Evaluation of Nested and Parallel Real Options: Case study of Ford's investment in fuel cell technology

By

Skander K. Oueslati

Ingénieur Diplômé de l'Ecole Polytechnique (1995)
Paris, France

Submitted to the Department of Technology and Policy
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Technology and Policy

at the

Massachusetts Institute of Technology

May 1999
[June 1999]

Signature of Author ....
Technology and Policy Program
May 14, 1999

Certified by ....
Richard de Neufville
Professor and Chairman, MIT Technology and Policy Program
Thesis Supervisor

Accepted by ....
Richard de Neufville
Professor and Chairman, MIT Technology and Policy Program

Evaluation of Nested and Parallel Real Options: Case study of Ford's investment in fuel cell technology

By

Skander K. Oueslati

Submitted to the Department of Technology and Policy on May 14th, 1999
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Technology and Policy

Abstract

This thesis explores nested and parallel real options and applies the suggested methodology to the Case of Ford Motor Company's investment in Ballard/DaimlerChrysler's joint venture.

After reviewing the different existing methods that could be applied to the evaluation of Ford's investment, an analysis of the previous major applications of the "Real Option Thinking" to real projects was included. A two dimensional approach in the evaluation of a project with uncertainty was introduced, followed by a suggested methodology.

Two approaches were considered in the Ford Case:

- The first divides the investment into two parts one associated with Ford Holdings in Ballard Power Systems (Ford holds 15% of Ballard shares) and the other relative to the investment in the research and development of fuel cells for automotive applications.
- The second adopts a more global view and looks at the investment as buying a portfolio of options. Each option is relative to a specific application of the technology.

The suggested methodology was applied to the Ford Case using the first approach only. In fact, with the right set of inputs, both methods should yield comparable results.

In the last part of the Thesis, a policy analysis that explores other dimensions that could have influenced Ford's decision was included. This analysis went through isolating the problem, identifying all the available options, analyzing external and internal factors and designing a strategy that would have helped implement the best available option.

Thesis supervisor: Professor Richard de Neufville
Title: Professor and Chairman, MIT Technology and Policy Program

Chapters Outline

Evaluation of Nested and Parallel real options: Case study of Ford's investment in fuel cell technology

List of Annexes

List of Figures

List of Tables

Acknowledgements

à mes Parents,

My deepest gratitude goes to Dr. Richard de Neufville. My experience at MIT has been gratifying thanks to his guidance and counseling. Without him, I would have never explored different evaluation systems for investments in research and development.

I would also like to thank Dr. Richard Tabors and Dr. Maria Illic for successfully transferring their interest in the power industry and in the energy field in general to me. Special thanks to Professor David Marks, Professor John Heywood and to Mr. Bradford Bates from Ford Motor Company for their comments.

This work was made possible thanks to the financial support of the Consortium on Environmental Challenges of the MIT Center for Environmental Initiative.

Needless to say, I would like to thank my family and friends. They know who they are and the importance of their support.

I. Introduction

1. Context

Recent research proved how uncertainty could considerably increase the value of an irreversible project. This effect can be measured through the use of financial tools that were developed for the evaluation of financial options. Many real option theories have been developed but the wide variety of real projects constantly pushes for the development of new tools.

Environmental constraints and corresponding government regulations pushed car manufacturers to try to power their future generation of automobiles using fuel cells. The coexistence of both technical and market uncertainties highlighted the need to use a "real option thinking" to evaluate investments in this technology.

2. Overview of the Thesis

The thesis starts (Chapter II) with an overview of existing methods for the evaluation of investments. The net present value (NPV) method proves to be inadequate for the evaluation of projects with uncertainty because it does not take into account managerial flexibility. Even if the decision analysis tool gets around this problem, the estimation of the required fundamental inputs (probabilities and discount rate) is often hard to justify. Real option methods deal best with uncertainty but can not be applied to all types of risks. In fact, it is extremely hard to model private or project risk using real options since these methods require the use of an underlying asset that is in-existent in most of the cases. It is possible however to apply it to market risk.

Research and development projects generally combine both market and project risk requiring the mix of decision analysis and real option tools. Chapter III will go through examples of research and development investments that aided in the design of a general methodology that is later applied to the Ford case.

Chapter IV introduces two dimensions that one has to consider in evaluating a project with uncertainty, combining the notion of parallel options with the one of Nested options. References to examples of each type are included as well as mathematical tools for their evaluation.

Chapter V suggests a practical methodology for the evaluation of investments in research and development. This methodology is based on the exploration of the two dimensions introduced in the previous chapter.

After describing the Ford case in Chapter VI, the next chapter (Chapter VII) evaluates Ford's investment in the DaimlerChrysler/Ballard joint venture using the suggested methodology. One evaluation is made by focusing on automotive applications of the technology. The effect of other possible applications on the value of this investment are reflected in Ford's stake in Ballard.

The last chapter of this thesis (Chapter VIII) goes through a general description of a policy making process that an auto-maker should have applied to design its fuel cell strategy. This process takes into account all external and internal factors that could influence the choice of a strategy. An application to the Ford Case is included.

3. Main Results

This thesis first highlights the need to adopt a "real option thinking" in the evaluation of irreversible investments with uncertainties. It also proves the necessity to look at two dimensions:

- The number of parallel options associated with the number of targeted markets
- The number of nested or combined options usually associated with the number of stages in the project.

A practical methodology for the application of the "real option thinking" to real projects was suggested and applied to Ford investment in the fuel cell technology.

Among other results, this thesis proves the importance of taking into account the correlation between the outcomes of the research and development phase and the commercialization phase in the case of the introduction of a major innovation. This translates into the use of different stocks as underlying assets to model the market risk according to the advances achieved in the research and development phase.

This thesis also applies a theoretical approach that was developed to identify the more valuable strategy to follow when dealing with the question of when and how to adopt a technological innovation to the Ford case. Annex IV goes through a detailed analysis of the adaptation of this theory to the considered case. It proves that, when dealing with an innovation with a high payoff and with a very long interval between innovations, as in the case of the automobile industry, the best approach is to "acquire" any new developments as soon as they are reached and not to wait for the final version. In the context of Ford, this is equivalent to acquiring any advances that are reached in the development of proton exchange membrane (PEM) fuel cells. Since Ballard is the leader in this field, this can be achieved through taking a stake in the company.

The policy analysis identifies all the fuel cell strategies that were available to Ford and proves, by taking into account external and internal factors, that this company made the best choice. It also suggests a strategy for the implementation of the selected option.

II. Financial Evaluation of Investments in R&D Projects: An Overview of the Existing Methods

This chapter reviews methods of evaluation of investments. The objective being to prove that the options framework is the most appropriate one for investments in Research and Development.

1. NPV method

Apart form its broad use, Net Present Value is one of the best methods for evaluating investment opportunities. As will be discussed later, this statement holds if no future decisions could affect the stream of expected cash-flows.

Two basic ideas are behind this method:

- A dollar today is worth more than a dollar tomorrow,
- A risky dollar tomorrow is worth less than a risk-less dollar tomorrow.

To account for the time value of money in a risk-free world, one should expect to receive \$100 + \$*X* next year for \$100 invested today. In order to evaluate *X*, one should ask oneself: what's the maximum I can get from \$100 invested in a risk-free project. The best available risk-free return corresponds to a one year US Treasury bond (around %5). This person should consequently expect to receive a minimum of \$105 next year. In absence of risk that's exactly the amount one should be receiving.

In the real world, no investor can be sure that next year, he/she will be paid back for every dollar invested today (in a non risk-free project). To account for this uncertainty this person should be asking for more than the risk free rate of return.

The following paragraphs introduce a method of selecting discount rates for investment opportunities.

Portfolio Theory

Most investors maintain a portfolio of securities. Each security carries two types of risks: unique risk (which stems from the notion that, many of the risks that surround an individual company are peculiar to that company) and market risk, which is due to economy wide perils that threaten all businesses. Unique risks can be eliminated through diversification in the selection of securities as shown in figure II.1.

Figure II.1 Effect of the number of securities included in a portfolio on its standard deviation

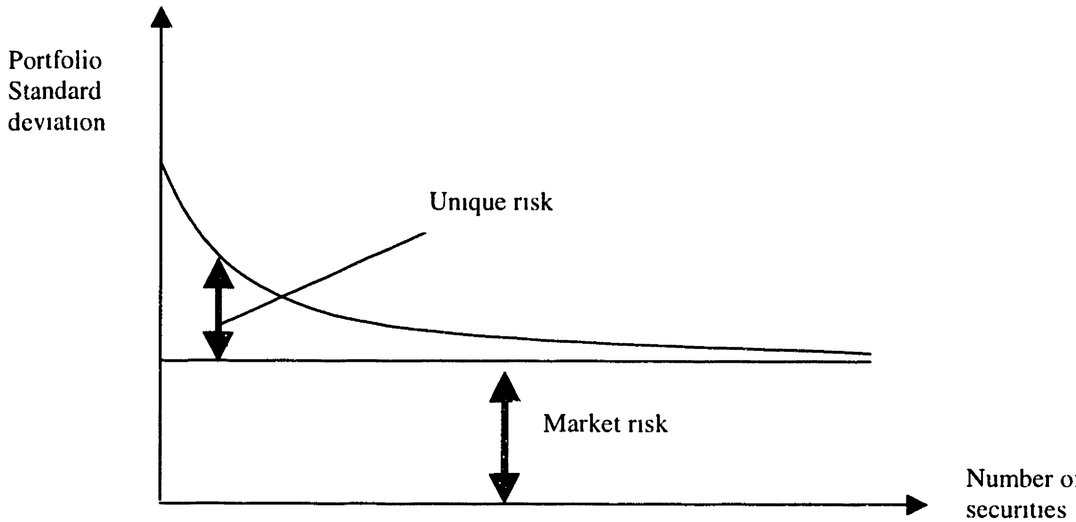
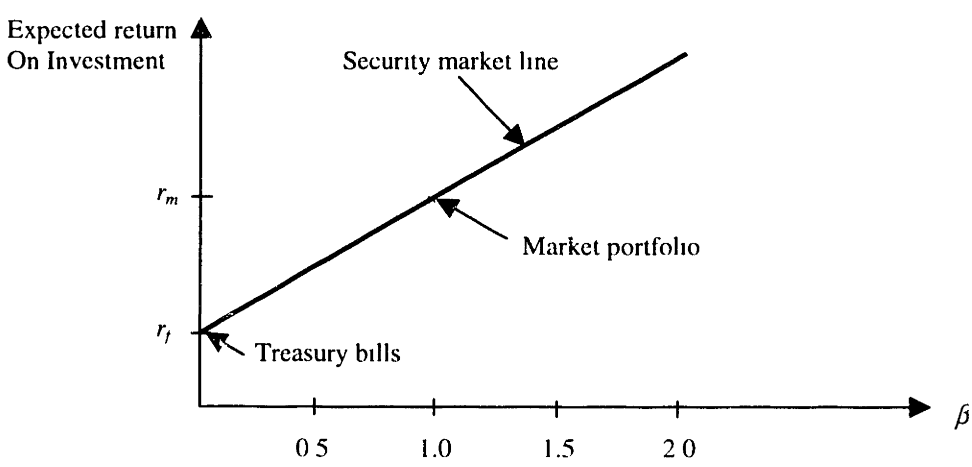


Figure II.2: Expected return as a function of the underlying Beta



A well-diversified portfolio therefore carries only the market risk of the securities included in the portfolio. Before an investor commits money to a project, he/she would like to find out the sensitivity of the new investment to market movements. The measure of this sensitivity to the market movement is called Beta (β).

$$\beta_i = \frac{\sigma_{im}}{\sigma_m^2} = \rho_{im}(\sigma_i / \sigma_m)$$

Where:

- β_i is the sensitivity of the new investment to market movements
- ρ_{im} is the correlation coefficient between the new investment and the market
- σ_i is the standard deviation (variability) of the new investment
- σ_m is the standard deviation of the market
- σ_{im} is the covariance between the new investment and the market

A large portfolio of common stocks can be used as a proxy for the market index. With more securities, and better diversification, the portfolio Beta could be very close to the Beta of the entire market. In essence the Portfolio beta will be equal to one ($\beta = 1$).

Capital Asset Pricing Model (CAPM):

In the mid-1960s three economists, Sharpe (1964), Lintner (1965) and Treynor invented the CAPM model. The model's message is both startling and simple. In a competitive market, the expected risk premium varies in direct proportion to Beta as shown in Figure II.2.

