the square brackets represent the three project stages: The first term is the cost in the pre-project stage, i.e., the cost of information acquisition. The second term represents the costs incurred development phase, i.e., the costs of choosing the optimal quality level. The third term is the value of the expected cash flows from the completed product. The firm optimizes the project value with respect to an investment strategy I_t, and an observation level H, during the development period.

3 Problem solution

In this section we solve the optimization problem in equation (4) applying a two step procedure: First we solve the partial information problem, given that the information arrives in the specified form (2), for some constant H. When the optimal control and value function for this first problem is characterized, the second step is to find the optimal information acquisition policy, i.e. find the optimal H. The presentation is based on Lund (2004), which in turn is a generalization of results in Fleming and Rishel (1975).

The first step is to find the optimal control and value for a corresponding problem, in which we treat the control H as a given constant,

$$\hat{V}(0,\mu,a^2) = \sup_{I\in\mathcal{B}} E\left[-\int_0^T e^{-rt}\left(AI_t^2 + 2FI_t\right)dt + v(K_T)|\mathcal{Z}_0\right]. \quad (5)$$

As noted above, we do not observe the true quality level K_t. Instead we observe the (noisy) signal Z_t, which represents the information the developer has about the product quality at time t. This information is based on historical observations of the state of the system in the period $[0, t]$. Based on this information, the producer can try to find an estimate of the (partially) unobservable state process K_t. This estimate is denoted $\hat{K}_t$, with precise definition

$$\hat{K}_t = E[K_t|\mathcal{Z}_t].$$

Fleming and Rishel (1975) show that this (observable) process satisfies the stochastic differential equation

$$d\hat{K}_t = I_t dt + R(t)H\frac{1}{\sigma_1}d\hat{W}_t, \tag{6}$$

with $\hat{K}_0 = E[K_0|\mathcal{Z}_0] = \mu$, and $d\hat{W}(t) = (dZ_t - H\hat{K}_t dt)/\sigma_1$. The function $R(t)$ represents the mean square error of the estimate, i.e., $R(t) = E[(K_t - \hat{K}_t)^2]$. The function R satisfies the Riccati differential equation

$$\frac{dR(t)}{dt} = \sigma_0^2 - \frac{H^2}{\sigma_1^2}R^2(t) \tag{7}$$

with initial value $R(0) = a^2$.

It can now be shown that the optimal investment strategy can be formulated as

$$I^*(t) = -e^{rt}\frac{1}{A}\left[\Pi(t)\hat{K}_t^* + Fe^{-rt} + \phi(t)\right]. \tag{8}$$

The variable $\hat{K}_t^*$ is observable, and given by the stochastic process

$$d\hat{K}_t^* = I_t^* dt + R(t)H\frac{1}{\sigma_1^2}d\hat{W}_t^*,$$

$d\hat{W}_t^* = (dZ_t - H\hat{K}_t^* dt)/\sigma_1$. The functions Π, ϕ solve the following ordinary differential equations,

$$\frac{d\Pi_t}{dt} - \frac{\Pi_t^2}{e^{-rt}A} = 0, \qquad \Pi(T) = e^{-rT}\frac{f}{r} \tag{9}$$

and

$$\frac{d\phi(t)}{dt} - \frac{1}{e^{-rt}A}\Pi(t)\phi(t) - \frac{F}{A}\Pi_t = 0, \qquad \phi(T) = -\frac{e^{-rT}p^2}{8c(r+2\theta)}. \tag{10}$$

These equations can be explicitly solved, giving

$$\begin{aligned}\Pi(t) &= \frac{Ae^{-rT}f}{rA + \frac{f}{r}(1 - e^{r(t-T)})} \\ \phi(t) &= \frac{e^{-rT}fF(T-t) + r\frac{e^{-rT}p^2}{8c(r+2\theta)}A}{-rA - \frac{f}{r}(1 - e^{r(t-T)a})}.\end{aligned}$$

The optimal control $I^*(t)$ in equation (8) is time dependent, and linear in the estimated quality level $\hat{K}^*(t)$. Note that the optimal control $I^*(t)$ is a continuous function, it does not give a bang-bang solution as in Schwartz and Moon (2000) and Miltersen and Schwartz (2002), among others.