This means that every investor should expect to receive a return that plots along the sloping line, known as the *security market line*. The expected risk premium for an investment with a beta of 0.5 is therefore, *half* the expected risk premium on the market and the expected risk premium on an investment with a beta of 2.0 is *twice* the expected risk premium on the market. This relationship can be written as:

$$r = r_f + \beta \times (r_m - r_f)$$

Where r_f is the risk free rate (Treasury bills) and r_m is the rate of return on the market portfolio.

The problem of selecting the right discount rate is now equivalent to looking for the right beta. For a given project, one should look at similar projects in the market, compute their un-levered beta (100% equity financed), take the average of those numbers and then reintroduce the effect of debt. The result of those computations would lead to the best estimate of the beta of the project. (For more details refer to: Principles of Corporate Finance by Brealey and Myers (1991)).

NPV Calculation:

Once the choice of the discount rate has been made, future expected cash flows have to be estimated and discounted. The net present value of the project is given by the following formula:

$$NPV = -I + \sum_{t=1}^{n} \frac{E(CF_t)}{(1+r)^t}$$

Where I is the initial investment that is needed, $E(CF_t)$ is the expected Cash-Flow in year i and r is the discount rate computed.

As a rule of thumb, one should invest in all positive NPV projects. However, two cases need to be considered:

- If one investor has to choose between investing in project A or B and if both investments are equivalent (I_A and I_B in the same range), he/she should be investing in the project with the highest NPV.
- If the NPV of project A is negative, he/she should not disregard the project before evaluating it using more sophisticated tools which will be introduced later.

The two biggest shortcoming of NPV analysis are:

- It does not take into account the possibility of taking subsequent decisions to improve the economics of a given project after the resolution of some of the uncertainties.
- It is hard to justify the choice of a discount rate in cases where there are no similar projects in the market (it is very often the case in R&D ventures).

Those two issues are addressed by the two following sections that introduce the Decision Analysis method and the Real Options method.

2. Decision Analysis

Decision Analysis is an evaluation method that attempts to account for uncertainty and the possibility of later decisions by management in investment opportunities. It helps management structure the decision process by mapping out all feasible alternative managerial actions contingent on the possible states of nature. As such, it is particularly useful for analyzing complex sequential investment decisions when uncertainty is resolved at distinct, discrete points in time. Decision Analysis forces management to examine its implied operating strategy and to recognize explicitly the interdependencies between the initial decision and subsequent decisions.

The basic structure of the decision setting is as follows:

- Management is faced with a decision (or a sequence of decisions) of choosing among alternative courses of action
- The consequence of each alternative action depends on some uncertain future event or state of nature which management can describe probabilistically on the basis of past information or other,
- Management is finally assumed to select a strategy consistent with its preferences for

uncertain consequences and its probabilistic judgments concerning the chance events. This means that management should choose the alternative that is consistent with maximization of expected utility or the risk-adjusted expected NPV.

Estimating probabilities is often controversial, especially in the case of research and development projects where no benchmark or historical data could be used. Each R&D project is unique and chances of Success/Failure can vary considerably from one project to another. In addition, the choice of a risk-adjusted discount rate is often subject to criticism because the existence of options can change the risk profile of a project.

The following section (Section II.3) illustrates this shortcoming of the Decision Analysis method and introduces Real Options as a way of evaluating investment opportunities.

Example of decision analysis with an option:

Company *X* faces the decision to invest $1million in Research and Development. The research will be conducted during one year. At the end of the first year, the management team will have the results of the research phase and will decide weather or not to implement the new technology. The implementation cost is expected to be around $4 million and the discount rate that is used in this case is 20%. The research team presented estimates of the possible scenarios to the management board. (see Table II.1)

In the High case scenario, the Present Value generated from the implementation computed in year one is equal to the expected benefits minus the implementation cost or $6 million (Table II.2). The company will implement the technology under these circumstances. In the Medium case scenario, the Present Value generated from the implementation computed in year one is equal to $1 million leading to the decision to implement the technology. In the Low case scenario, the same Present Value generated computed in year one is equal to -$3 million leading to the decision to avoid implementing the technology.

The next step would be to take into account the initial investment of $1 million and to discount the values for one more year. Table II.3 explains those operations and computes the total value of the project. The net Present Value of the investment opportunity with the option to drop the project in the case of poor R&D results is equal to $0.167 million. After redoing all the analysis without the option to drop the project, the corresponding results are summarized in Table II.4. The project without flexibility has a negative value.

The value of the option is equal to the difference between the value of the project with and without flexibility: 0.167 - (-0.708) = $0.875million. Figure II.3 plots the corresponding decision tree.

The previous analysis highlights two points:

- Ignoring flexibility can lead to an under-valuation of the project and consequently to the decision to refuse investing in a profitable venture
- Options can be evaluated using the decision analysis tool

Table II.1 Expected benefits over project's life

Scenario	Probability (%)	Expected Benefits over project's life ($million)
High	15	10
Medium	50	5
Low	35	1

Table II.2 Expected Values of implementation computed in year 1

Scenario	PV of implementation in year 1 ($million)	Implementation Decision
High	+ 6	Yes
Medium	+ 1	Yes
Low	- 3	No

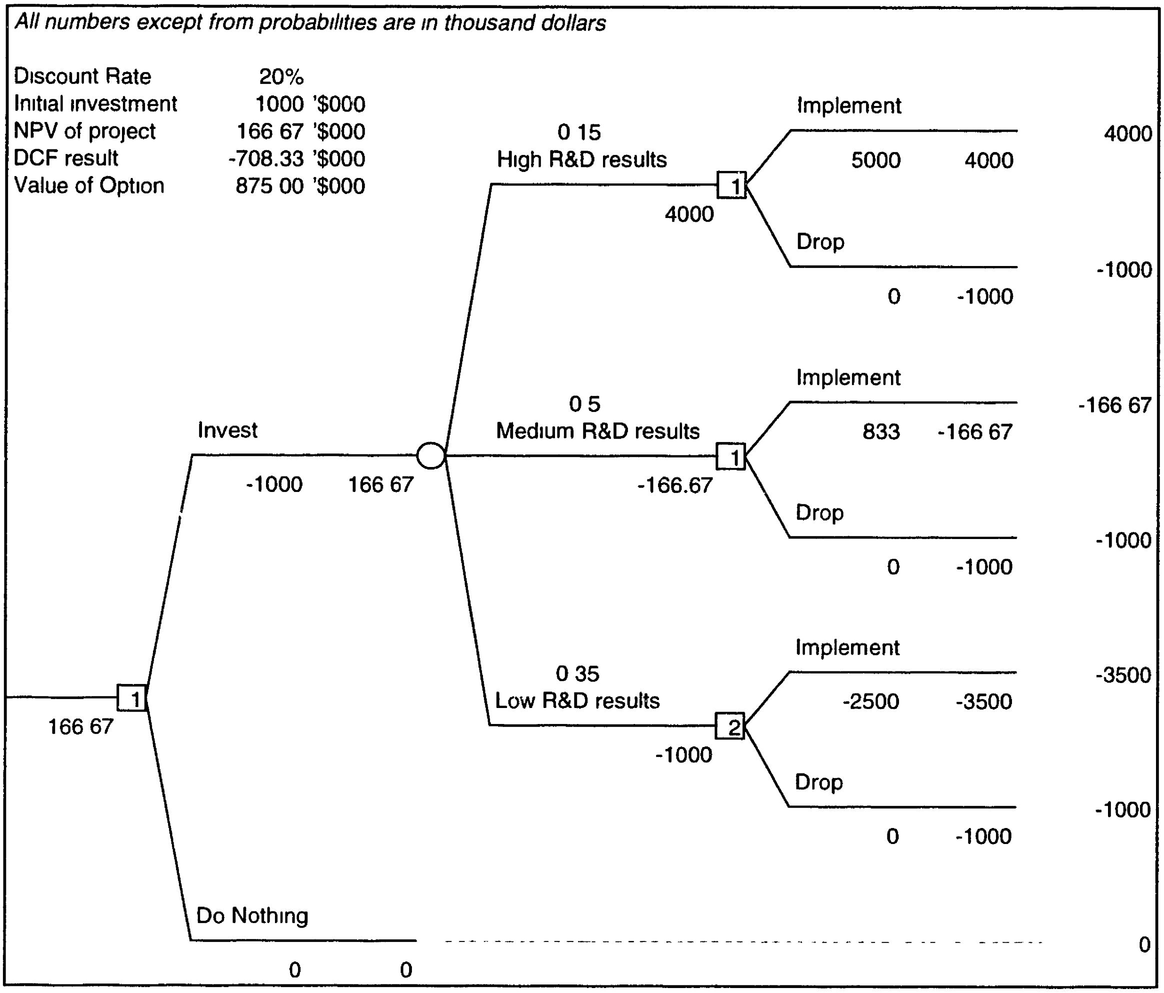
Table II.3 Project's value computation (including flexibility)

Scenario	Present Value ($million)		Probability (%)	Weighted PV ($thousand)
Computed in	*Yr 1*	*Yr 0*		*Yr 0*
High	+ 6	5 - 1	15	0.600
Medium	+ 1	0.83 - 1	50	-0.083
Low	0	0 - 1	35	-0.350
			Total	0.167

Table II.4 Project's value computation (No flexibility)

Scenario	Present Value ($million)		Probability (%)	Weighted PV ($million)
Computed in	*Yr 1*	*Yr 0*		*Yr 0*
High	+ 6	5 - 1	15	0.600
Medium	+ 1	0.83 - 1	50	-0.083
Low	- 3	-2.5 - 1	35	-1.225
			Total	-0.708

Figure II.3 Decision Tree for the example of Decision Analysis



3. Real Options Only

Since the Real Options concept was derived from Financial Options, it is appropriate to start with an overview of some financial options and to introduce ways of evaluating them.

What is a financial option?

An *option* is defined as the right, without an associated symmetric obligation, to buy (*if call*) or sell (*if a put*) a specific asset (e.g., common stock) by paying or receiving a pre-specified price (the exercise or strike price) on or before a specified date (the expiration or maturity date). If the option can be exercised before maturity, it is called an *American* Option; if only at maturity, a *European* Option.

The beneficial asymmetry derived from the right to exercise an option only if it is in the option holder's interest to do so lies at the heart of an option's value. By holding an option contract, a call or a put, one can only expect to receive a positive payoff (price of the contract ignored). Figure II.4 gives the payoffs from holding a call or a put contract on a stock *S* with a strike price of *K*.

Options differ form *futures contracts*, which involve a commitment to fulfill an obligation undertaken to buy or deliver an asset in the future at terms agreed upon today whether the holder likes it or not. Thus, unlike the potential payoff to futures contracts, which are symmetric with regard to up or down movements of the underlying asset, the payoff to options is asymmetric or one-directional.

How to evaluate a financial option?

a. Binomial option valuation method

The binomial option valuation model is based on a simple representation of the evolution of the value of the underlying asset. In each time period the underlying asset can take only one of two possible values: up (*Su*) or down (*Sd*).

In the most widely used version, the multiplicative binomial model of uncertainty, the asset has an initial value *S*, and within a short time period either moves up to *Su* or down to *Sd*. In the next period, the possible asset values are Su^2, *Sud*, or Sd^2. (see figure II.5)

The specific parameter values are chosen so that the resulting final distribution corresponds to the empirical reality. The risk-neutral approach requires the use of the risk free rate of interest for discounting purposes and uses the risk-neutral probabilities computed as follows.

The probability of an up event is: $p = (r-d)/(u-d)$

Figure II.4 Call and Put options payoff diagrams

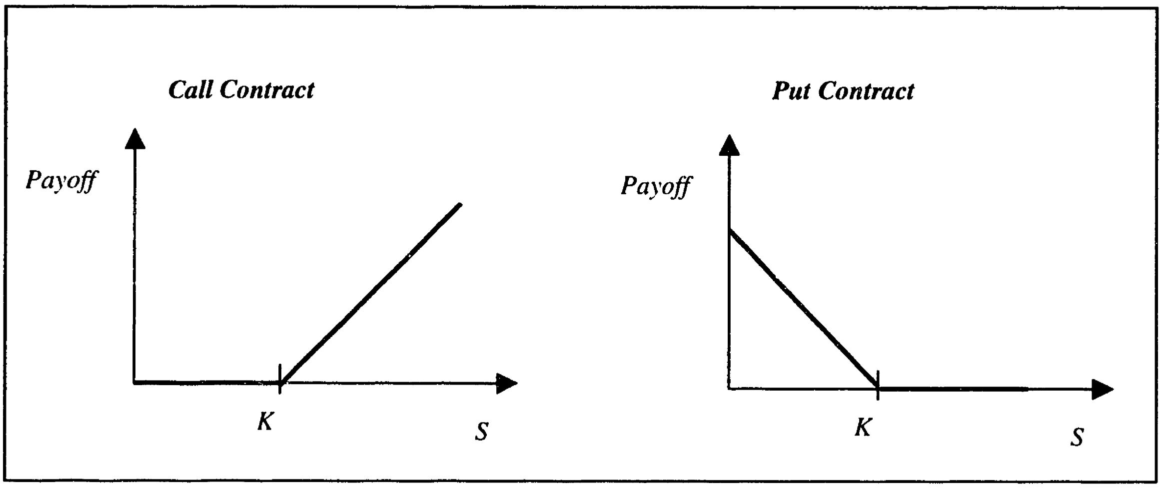
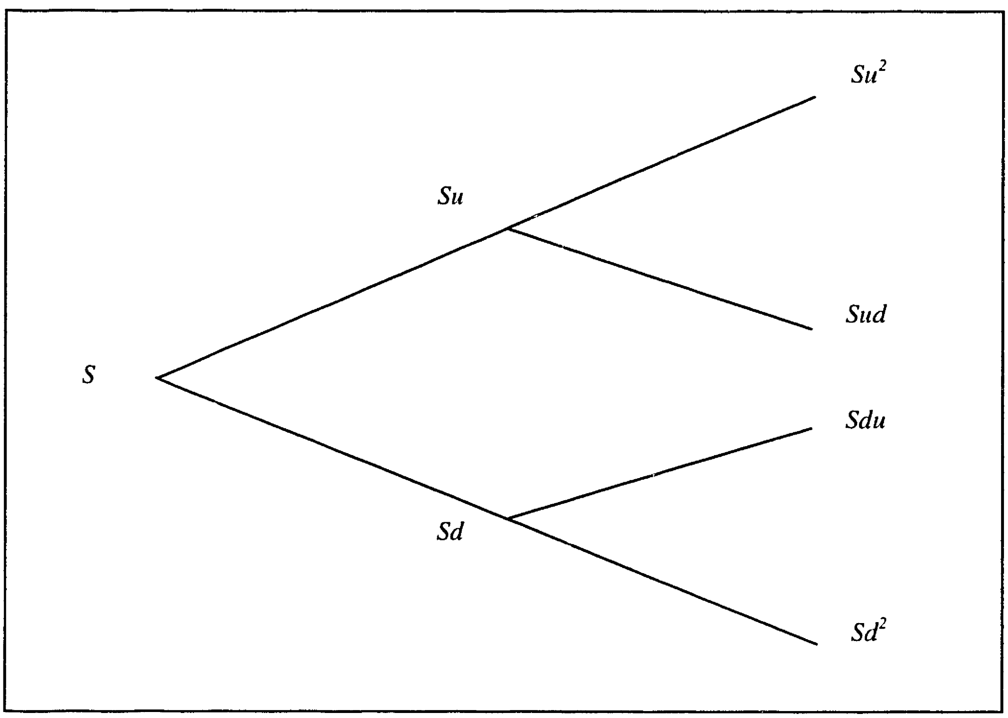


Figure II.5 Two period binomial method



Where r = 1 + risk-free interest rate, u = one-period asset price change factor for an up event and d = one-period asset price change factor for a down event.

The probability of a down event is: $p' = 1 - p$

The binomial method assumes that the underlying asset follows a mean-drift process. This process has two components, an average drift rate that represents long-term expected returns on the asset and a stochastic term that describes the uncertainty in future prices.

$$dS/S = \mu\, dt + \sigma\, dZ$$

Where, μ = expected return on S, σ = standard deviation of expected returns on S and

$dZ = \varepsilon\sqrt{dt}$ is a Weiner process (random walk)

This process leads to a lognormal distribution of relative price changes, represented in the following equation where Z becomes the standard-normal distribution for short periods of time.

$$LN(S_{t+\Delta t} / S_t) = \mu\, \Delta t + \sigma\sqrt{\Delta t}\, Z$$

For short time periods, the upward change in S can be estimated as shown below:

$$LN(S_{t+\Delta t} / S_t) = \sigma\sqrt{\Delta t} = LN(u)$$

Since relative price changes in the lognormal distribution are equally likely, u and d for the binomial model can be estimated as follows:

$$u = 1/d = e^{\sigma\sqrt{\Delta t / n}}$$

Where, n is the number of intervals used to simulate the one-period price change.

We can verify that this analysis is risk-neutral by examining the expected return on the stock $EV(S)$:

$$EV(S) = p\,Su + p'Sd = (r-d)/(u-d)Su + (u-r)/(u-d)Sd$$
$$[EV(S)](u-d) = r\,Su - r\,Sd$$
$$EV(S) = r\,S$$

The last equation shows that the binomial model acts as if the return on the underlying asset is expected to be the risk-free rate of return. Since this represents the return expected in a risk-neutral world, the risk free rate can be applied to discount cash flows that are functions of the underlying asset (benefits, call option, etc...).

The price of a European call option on the asset S, with a strike price K and a time to maturity equal to the length of the two periods considered in figure II.5 is computed as follows:

$$C = [p^2 Cuu + 2pp'Cud + p'^2 Cdd] / r^2$$

Where, Cuu = Max [0, Suu - K], Cud = Max [0, Sud - K], and Cdd = Max [0, Sdd - K]

For one period : $C = [pCu + p'Cd] / r$

b. The Black-Scholes asset pricing formula

The Black-Scholes (1973) pricing formula is one of the best methods for the computation of the value of a European call option. It is the solution to the following partial differential equation:

$$\tfrac{1}{2}\sigma^2 S^2 C_{SS} + rSC_S - C_\tau - rC = 0,$$

Subject to :

$$C(S,0;E) = \max(S - E, 0),$$
$$C(0,\tau,E) = 0, and$$
$$C(S,\tau;E)/S \rightarrow 1 \; as \; S \rightarrow \infty$$

Where the subscripts denote partial derivatives and $C_\tau = -C_t \equiv -\partial C/\partial t$
S is the price of the underlying asset, E is the exercise price, C is the value of the call option, r is the risk-free rate of return and σ^2 is the variance of asset returns.

Black and Scholes solved the previous partial differential equation obtaining their famous formula which corresponds to the limit of the multiplicative binomial process when the number of periods (n) increases indefinitely.

The solution is the following: $C(S,\tau;E) = S\,N(d_1) - Ee^{-r\tau}N(d_2),$

Where:

$$d_1 = \frac{\ln(S/E) + (r + \tfrac{1}{2}\sigma^2)\tau}{\sigma\sqrt{\tau}},$$
$$d_2 = d_1 - \sigma\sqrt{\tau},$$

And $N(.)$ is the cumulative standard normal distribution function.

Why a Decision Analysis approach can be not satisfactory in some cases?

One shortcoming of decision analysis is that it does not solve the discount rate problem that plagues NPV when projects have future decision opportunities.
The following example illustrates how the Real Options model gets around some problems that can not be solved through the use of traditional capital budgeting.

A car manufacturer wants to value the opportunity to invest in a project (such as a research and development effort to reduce tailpipe emissions). One year later, this project is expected to generate a value of subsequent cash flows of $180 million under good conditions ($V^+ = 180$) or $60 million under bad conditions ($V^- = 60$). Each outcome has an equal probability of ($q = 0.5$). The government, wishing to support this project, offers a guarantee (or insurance policy) to buy the entire output for $180 million if the bad conditions occur. Without the government's guarantee, the project's cash flows have an expected rate of return of $k = 20\%$, while the risk-free interest rate is $r = 8\%$. (Figure II.6)

The task here would be to comp¹te the present value of the project and the value of the put option provided by the guarantee (P).

The government's guarantee is like a put option giving the company the right to "sell" the project's value ($V^- = 60$) and receive the guaranteed amount (or exercise price) of $180 million. As illustrated above, under good conditions, next year the guarantee would be worthless ($P^+ = 0$); under the bad conditions it would be worth $120million ($P^- = 180 - 60 = 120$).

Using traditional DCF techniques, one would get the following for the present value of the project without guarantee:

$$V = \frac{E(CF_1)}{1+k} = \frac{qV^+ + (1-q)V^-}{1+k} = \frac{0.5 \times 180 + 0.5 \times 60}{1+0.20} = 100$$

And for the value of the project with the guarantee:

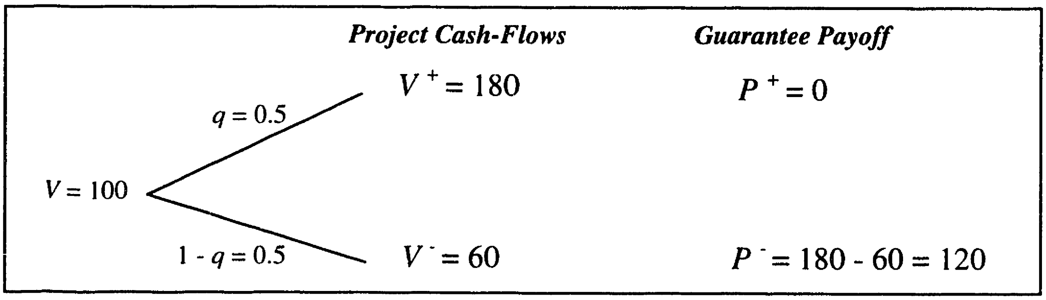
$$V^* = \frac{0.5 \times 180 + 0.5 \times (60+120)}{1.20} = 150$$

The value of the put option provided by the guarantee would be estimated as follows:
Value of guarantee = Project's value with guarantee (V^*)
- Project's value without guarantee (V)
= 150 - 100 = 50

This traditional valuation assumes that the payoff of the put option (guarantee) has the same risk and could be discounted at the same rate as that for the bare project (without the guarantee), i.e.,

$$\textit{Value of guarantee (put option)} = \frac{0.5 \times 0 + 0.5 \times 120}{1.20} = 50$$

Figure II.6 Project payoffs under different scenarios



This traditional DCF calculation however, is clearly wrong. Since the flexibility to abandon the project for a guaranteed price would alter the project's risk and its discount rate. In fact, in this case where the exercise price is the same as $V^+ = 180$ the government guarantee eliminates the project's risk entirely, since the firm will receive $180 million under any conditions. Thus, done correctly, the expected cash-flow should be discounted at the risk-free discount rate: $V^* = 180/1.08 = 166.7$
The value of the guarantee is consequently: 166.7 - 100 = 66.7

Although the correct discount rate for the project with the guarantee is clear in this special case where risk is eliminated completely, finding the correct risk-adjusted discount rate via standard DCF analysis is practically infeasible in most actual situations involving real options.

The use of a Real Option evaluation based on a "risk-neutral" probability distribution, would lead to the same value for the put option with a guarantee at 180. (See following sections for more details about this methodology)

What is a real option?

Real Options is another method for valuing projects with future decision opportunities. It is based on models that are used to value financial instruments.
Three important investment decision characteristics are relevant in Real Options approach:

- Irreversibility
- Uncertainty
- Managerial Freedom Degree and Timing

Most investments are like a call option on a common stock. They give the holder the right to make an investment and receive a project (see the call option analogy *p.*15). The project value fluctuates stochastically and most investments options (or investment opportunities) are not "now or never" opportunities. There is a value of waiting to invest. One would exercise the option (not the obligation) to invest only if the project is sufficiently "deep in the money". In others words, if the project's output price and/or the dividend yield of the project are sufficiently high. Some financial options solutions may be useful in the context of real investments (with some relevant adaptations and parameters interpretations) using analogies like the dividend yield analogy.

For example, one can think about R&D as the creation of options. Through its research investment, a company is establishing the basis to develop and ultimately launch a new product. If the research suggests real commercial potential, management can commit additional funding. If not, executives can cut short both the research and the investment and apply the resources elsewhere. In many cases, options theory can lead to decisions that are directly opposite to those arrived at using net present value (NPV) calculation.

Call option analogy:

An irreversible investment opportunity (F) is like a financial call option: the manager can (but is not obligated to) spend the investment cost (D) to obtain a production asset (V), and usually this investment opportunity remains only by a time interval (T-t).
The financial call option is like F, its exercise price is like D, the stock (received with the exercise of the option) is like V, and the call's expiration time is like (T-t). The financial analogy is more adequate with financial assets paying continuous dividends (or interest) because of the analogy with cash flows (see below the dividend yield analogy).

The expiration time in real investment could be the time from a patent's right expiration, the time from the expiration of a lease in an offshore tract, or an estimated time considering the threat of preemption or intense industry rivalry (see Kester, 1984).
However, there are some differences and considerations when performing this analogy:
According to Sick, 1995 (abstract):

- "the early exercise decision is more important in real options analysis, greater flexibility in modeling project is needed" and his instructive practical lesson,
- "The ability to be able to build a useful and understandable model, is more important to the analyst than precise estimates of option value."