The results imply that the value function for the partial observation problem with a specified information rate H is given by

$$\hat{V}(0, \mu, a) = -\Pi_0\mu^2 - 2\phi_0\mu - \hat{q}(0) - e^{-rT}\frac{f}{r}R(T) \tag{11}$$

where

$$\hat{q}(0) = \int_0^T \left[(R(t)H\frac{1}{\sigma_1^2}\sigma_1)^2\Pi_t - \frac{1}{e^{-rt}A}(e^{-rt}F + \phi_t)^2 \right] dt.$$

The optimal information acquisition problem can therefore be stated as

$$\begin{aligned}V(0, \mu, a) &= -\Pi_0\mu^2 - 2\phi_0\mu - \int_0^T \frac{1}{e^{-rt}A}(e^{-rt}F + \phi_t)^2 dt \\ &- \inf_{H \in \mathcal{B}} \left[\int_0^T \left\{ R^2(t)H^2\frac{1}{\sigma_1^2}\Pi_t \right\} dt + M(H) + e^{-rT}\frac{f}{r}R(T) \right].\end{aligned}$$

Thus, the optimal information policy is given as the solution of this minimization problem.

Remark 3.1 *In this paper we are in a setting where the control variable with respect to information acquisition, H, is assumed to be constant. We have also assumed that this constant maybe chosen at time zero. This makes the process of characterizing the optimal H particularly simple. It is however possible to formulate a more general problem, where* *we relax the condition that H is constant. We could allow it to vary as a (deterministic) time dependent function. In this case the problem of finding the optimal information acquisition function turns out to be a deterministic optimal control problem.*

Since H is assumed constant, the Riccati equation (7) is explicitly solvable with solution

$$R(t) = -\frac{\sigma_0\sigma_1(Ha^2(1+e^{\frac{2\sigma_0 Ht}{\sigma_1}}) + \sigma_0\sigma_1 e^{\frac{2\sigma_0 Ht}{\sigma_1}} - \sigma_0\sigma_1)}{H(Ha^2(1-e^{\frac{2\sigma_0 Ht}{\sigma_1}}) - \sigma_0\sigma_1 e^{\frac{2\sigma_0 Ht}{\sigma_1}} - \sigma_0\sigma_1)}$$

The optimal H level can now be found (numerically) by

$$\min_H \mathscr{P}(H)$$

where

$$\mathscr{P}(H) = \int_0^T \left\{ R(t)^2 H^2 \frac{1}{\sigma_1^2} \Pi_t \right\} dt + M(H) + e^{-rT} R(T).$$

From a dynamical programming point of view, this can be seen as the equation characterizing H as a function of the "state" a^2 at time 0 when it is given that the control may not be updated.

4 Discussion and numerical results

The choice of the control H must be found numerically. Suppose that

Volatility, true quality level:	σ_0	$=$	0.4
Volatility, noisy signal:	σ_1	$=$	0.5
Development cost parameter:	A	$=$	0.1
Development cost parameter:	F	$=$	1
Production cost parameter:	f	$=$	0.05
Production cost parameter:	c	$=$	0.1
Reduced demand over time parameter:	θ	$=$	0.1
Product price parameter:	p	$=$	1
Time for launching the product:	T	$=$	2
Risk free interest rate p.a.:	r	$=$	0.05
Volatility with respect to initial quality level:	a	$=$	2
Expected initial quality level:	μ	$=$	1

in the base case. Assume further that the information acquisition costs are cubical in the information level, we assume $M(H) = 1.2H^3$.

The value of the project, V, as a function of information level, H, is illustrated in figures 1 and 2. Figure 1 shows that the optimal choice of the control level H increases with respect to volatility in the noisy signal, σ_1. Thus, the more noise in the observed signal, Z_t, the more costly effort will the decision maker put into the pre-project, as a high effort H increases the information level about the product quality in the development phase of the project. Moreover, the project value, V, also decreases with respect to the volatility of the noisy signal, σ_1. Figure 2 illustrates that the project value decreases with respect to volatility in the true quality of the product to be developed. The optimal effort level of H is relatively insensitive with respect to the volatility level, although we observe a slight increase in the effort level H with respect to the volatility parameter σ_0.