Dividend Yield Analogy:

The net cash flows from a production project are analogous to dividends received from holding a stock or periodic revenues from assets in general. There is an analogy between the dividend yield from a project and the dividend yield characterized by the currency interest rate in the currency option market, because the dividends are close to continually distributed over the time. This analogy is more general: the option in a project paying a continuous net cash flow is analogous to options written on commodities and commodity futures contracts. The underlying commodity varies from a natural resource like petroleum or silver to a financial issue such as foreign currency or a Treasury bond. Each case has its specific adaptations, but the general understanding is the same. In most cases, it is reasonable to consider the dividend yield from the project as a constant even when cash flows diminish over time (like a depletive oil field). In fact, the project value (the oil field value) also decreases, so the percentage variations can be considered more or less the same (or when using an average value is reasonable). With a constant dividend yield, a simplified solution could be used, such as an analytic approximation. Some analytic approximation models are available in the literature on financial options that could be used in the real options context. Other approaches just find numerical solutions, such as models that consider the dividend yield as a function of the underlying project value or even models considering the dividend yield as stochastic process itself, correlated with the project's value.

Example of a real option analysis:

A car manufacturer has the opportunity to invest in new painting facilities that will reduce the total cost of painting a car by $9.5 per unit. This company has the choice between investing today or in one year. The needed investment is of $1.2billion and it will take one year to make these units fully operational. The benefits from the implementation of this technology are equal to the per unit benefits multiplied by the expected future sales of vehicles. The critical uncertainty here is relative to future sales of vehicles.

By running a regression to look for the relationship between past variations in car sales and fluctuations in the price of the stock (Ford Stock was used in this example), one can derive the following equation:

$$\text{Equation 1: } Demand_{t+n} = Demand_t \, e^{(A+B\ln(S_{t+n}/S_t))}$$

Where $A = 0$ and $B = 0.253$ for $n = 1$

Annex I includes a detailed analysis of the characteristics of Ford stock. By assuming that today sales amount to 6 million cars per year and that the uncertainty relative to the demand for Ford cars will last only for one year (simplifying assumption), one could do the following analysis:

Given the yearly expected evolution of Ford's stock plotted in figure II.7 and through the use of Equation 1, one could derive estimates of the expected evolution of Ford's sales (see figure II.8).

Using these estimates and the assumptions made before, one could compute the value of the project under both scenarios: make the decision today and invest next year only if it is appropriate to do so. (The results are summarized in Table II.5)

Table II.5 proves that it is valuable to wait and that the value of the option to wait is worth \$34.76 million.

This is an example of the evaluation of a real option using the binomial method and Ford Motor Company's stock as an underlying asset.

Figure II.7 Expected evolution of Ford's Stock using the Binomial method (over one year)

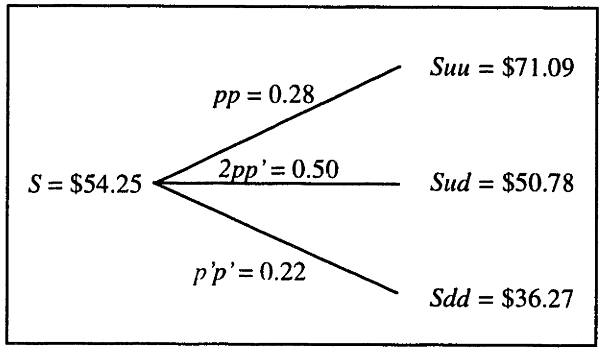


Figure II.8 Expected evolution of Ford's sales (for illustration purposes only)

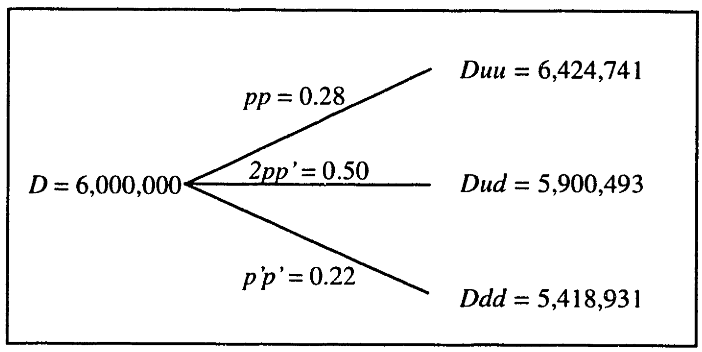


Table II.5 Evaluation of the option to postpone the investment decision for one year

	NPV (in $million) if invest	
Scenario	Today	Only if appropriate
High	77.84	74.14
Medium	(21.76)	-
Low	(113.26)	-
Expected value	(14.00)	20.76
Value of Option to wait		34.76

When or when not to use the Real Options approach:

The real options approach is not always needed. Some decisions do not require an intensive analysis, The Boston Consulting Group refers to them as "no brainers" the investment is either incredibly valuable or a "total dog", and a Real Options analysis will not change this result. Many decisions fall into a gray area requiring hard-headed thinking, and the real options approach can help.

Traditional tools work well when there are no options at all, or there are options but very little uncertainty. Traditional tools correctly value the proverbial "cash-cow" business (The one that steadily produces the same gently declining cash flow each year without further investment) and products that have no follow-on opportunities. Although uncertainty is everywhere, the consequences of uncertainty for some projects are sufficiently small that they can be ignored.

A real option analysis is needed in the following situations:

- There is a contingent investment decision. No other approach can correctly value this type of opportunity.
- Uncertainty is large enough that it is sensible to wait for more information, avoiding regret for irreversible investments.
- The value seems to be captured in possibilities for future growth options rather than current cash flow.
- Uncertainty is large enough to make flexibility a consideration. Only the real options approach can correctly value investments in flexibility.
- There will be project updates and mid-course strategy corrections.

4. Which method should be used in the evaluation of R&D projects?

Although the following section refers to examples from the automobile industry, the reasoning could be easily applied to any R&D venture.

In April of 1998, Ford Motor Company invested a total of US$430 million in the Ballard/DaimlerChrysler joint venture. Their objective was to participate in the joint development of a Fuel Cell powered drive-train. According to the announcements made by the members of the "Global Alliance", many decisions regarding future developments of this technology would be made down the road. Figure II.9 illustrates the different needed steps in the development of a new model in the automobile industry.

Figure II.9 Needed steps in the development of a new model in the Automobile industry

Research	Concept	Advanced Vehicle Design	Component Design	Prototype Building and Testing	Process Engineering
• Powertrain Research • Materials Research • Electronics and Controls	• Product Planning • Technology Planning • Powertrain Planning	• Vehicle Engineering • Design Engineering • Styling	• Product Engineering • Body, Chassis Powertrain, Engine, Transmission, Electrical Engineering	• Prototype Building • Testing	• Plant Engineering • Manufacturing Engineering

Table II.6 Decision Analysis versus Real Options

Decision Analysis		Real Options	
Appropriate for specific/private risk		*Appropriate for market risk*	
Pros	**Cons**	**Pros**	**Cons**
No need for an underlying			Hard to select the right set of underlying
	Hard to justify the choice of the discount rate	Direct use of the risk free rate	
	Hard to estimate the probability distribution	Justified use of the risk-neutral probability distribution	
Easy to explain the strategies/scenarios			Obscure without the use of the binomial method

The "Global Alliance" is still in the Research Phase, but by the end of 1999 they will be deciding if they are going to follow up with this project by proceeding to the next step or not. The research phase will resolve some of the uncertainty about the feasibility of such product.

Managers have the objective to maximize shareholders' value. They will consequently adapt their strategic decision each time there is uncertainty resolution. To evaluate an investment in technology innovation in the automobile industry, the financial analyst should take into account managerial flexibility. Since the DCF method is based on the forecast of future (out/in) cash-flows according to a given plan, and to discount them to the present time, it is impossible to model the benefits of flexibility using this approach. A DCF approach will undervalue this project.

To account for managerial flexibility one could use a decision analysis approach. However, the coexistence of many decisions to take that would affect the overall value of the investment increases the number of inputs. In fact, for each stage, a Decision Analysis approach would require that the financial analyst estimate the probabilities of the different outcomes and the discount rate. It is relatively hard to justify the choice of those values in a Decision Analysis approach. In addition, running a sensitivity analysis would not solve the problem since the "Base Case" scenario is hard to define.

The only remaining methodology is a Real Option approach. It is relatively easy to look at Ford investment in the Joint-Venture as an option. In fact, through its investment, Ford Motor Company holds the right and not the obligation to use the Fuel Cell technology in future models if the economics of the implementation justify the investment (strike price) at the maturity date. The Case study will prove that this investment includes more than one option.

In the general case, it is not always possible to find a proxy in the market from which all the information needed to apply financial option evaluation tools can be extracted. This depends on the type of risk embedded in the analysis. The following sections introduce the two types of risks that are usually encountered in the analysis of an investment with uncertainty.

Private or Project risk:

As highlighted by Amram and Kulatilaka (1999), Real Options have risks that are not contained in the available set of traded securities, risks that are not priced in the financial markets. For example, risk of failing to develop a new technology is a *private risk* carried by a high-tech firm. The risk of not finding a large amount of oil in a particular prospect is a private risk borne by an oil firm. The effect of private risk in an option valuation model can be quantified, but it is not tracked by traded securities (no financial option evaluation tool can be used).

The nature of private risk may vary over time. For example, a nuclear power plant may be periodically inspected, leading to a periodic probability of a forced shutdown.

Staircase reductions in private risk arise in learning investments. When each stage of investment reduces the range of possible outcomes; without the investment, there is no reduction in the private risk.

Carefully specifying the nature of private risk leads to better results. Computationally, it is difficult to value options with more than three or four sources of uncertainty, so an iteration back to the word picture may be needed, picking out only those sources of private risk most important for decision making.

The current level of this private risk and the estimate of the range of uncertainty about that value are based on historical data, actuarial information, engineering estimates, and so on. Often organizations have not tracked levels of private risk in the past, but they develop better estimates after a few iterations using the real options approach. The use of Decision Analysis tools is recommended to deal with such uncertainties.

Market-priced risk (volatility of the underlying asset):

In most of cases, this input cannot be observed in the financial markets and must be estimated from either historical data or traded options contracts. For real assets, the most common way to estimate volatility is to make a simple statistical calculation from historical data.

A second method to estimate volatility uses the price of option contracts on the same underlying asset. For example. five option contracts might be traded on Intel stock with the same maturity but different exercise prices. The prices of these contracts are observed and can be used along with the other option pricing inputs to solve for volatility. This estimate is known as the implied volatility (it is implied from the price of the option and the other inputs) and is viewed as the financial market's forecast of the volatility expected to prevail until the maturity date of the contracts.

The previous paragraphs suggested ways of estimating volatility when dealing with market risk. Once a good estimate of such volatility is obtained, one should use financial option evaluation tools to estimate the value of the corresponding investment opportunity.

It is very common to identify both private and market risk in a research and development project highlighting the need to mix both DA and OPT tools in the evaluation of R&D investment opportunities (See section III.3). Table II.6 summarizes the major differences between both tools.

III. Overview of Applications of Existing Methods to the Evaluation of Investments in Research and Development

This chapter investigates three different applications of both the real options and decision analysis tools to the evaluation of investments in research and development. The first is a pure real options approach adopted by Merck in their evaluation of investments in new drugs. The second is a pure decision analysis approach adopted by Kodak in their evaluation of investments in R&D for the design of color printers. Finally, the third combines both real options and decision analysis tools to the evaluation of R&D ventures in the automobile industry.

Annex II includes an overview of some project evaluations using the real options framework.

1. The Merck approach

According to Nichols (1994), the Financial Evaluation and Analysis Group at Merck uses real options in its evaluation of investment opportunities. In fact, besides its in-house research efforts, Merck invests in small Biotech companies that will conduct research and development for them. In such cases, the pharmaceutical company will make an up-front payment followed by a series of progress payments to the smaller company (or university) for research. These contingent progress payments give Merck the right but not the obligation to make further investments and receive the right to use the findings if any. This falls under the *real options* contract type.

In its evaluation of one of those projects, "Project Gamma", Merck's finance department used the Black-Scholes option pricing model. Under the terms of the proposed agreement, Merck would make a $2 million payment to Gamma over a period of three years. In addition, they would pay Gamma royalties should the product ever come to market. Merck had the option to terminate the agreement at any time if dissatisfied with the progress of the research.

For the purpose of the evaluation of "Project Gamma", the finance department defined the following factors:

- *The exercise price*: Capital investment to be made approximately two years hence.
- *The stock price*: Present value of the cash flows from the project (excluding the "exercise price", the present value of the up-front fees and development costs over the next two years).
- *The time to expiration*: The option could be exercised in two years at the earliest and was structured to expire in four years because of possible competition.
- *The volatility of the underlying*: A sample of the annual standard deviation of returns for typical biotechnology stocks was used as a proxy measure for project volatility.

The option value that the Financial Evaluation and Analysis Group arrived at from the above factors showed that this option had significantly more value than the up-front payment that needed to be invested.

It is important to highlight two points here:

- Merck does not separate the endogenous risk relative to the research phase from the exogenous risk associated with market conditions.
- The existence of financial information on a number of Biotechnology companies makes the search for the underlying easier and might justify the previous point.

2. The Kodak approach

In his article "Applying 'Option Thinking' to R&D Valuation", Faulkner (1996) proves that the decision analysis tool combined with an "option thinking" is the most appropriate tool for the valuation of investments in R&D. After showing the shortcomings of the DCF approach, he proves that the Black-Scholes formula can appear complex and obscure to managers. It is consequently considered as unpractical. In addition, he claims that the use of a lognormal distribution to describe future uncertainty can not be justified in the case of real options. Finally, he considers the binomial method as being a particular application of the decision tree approach.

The case discussed in his article describes Kodak's valuation of their investment in the research and development of a high-resolution color printer (Figure III.1). He compares the result obtained through the use of Decision Analysis and a "real options thinking" to both a classical and modified DCF analysis. As expected, the result of the "option thinking" approach gives the highest value.

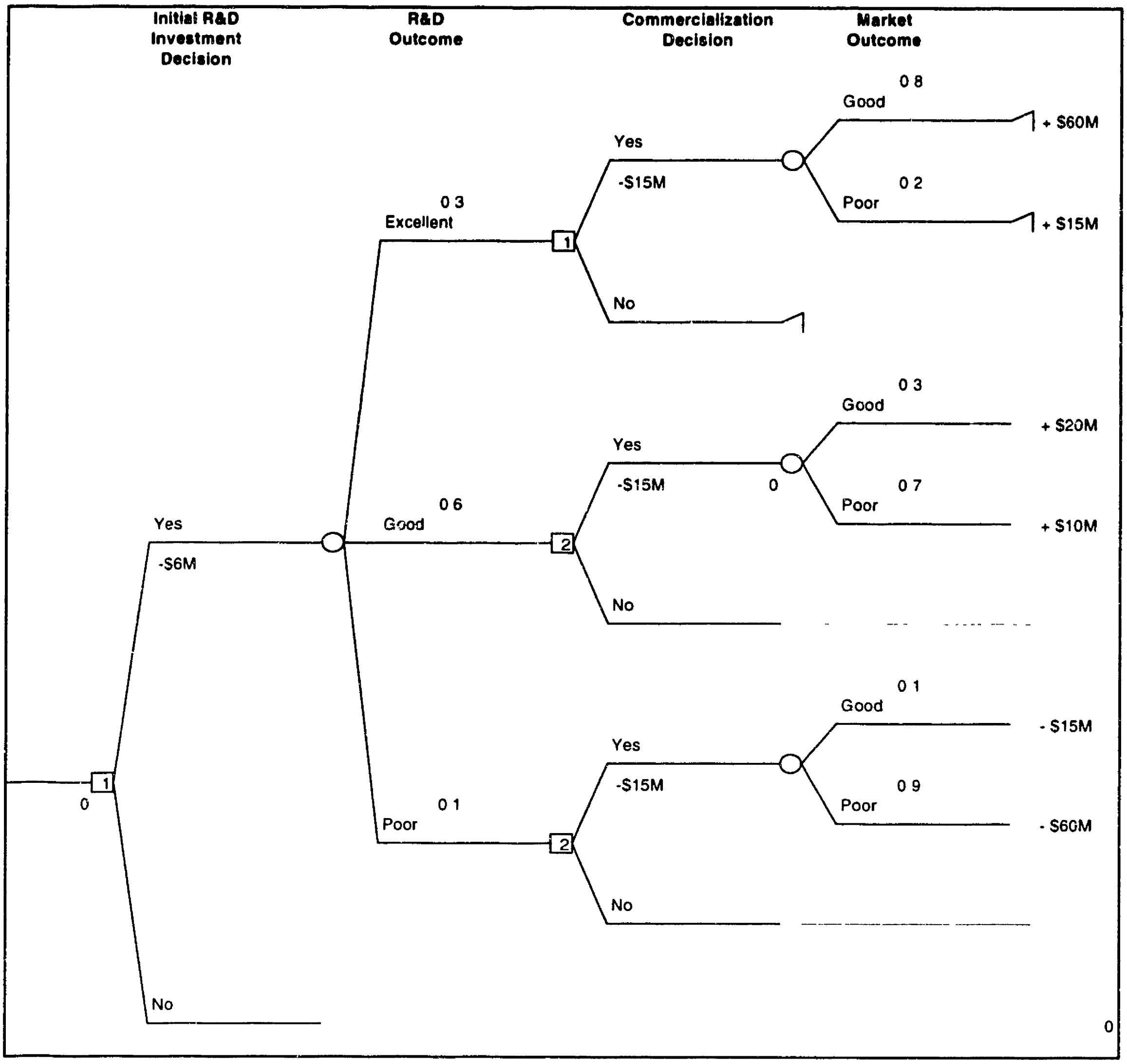
Kodak's approach takes into account two sources of uncertainty:

- First Phase: R&D outcomes
- Second Phase: Market outcomes

In the first phase, three R&D outcomes were considered: excellent, good and poor. However, only two market outcomes were considered in the second phase. The "option thinking" was included between the two phases. In fact, at the end of the first phase the R&D uncertainty would be solved and managers would have to decide either to exercise the commercialization option or to drop the project. For both sources of uncertainties, a Decision Analysis approach was used.

Faulkner did not recommend the use of market priced assets as a proxy in the commercialization phase because the market was an emerging one and the returns were highly uncertain. In addition, the future returns depended on the cost/performance characteristics of the product that the R&D phase would have delivered. This means that both phases are correlated and that the methodology suggested by Neely (1998) and discussed in the next section is not applicable to this case.

Figure III.1 Kodak's Valuation of Color Printer Project



3. The Composite Approach

Neely, (1998) introduces a composite model for the valuation of the option to implement a successful R&D project in his estimate of project value. He assumes that the underlying R&D project has three phases:

- The R&D investment decision
- Uncertainty resolution through R&D
- The implementation decision (commercialization)

For the R&D phase he assumes that if R&D is initiated, the project continues until the technology is potentially implementable and limits the analysis to a single choice: pursue R&D or not. This phase is characterized by the existence of endogenous uncertainties. These uncertainties have no relation to external market events explaining why it is not appropriate to use a real option approach at this stage. In fact the real option methodology is based on the use of market priced assets as proxies for the evaluation.

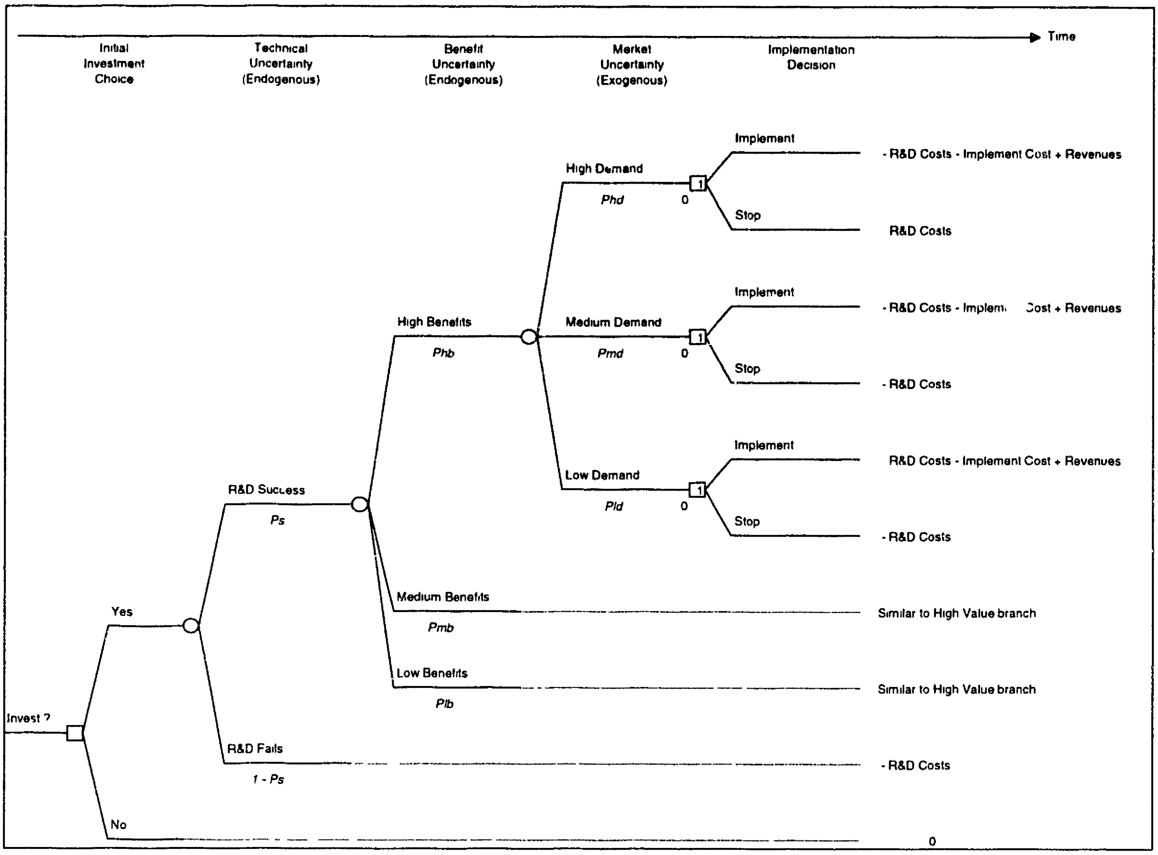
He recommends the use of Decision Analysis for which two related sets of information are required: discrete outcomes and associated probabilities. There is no need to be concerned with the choice of the appropriate discount rate here. In fact, since the corresponding uncertainties are endogenous and not correlated with prices of exogenous factors, no risk premium is required: r = risk-free rate. He suggests different ways of estimating the discrete probabilities.

Once the uncertainty about the research phase is resolved, the next step would be to focus on the implementation phase. For pure decision analysis approaches, the same procedures for quantifying endogenous uncertainties are applicable to exogenous uncertainties. However, this approach will always lead to errors in valuation since decision trees that model project options cannot correctly adjust market related outcomes for risk. Therefore, he recommends the use of real options.

Real options based models require a two-step process for quantifying exogenous uncertainties. First, a factor that influences project revenues must be identified. Second, the cash-flow driver must be related to one or more exogenous, priced factors. The priced factors are subsequently transformed into risk-neutral distributions and used to estimate the influence of the cash-flow driver on project value. Because risk-neutral distributions are used to represent the factors that create exogenous project risks, the risk-free rate can be applied to the resulting cash-flows.

This methodology separates endogenous uncertainties from exogenous uncertainties and treats each one of them separately. Figure III.2 illustrates the architecture of the Composite analysis suggested by Neely (1998).

Figure III.2 The Composite Methodology



The tree in figure III.2 first considers technical uncertainty, which refers to the likelihood that a workable technological result is obtained. It considers two possible outcomes: success or failure. For each outcome, the decision tree requires an associated probability denoted as *Ps* for success and (1- *Ps*) for failure. For a successful outcome, a subsequent decision to implement the technology will result in a flow of revenues. Projects that are not successful are assumed to be worthless.

Next, the decision tree examines uncertainty related to project benefits. These are variations in the level of expected project benefits, contingent upon having achieved a technical success. Again, for each possible outcome, the model requires an associated probability and a traceable influence on a factor that drives project option value.

The market uncertainty that the decision tree considers is an exogenous uncertainty, which reflects the influence of external, market related outcomes on project revenues. For example, the general state of the economy might lead to volatility in the sales of a product that R&D improves. The revenues that result from implementing the R&D project are exposed to these risks.

Exogenous uncertainties are treated differently in a hybrid of Real Options and Decision Analysis than in pure decision trees. The first model uses risk-neutral valuation techniques to model the uncertainties and enable the application of the risk-free rate to the project cash-flows. In contrast, Decision Analysis models model the uncertainties directly, and are forced to apply an arbitrary discount rate to the cash-flows. However, the key objective of both methods is to incorporate these uncertainties and their influences on project cash-flows into the valuation.