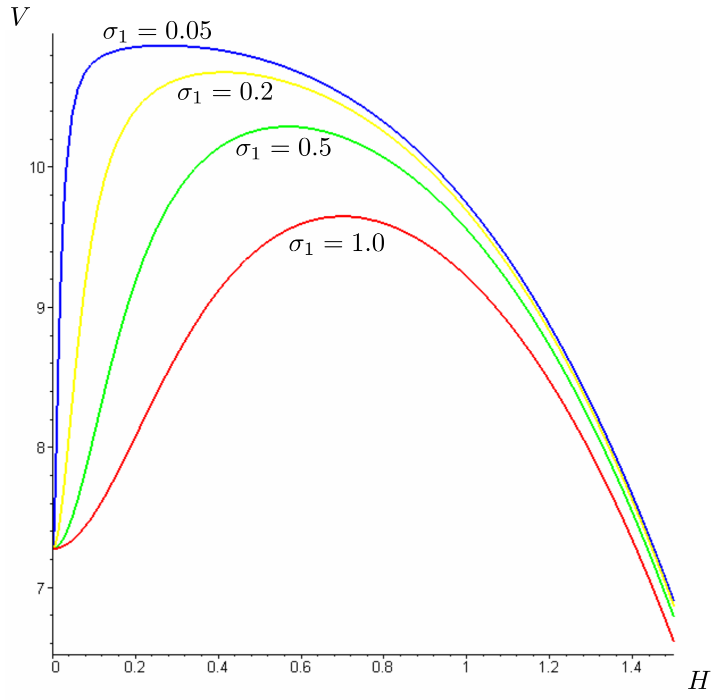

Figure 1: The project value, V, as a function of information level H for different values of the volatility parameter, σ_1, of the noisy signal, Z_t.

5 Summary and conclusions

We have in this paper focused on a telecommunication company planning to launch a new product at a future time T. The project consists of three stages: In the pre-project phase effort is made to acquire information about new technological innovations and product features that will be in demand in the future. This phase is necessary to gain insight into the expected quality level demanded by future consumers. In the product development phase the company aims to develop a product of a certain quality. However, the observability of this quality level depends crucially on the research done in the first project phase. A thorough market analysis is costly but will give a relatively precise knowledge about the "correct" future quality level. Such an in-depth analysis could for instance include consumer questionnaires. A brief analysis would on the other hand be inexpensive, but leads to more uncertainty about the proper product quality level.

The final quality of the product is stochastic, but could be influenced by the firm in

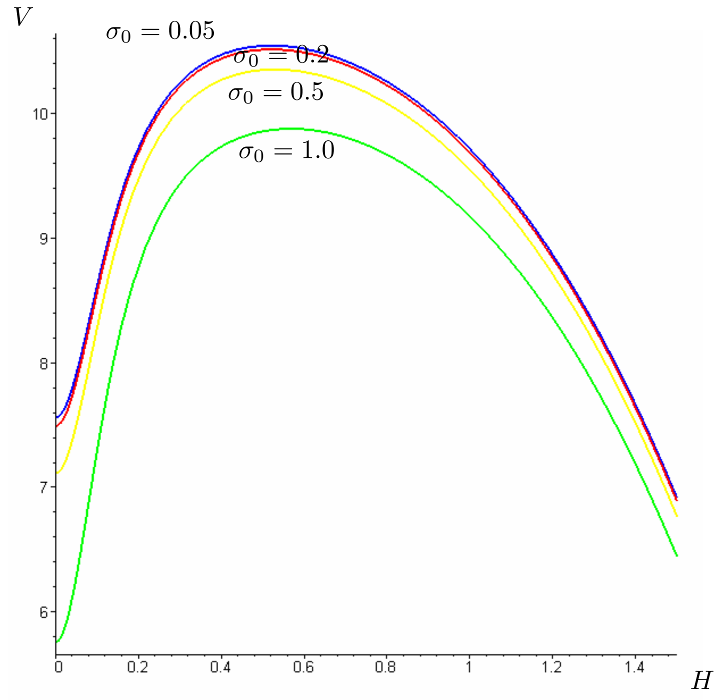

Figure 2: The project value, V, as a function of information level H for different values of the volatility parameter, σ_0, of the true variable, K_t.

the development phase. In this respect we can say that the quality of the product depends on the (chosen) observability of quality, and the costs of developing and producing products of a certain quality. At time T the third project stage starts. The product is now produced and sold in a competitive market.

The objective for the firm is to characterize the optimal investment strategy when the product is developed. It is further necessary for the firm to choose the optimal quality observation level, given that observation costs increases with more precise observations.

In the pre-project phase a market analysis is performed. We have assumed that the costs of this analysis can be model as a function $M(H)$, where H is interpreted as the observation precision level.

When the production begins it is assumed that the quality level of the product is given by a stochastic process which may be influenced by investments I_t. A simple process is assumed. While in the development phase, the current quality level is observed with noise, the precision depends on the chosen level of H specified by the effort in the first stage. Investments incur costs modeled by a function linear-quadratic in I. At time T the firm is assumed to achieve a quality dependent payoff. This payoff function is deduced by working backwards from the specifications in the last phase.

In the last phase we have assumed that the (market) price of the developed product increases linearly with the obtained product quality. To model a "quality decay" due to new products entering the market, we have incorporated a reduction in price as a function of time. We have also assumed that the production cost is quadratic in both quality and quantity.

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