In his analysis, Neely (1998) assumes that once the decision to implement the new technology is taken, there is an immediate phase-out of the old one. The specific case study he introduces in his Thesis, deals with the replacement of a component in an automobile with one that will increase the overall benefits for that specific model. Both the research outcomes and sales are not correlated. Once he has an estimation of the benefits generated from the new technology, he multiplies this number by the future expected number of cars that will be affected by this innovation (sales numbers of a given model or group of models). The success/failure of the R&D venture will not affect the number of sales that depend on market outcomes. This is not true in the case of the implementation of the fuel cell technology in Ford automobiles (See attached Case Study). In fact, the expected future sales of such vehicles will depend on, among other things, the results of the R&D venture.

In light of the previous comment, one can conclude that the composite method needs to be adapted before using it in the evaluation of Ford's investment in the DaimlerChrysler/Ballard joint venture.

IV. Dimensions in the Application of the "Option thinking" to Projects with Uncertainty

This chapter introduces two dimensions over which one should focus his/her attention while evaluating an investment opportunity with uncertainty such as investments in Research and Development.

1. Nested set of options vs. parallel options

While exploring an investment in a Research and Development venture, one could identify two dimensions over which the complexity of valuing the investment could vary:

- Number of possible applications of a given technology (or number of targeted markets)
- Number of compound options relative to one single application (decisions that need to be taken and changes that need to be implemented during the development of one single application).

The first suggests that the investment be looked at as a portfolio of parallel options while the second considers the effect of having compound options. In light of those two remarks the "Real Options space" can be defined as illustrated in Figure IV1.

All the "Real Options" examples that can be found in the literature focus on only one dimension of the "Real Options space". In addition most of those articles cover the effect of having combined options rather than the effect of having parallel options as it is the case when dealing with more than one application of a technology. In fact, Geske (1979), Paddock (1988), Faulkner (1996) and many others discussed the evaluation of projects using the "compound options" framework while very few, Trigeorgis (1996) and Childs (1998) addressed the issue of interaction among parallel options.

Even if by focusing on one of those dimensions, one can usually capture most of the value of flexibility imbedded in the analysis, it is important to adopt a more general approach in the beginning. For the purpose of the evaluation, one could focus in a second stage on the most important aspects by either applying a Parallel or a Nested Options approach.

Figure IV.1 locates an investment in the fuel cell technology R&D in the two dimensional space defined earlier. In fact, three different applications of the technology have been considered by industry leaders so far, explaining the need to consider a minimum of three parallel options. In addition, for the development of each one of these applications, the three phases highlighted in Figure IV.2 are needed, requiring the consideration of two combined or nested options.

The two dimensional aspect introduced in Figure IV.1 is not specific to investments in R&D and can be identified in all investment opportunities or evaluations with uncertainty. In fact it is more related to the way one should apply the option thinking to the uncertainty imbedded in one's analysis.

Figure IV.1 Real Options space for the analysis of complex investments

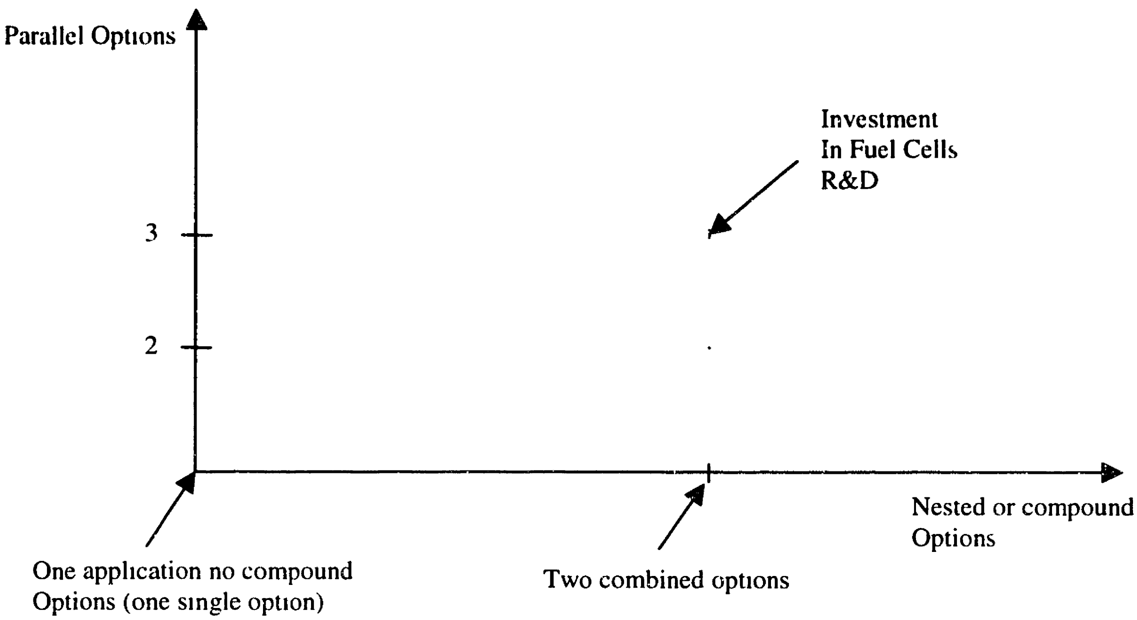
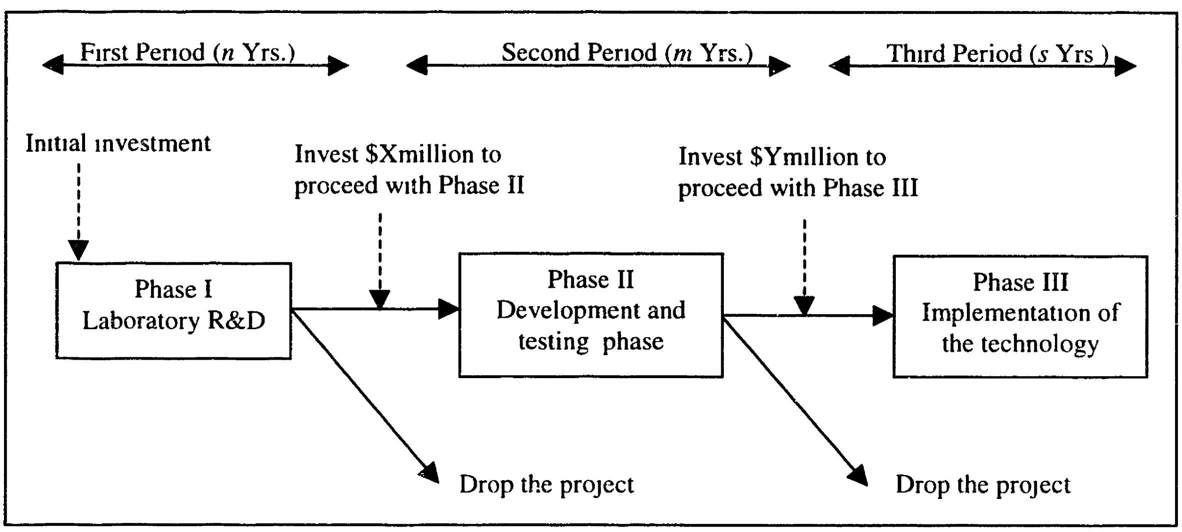


Figure IV.2 Decision process needed for the development of a new product



The value of an investment opportunity is expected to vary as follows while moving along each one of the two axes. On the one hand, the more applications there are for a given technology on which the research is conducted, the higher is the value. On the other hand, any increase in the number of options that could be identified on the way to the implementation process increases the value of the initial investment.

The two following sections explore option evaluations along the "*X*" axis and then along the "*Y*" axis.

2. Analysis of investments in R&D as a nested set of options

Most of the Research and Development projects include three distinct phases (see Figure IV.2):

a. Laboratory research and development. Eventually including the design of a prototype.
b. Development and Testing phase: the final product is developed and tested. Prototypes could also be introduced in the market or more likely in a niche market during this phase. In the Fuel Cell case discussed later, the market test could be achieved through the commercialization of the technology in a niche market like transit buses.
c. Implementation phase: All the necessary steps towards the manufacturing of the final product are taken in order for the company to be ready to mass-market the product.

At the end of either of the two first stages, the company has the option but not the obligation to continue the research/development effort through an additional investment. By making the first investment to initiate the research phase, the company acquired an Option on another Option. This is referred to as *compound options* or *nested set of options* in finance. The first evaluation of such options was introduced by Geske (1979).

The most common example of such nested set of options is the valuation of claims on Offshore Petroleum Leases. In fact, valuing such a lease involves valuing the cash flows from a three-stage process: exploration, development and extraction. These stages form a nested set of options and each one of these stages has distinct characteristics relevant to the option valuation approach. For more details about this analysis refer to Annex II or to Paddock, Siegel and Smith (1988). Figure IV.3 locates this case in the Real Option space.

In their analysis, the three authors suggest the following approach:

- The exploration stage can be represented by the option to spend the exploration cost and receive the expected value of undeveloped reserves.
- The development stage can be represented by the option to spend the per-unit development cost and receive the expected value of developed reserves. This option is not available if the exploration option is not exercised.
- The extraction option can be represented by the option to spend the extraction cost and receive the expected value of the extracted oil. This option is not available if the development option is not exercised.

Investment in Research and Development as buying compound options

Figure IV.2 illustrates a simplistic example of the decision process that companies usually undertake during the development of a new product.

Investing in the beginning of phase two corresponds to buying an option to implement the technology at the end of phase two. By walking backward one more step, one could notice that the initial investment decision corresponds to buying an option on the option just described. In fact, by making the first investment, the company acquired the option to develop and test the technology if the research phase proves to be successful. The two options considered here are similar to call options. The first has a time to maturity of n years and an exercise price of X, while the second has a time to maturity of m and an exercise price of Y. For the second option the underlying asset is the value of implementing the technology while for the first, the underlying asset is the value of the implementation option. The following section introduces a way of evaluating such compound options as suggested by Geske (1979).

Evaluation of compound options:

Geske (1979) derives a formula for valuing a call option on stock, seen itself as a European call option on the value of the firm's assets. The valuation of such options on options has potential implications for the valuation of compound real (growth) opportunities where earlier investment opportunities are prerequisites for others to follow.

In the following equation, C denotes a European call option providing the right at its maturity T' to acquire, with exercise price E, another (European call) option, S, on an asset V with maturity T and exercise price I. Thus, C is a claim whose value is directly contingent on S and indirectly contingent on V and t:

$$C = f(S,\tau) = f(g(V,\tau),\tau)$$

Assuming that the value of the underlying asset (a stock, or potentially a real project), with no cash dividends, follows the diffusion process:

$$\frac{dV}{V} = \alpha\, dt + \sigma\, dz,$$

Geske shows that a riskless hedge portfolio can be created duplicating the value of the compound option, which must satisfy the partial derivative equation.

$$\tfrac{1}{2}\sigma^2 V^2 C_{VV} + rVC_V - C_\tau - rC = 0 \qquad \text{Where} \qquad C_V = \frac{\partial C}{\partial V}, C_{VV} = \frac{\partial^2 C}{\partial V^2} and, C_\tau = -\frac{\partial C}{\partial t}$$

Subject to: $C_{T'} = \max(S_{T'} - E, 0)$

This is similar to the Black-Scholes partial derivative equation, except that the variable entering the boundary condition now is S (instead of V), itself an option on V whose value is given by the Black-Scholes solution. Geske then provides the following closed-form solution for the value of the European compound option in the absence of dividend payouts:

Equation 1: $$C = V\,B(h+\sigma\sqrt{\tau'}, k+\sigma\sqrt{\tau}, \rho) - Ie^{-r\tau}B(h,k,\rho) - Ee^{-r\tau'}N(h),$$

Where: $$h = \frac{\ln(V/V^*) + (r - \frac{1}{2}\sigma^2)\tau'}{\sigma\sqrt{\tau'}}, \qquad k = \frac{\ln(V/I) + (r - \frac{1}{2}\sigma^2)\tau}{\sigma\sqrt{\tau}},$$

$$\tau = T - t, \qquad \tau' = T' - t,$$

$N(\,)$ is a (univariate) cumulative standard normal distribution function, $B(a, b, \rho)$ is a bivariate cumulative normal distribution function with upper integral limits a and b and correlation coefficient ρ (where $\rho = \sqrt{\tau'/\tau}$) and V^* is the schedule of asset value V above which the compound option should be exercised (obtained by solving $S(V^*) - E = 0$).

The Black-Scholes formula is actually a special case of equation 1, as can be seen by setting $I = 0$ or $T = \infty$. Furthermore, one of the implications of compound option valuation is that even if the expected rate of return (discount rate) or the variance of returns of the underlying asset (the value of the firm's assets or the project's gross value, V) are constant, those for the option will generally be nonstationary and will depend in a complex manner on a variety of factors. In such compound option situations, discounting expected future values at a constant discount rate maybe grossly inappropriate.

Is it possible to isolate different options, evaluate them separately and then add them back?

According to Trigeorgis (1996):

> "The nature of interaction, and hence the extent to which the values of two separate options may or may not approximately add up, can be summarized as follows: There is no [small] interaction, and hence the separate option values will be [approximately additive] additive, if the conditional probability of exercising both options before maturity is zero[small]. Conversely, the interaction will be highest [high], making it most inappropriate to add up the separate option values, if it is certain [likely] that both options will be exercised jointly (or if the conditional probability of a joint exercise, $P_{L/F}$, is 1 [high]). The interaction will typically be positive if the prior option is a call and negative if a put. In the latter case (as when the separation between two similar-type options is negligible), the combined option value may be only [somewhat higher than] the higher of the separate individual values. That is, the incremental value of the lesser option may be negligible [small]." (pp 236-237)

In the general case introduced in Figure IV.2, if by the end of phase I, the company decides to go ahead with the development phase, it is very likely that they will exercise the following option (i.e. go ahead with commercialization). This comment implies that the probability of a joint exercise is high and consequently that in most of the cases, adding up the value of isolated options would be inappropriate.

3. Analysis of investments in R&D as a combination of parallel options

This section deals with the interaction between "parallel" options as opposed to "serial" options. Very few examples of combination of parallel options (with interaction) are available in the literature. The need to explore this dimension of the real option analysis appears in many project/investment evaluations:

- Decision to invest in one option among two available rather than invest in both of them or vice-versa (especially when there are budget constraints)
- Valuing an investment in an R&D venture with different targeted markets
- Valuing an investment in R&D where the outcome of the research phase could affect the choice of the underlying asset, etc.

Figure IV.4 locates some parallel options in the Real Options space.

Evaluation of parallel options:

In their paper "Capital Budgeting for Interrelated Projects: A real option approach", Childs, Ott and Tritanis (1998) introduce a way of measuring the value of interrelated projects under both the parallel and sequential development assumptions.

Since the focus here is on parallel options, the case where the two projects are developed in a sequential way will be disregarded for the moment.

The authors consider a firm that has the opportunity to invest in two projects a and b. This firm will invest C_a and C_b to develop each one of them and resolve the uncertainty regarding their future profitability. It can then make a further investment of K_a or K_b or the sum to "implement" one of them or both. Investments in research and development with more than one application of the technology fall under this case.

At $t = t_0$ the firm will invest $C_a + C_b$. Once the development is complete at t_1, the firm decides whether to invest K_a or K_b or the sum to implement project *a* or project *b* or both, respectively. The firm may decide not to implement either project. In the following analysis, X_i ($i = a$ or b) denotes the present value of project *i*'s stream of future cash flows upon implementation while x_i denotes the value net of the implementation cost K_i.
$x_i = X_i - K_i$, x_a and x_b are assumed to be normally distributed.

The following notations will be used:

$$E[x_i] = \mu_i, \quad i = a,b$$

$$E[(x_i - \mu_i)^2] = \sigma_i^2, \quad i = a,b,$$

$$E[(x_a - \mu_a)(x_b - \mu_b)] = \rho\sigma_a\sigma_b,$$

Where $E(.)$ refers to the expected value of the considered variable.

Figure IV.3 Location of some Nested Options in the Real Options Space

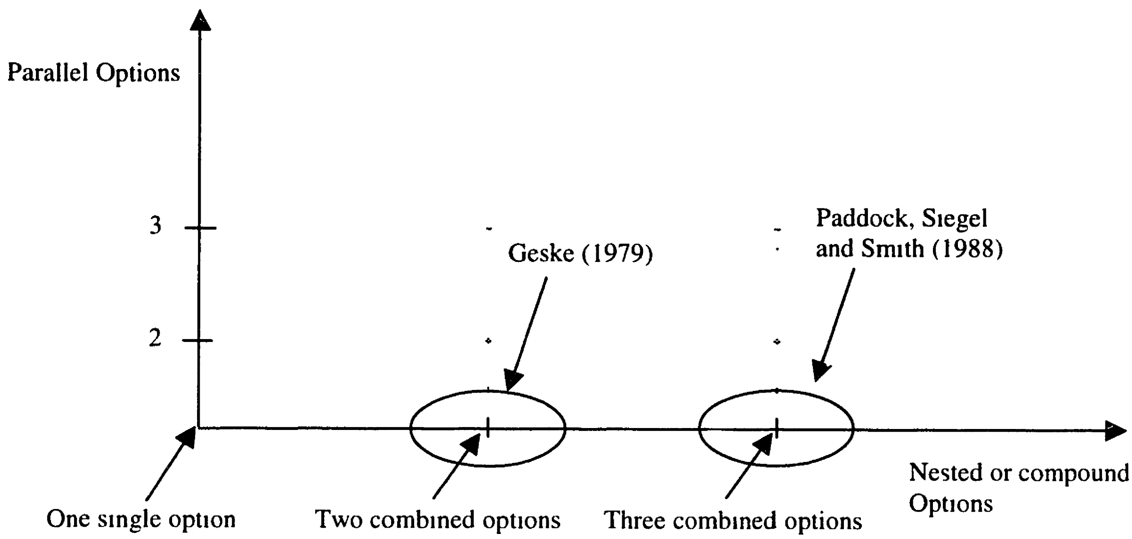
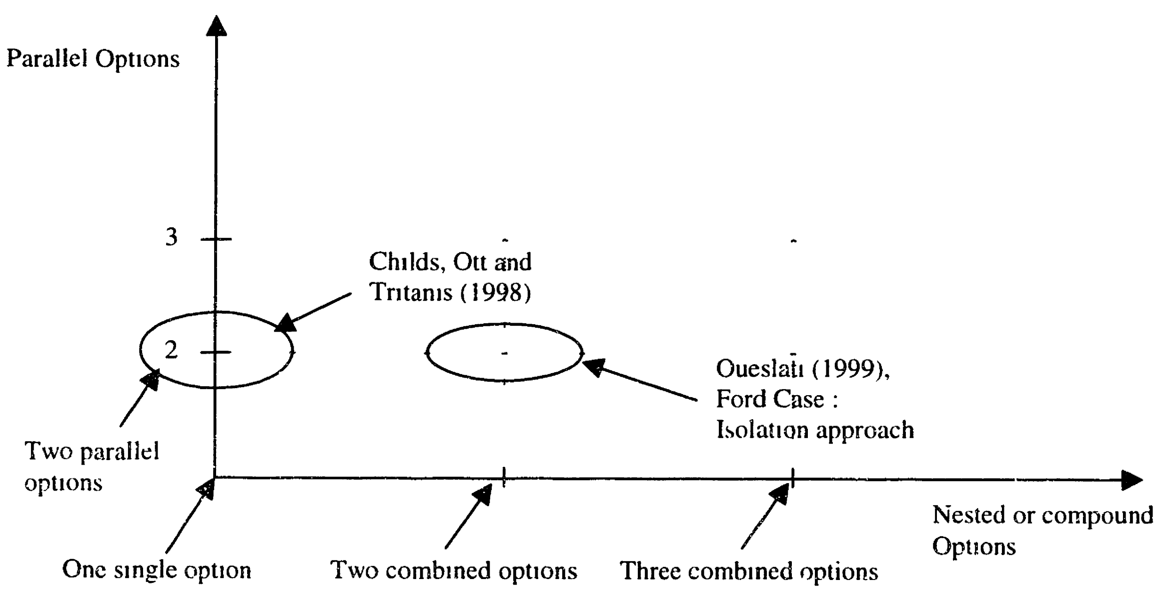


Figure IV.4 Location of some Parallel Options in the Real Options Space



First Case: project a and b are mutually exclusive, meaning that only one could be implemented if any.
The value of the program at $t_0 = 0$ is

Equation 1: $V^P = e^{-rt_1} E[(x_a, x_b)^+] - [C_a + C_b]$

Where $(x_a, x_b)^+ = \text{Max}(x_a, x_b, 0)$

The value of the program can also be rewritten as:

$$V^P = (e^{-rt_1} E[x_a^{\,+}] - C_a) + (e^{-rt_1} E[(x_b - x_a^{\,+})^+] - C_b)$$

Under these circumstances, one can interpret parallel development as the development of project *a* together with a European exchange option to replace project a with project *b*, maturing at t_1 and purchased at a cost of C_b at t_0.

Under the joint normality assumption for x_a and x_b, the expectation in equation 1 can be solved explicitly, yielding an expression for the value of the investment program under parallel development, V^P,

$$\begin{aligned} V^P &\equiv e^{-rt_1} \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} (x_a, x_b)^+ g(x_a, x_b) dx_a dx_b - C_a - C_b \\ &= e^{-rt_1} \left[\int_0^{+\infty}\int_{-\infty}^{x_a} x_a g(x_a, x_b) dx_b dx_a + \int_0^{+\infty}\int_{-\infty}^{x_b} x_b g(x_a, x_b) dx_a dx_b \right] - C_a - C_b \\ &= e^{-rt_1} (G(x_a, x_b) + G(x_b, x_a)) - C_a - C_b, \end{aligned}$$

Where $g(x, y)$ is the bivariate normal density function and the conditional expectation term $G(x_i, x_j)$ can be expressed as:

$$G(x_i, x_j) = \mu_i N_2(h_{ji}, -h_i; \alpha_j) + \sigma_i [n(h_i) N(\kappa(h_i, h_{ij}, -\alpha_j)) + \alpha_j n(h_{ji}) N(-\kappa(h_{ji}, h_i, -\alpha_j))]$$

N and N_2 are cumulative standard normal univariate and bivariate distribution functions, respectively, and n is the univariate standard normal density function.

The other terms are defined as follows:

$$h_i(x) = \frac{x - \mu_i}{\sigma_i}, \qquad h_{ij}(x, y) = \frac{x - \mu_i + y\mu_j}{\sqrt{v_T(y)}},$$

$$h_i = h_i(0), \qquad h_{ij} = h_{ij}(0,1),$$

$$\alpha_{ij}(x) = -\frac{\rho\sigma_i - x\sigma_j}{\sqrt{_T(x)}}, \qquad \kappa(x, u, v) = \frac{u - vx}{\sqrt{1 - v^2}},$$

$$\alpha_i = \alpha_{ij}(1), \qquad v_T(x) = \sigma_b^{\,2} - 2x\rho\sigma_a\sigma_b + x^2\sigma_a^{\,2}.$$

Second Case: No mutual exclusivity.

The value of parallel development is higher than in the mutually exclusive case if the firm finds that implementing both projects is better than implementing a single project. Such as when projects are partial substitutes, independent, or complements.

If both projects are implemented simultaneously, each project is allowed to affect the other project's cash flows by using cash flow multipliers, $\gamma_i > 0$. Thus, $(\gamma_a x_a + \gamma_b x_b)$ represents the total value received if the projects are implemented simultaneously. In the case where project cash flows are independent one should use the following values: $\gamma_a = \gamma_b = 1$

The value of parallel development with no mutual exclusivity is:

$$V_p = e^{-rt_1}(G(x_a, x_b) + G(x_b, x_a) + H(x_a, x_b, \gamma_a - 1, \gamma_b) + H(x_b, x_a, \gamma_b - 1, \gamma_a)) - C_a - C_b,$$
$$or,\ V_p = e^{-rt_1}(G(x_a, x_b) + G(x_b, x_a) + H(x_a, x_b, 0, 1) + H(x_b, x_a, 0, 1)) - C_a - C_b$$

The second equation corresponds to the case where project cash flows are independent

Where $$H(x_i, x_j, \alpha, \beta) \equiv \int_0^{\infty} \int_{-\frac{\alpha}{\beta}x_i}^{x_i} (\alpha x_i + \beta x_j) g(x_i, x_j) dx_j dx_i$$

The previous equation could be used in the evaluation of two parallel options among the three considered in the Ford Case. According to Trigeorgis (1996) by considering different parallel options the value of the investment increases but the marginal effect of considering an additional option becomes very little, very quickly.

V. Practical Methodology for the Evaluation of investments in Research and Development

This chapter focuses on practical ways of evaluating projects with uncertainty. By applying this methodology, one would have an idea of the value of the options that are imbedded in one's analysis. More advanced tools can lead to a more accurate valuation of those investments, but their complexity may be confusing and might push decision makers to disregard options "to keep things simple".

For the evaluation of an investment in R&D one should start, in Step 1, with identifying the possible applications of the related technology (it corresponds to moving along the "*Y*" axis in Figure IV.1). If, for example, there are two evident applications *A* and *B* of the technology, one could proceed with the evaluation in two ways:

1. Evaluate the option specific to application *A*, evaluate the option specific to application *B*, then combine both of them to estimate the value of the option.
2. Make one overall evaluation of the option taking into account all possible applications.

It is important to note here that application *A* and *B* do not necessarily mean two different products. It is more appropriate to think about the targeted markets and not the targeted products. In fact, it is the information relative to each specific market that will be used in the selection of the appropriate underlying asset. As discussed in the attached Ford Case, it is common to have the results achieved in the R&D phase affect the type of market that will be targeted by the product.

For a given future application and a given market, it is important to identify all the steps that need to be taken before reaching the market. This allows to estimate the optimal number of nested options that one should consider in one's evaluation of the option (it corresponds to moving along the "*X*" axis in Figure IV.1). The considered case can now be located in the real option space defined in Chapter IV.

Step 2 starts with an identification of the different risks that are present in the considered case and suggests a set of tools that model the best the kind of imbedded uncertainty. This methodology gives the priority to the use of real option tools. In case it is impossible to find an underlying asset in the market, the use of decision analysis is recommended.

Step 3 lists the inputs that are required for the application of both the real option method and decision analysis. It also suggests some methodologies for the estimation of those numbers.

Step 4 uses all the previous steps in order to estimate the project's value. It also recommends that one adopts a critical approach and runs sensitivity analysis on the critical inputs. This step recommends the search for break-even points in order to check the robustness of the recommended strategy.

Chapter VII goes through a detailed application of this methodology.

Needed steps in the application of the methodology:

Step 1: *Location of the considered case in the Real Option Space*		
Step	**Objective**	**Comments**
a. Identify all the possible applications of the technology	Locate the considered case on the "*Y*" axis	One should focus his/her effort on the most likely applications.
b. For each application identify the corresponding market(s)	Identify a possible migration form one point on the "*Y*" axis to a higher one	There could be more than one market for a given product (Ford Case).
c. For a given application identify all the needed steps in the development of such application	Locate the considered case on the "*X*" axis	Helps think about the number of nested options needed if any.
d. For each step identified in (*c*) all the possible outcomes need to be considered and a following strategy needs to be designed through an iteration of this step	Explore different scenarios	Helps think about a dynamic response to the resolution of uncertainty and allows to draft the decision tree.

Step 2: *Selection of the appropriate tools for the application of the option thinking*		
Step	**Objective**	**Comments**
a. Identify and classify the major risk/uncertainties encountered in the case	Group the different risks/uncertainties under private or project risk versus market risk	
b. Select the appropriate set of tools		
<u>Case 1</u> There is only private or project risk: it is recommended to use Decision Analysis		
<u>Case 2</u> There is only market risk: it is recommended to use the tools that are derived from the evaluation of financial options like the Binomial method or the Black-Scholes Option pricing formula.		This can be done only if it is possible to identify an asset from which all the information can be extracted. If no market information is available, one should consider the use of Decision Analysis.
<u>Case 3</u> There is a combination of both private and market risk: - With an underlying asset: financial tools should be considered first. If there is a specific risk that is not reflected in any of the traded assets, one should consider the mixed method introduced by Neely (1998). - With no underlying asset: One should consider the use of Decision Analysis		The Kodak case discussed in III.3 is a good illustration.

Step 3: *Search for (estimation of) the required set of inputs*		
Step	**Objective**	**Comments**
a. Estimation of the length of each identified phase	Include "time" for discounting purposes.	The value of the option of delaying an investment can be included
b. Selection of the probabilities		
Case 1 For the Decision Analysis part: probabilities can be estimated through the assessment of the opinion of knowledgeable people or through the use of theoretical approaches like Pearson-Tukey.		It might be appropriate, in some cases, to use a multi-attribute Utility analysis.
Case 2 For the Real Option part: probabilities can be computed through the use of the Risk-Neutral method.		
c. Estimation of the Costs/Benefits: In the case of real options, one should look for the correlation between future benefits and the evolution of the underlying asset(s)		One could run a regression to identify such correlation
d. Estimation of the discount rate		Applies only to the Decision Analysis Part.
Case 1 The risk is endogenous: in most of the cases, this risk can be diversified away. There is no need to add a risk premium. The risk-free rate will be used in such cases.		
Case 2 The risk is non-diversifiable: the discount rate could be estimated through the use of the CAPM formula or the APT method		It might be necessary to look for priced assets that reflect the same kind of risk.

Step 4: *Evaluation of the investment*		
Step	**Objective**	**Comments**
a. Use all the previous information to compute the value of the project.	Compute a first number	If the number found here is irrelevant, one should go through all the previous steps again.
b. Run sensitivities on critical inputs	Estimate the effect of those inputs on the value of the project.	Only one input should be modified at a time
c. Search for Break-even points	Look for values for which the decision to invest changes.	

VI. Description of Ford Case

1. Overview of the Facts

On April 7th, 1998 Ford Motor Company, DaimlerChrysler, and Ballard completed an agreement to develop Fuel-Cell Technology for Future Vehicles. The Global Alliance's goal was and continues to be the world's leading commercial producer of fuel-cell powered drive-trains and components for cars, trucks and buses.

Ballard and its partners say it is possible for consumer cars to be equipped with the technology as early as 2004. DaimlerChrysler, in particular, hopes to have 40,000 cars powered by fuel cells by that time, but even Ballard's chief financial officer Umedaly (1998) says costs must be reduced "by an order of magnitude of 90 per cent" before this can be achieved.

According to Plant (1998), Canada's Industry Newspaper, Ford's C$650 million investment consisted of cash, technology and assets:

- C$330 million investment in Ballard Power Systems,
- C$116 million in becoming a partner in DBB Fuel Cell Engines GmbH along with Ballard and DaimlerChrysler, and
- C$202 million in a new entity known as Eco which will develop drivetrain systems converting electricity generated from the cells into tractive power. Ballard and Daimler-Benz are each contributing $48 million into the entity as well.

This alliance is meant to join the efforts of three companies (see Figure VI.1):

- *Ballard Power Systems*: Responsible for the design and supply of fuel-cells, with DaimlerChrysler and Ford holding 20 percent and 15 percent, respectively.
- *DBB Fuel Cell Engines GmbH*: Responsible for fuel-cell engine systems, with Ballard holding about 27 percent and Ford 22 percent. (DaimlerChrysler owns the majority of the company).
- *Ecostar Electric Drive Systems Co.* : Responsible for electric drive-train systems, with Ballard and DaimlerChrysler owning 21 percent and 17 percent, respectively.

Figure VI.1 Structure of the "Global Alliance"

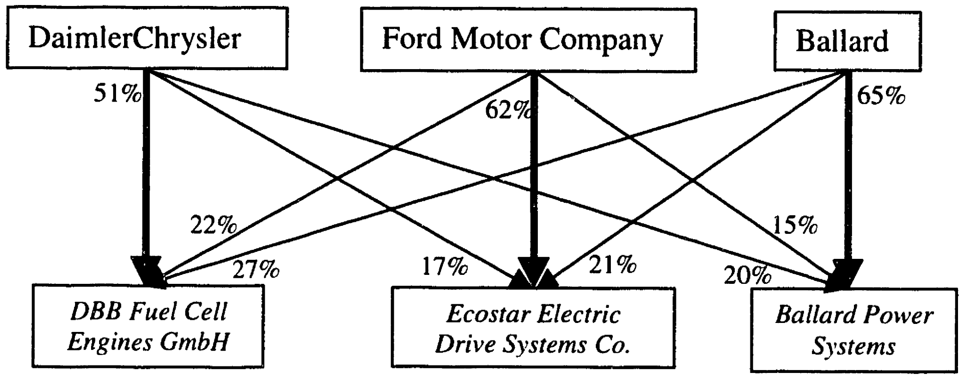
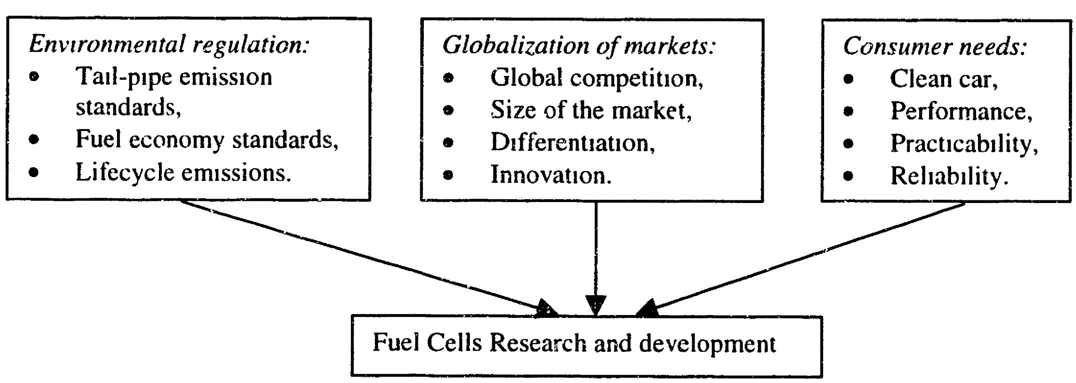


Table VI.1 Summary of the Ford-Ballard Stock Transaction

Title	Value	Unit
Ford investment in C$	330	C$ millions
Exchange rate	1.43	C$/US$
Ford investment in US$	230	US$ millions
Number of Shares	4,079,055	
Split adjustment	1 for 3	
Adjusted Number of Shares	12,237,165	
Price paid per share	18.83	US$

Figure VI.2 Key drivers to the development of Fuel Cell Vehicles



Together Ballard, DaimlerChrysler, and Ford have invested over a billion Canadian dollars in this alliance. Mazda Motor Corporation will also participate in this alliance through its close association with Ford Motor Company.

Comments:

When Ford Motor Company invested in the DaimlerChrysler/Ballard joint venture, they acquired three things:

- 15% of the total common shares of Ballard
- Access to the latest developments in FC technology through its stake in Ballard
- An option to implement the FC technology in a range of vehicles sold by Ford Motor Company.

In the first evaluation covered by Chapter VII, the investment is split in two parts:

1. The value of the technology itself: Including access to the technology and the option to implement the Fuel Cells Technology in the automobile industry.
2. A pure financial holding: Ballard stocks (its value should not depend on the fact that Ford holds the stocks).

2. Financials of the transaction

On April 7, 1998: Ford purchased Ballard common shares in two transactions at a price of Cdn $80.80 per share for an aggregate purchase price (including the subscription and acquisition) of Cdn $329,587,644. Ford owned 4,079,055 Common Shares of Ballard (prior to the 1:3 stock spilt), which is approximately 15% of the total Common Shares of Ballard presently issued and outstanding.

Ford acquired all such Common Shares on April 7, 1998 as follows : 3,746,900 of the 4,079,055 Common Shares were acquired directly from Ballard for a cash payment of Cdn $80.80 per share (or Cdn $302,749,520 in the aggregate) and 332,155 of the 4,079,055 Common Shares from Daimler-Benz for a cash payment of Cdn $80.80 per share (or Cdn $26,838,124 in the aggregate). According to the agreement signed by the three parties, Ford Motor Company has an obligation to hold Ballard stocks for a period of three years (up to December 31st, 2000).

Since the transaction was made public on December 15th 1997, the closing price of the prior day to the announcement date will be used as a reference. As of December 12th 1997, the price of Ballard stock was equal to US$20.83 or C$29.6 (adjusted for the 1:3 split).

The average exchange rate (Dec97 and Jan98) was C$1.43 for one US$. Using these figures, the market value of Ford investment in Ballard would amount to US$255million. The value of the non-stock related investment is equal to the total investment minus the market value of the stocks or approximately US$200million.
Table VI.1 shows that Ford saved 20.83 - 18.83 = $2 per stock or a total amount of US$24.474 million.

Usually, when new stocks are issued, one would expect that the issuer to ask for a premium of 10 to 15% over its market price to avoid a drop in price. The reverse phenomenon was observed here since Ford bought the shares at a discount. This could be explained by the fact that they are bound to hold them for at least 3 years (no stock sales before Dec.31st 2000).

3. Why invest in the Fuel cell technology

a. Automotive applications:

Investments in the Fuel Cell technology have been driven by the following (figure VI.2):

- Globalization of markets,
- Evolution of environmental regulation,
- Satisfaction of consumer needs.

The globalization of the automotive industry pushed manufacturers to reduce costs, enhance product differentiation and make large R&D investments. R&D costs increased the pressure to evaluate outsourcing of R&D functions and to implement closer cooperation with suppliers/competitors in product development. However, automobile manufactures have always been reluctant to outsource engine design and manufacturing. In fact, most manufacturers view engine design as a core competence and integral part of product development. Large investments of up to $1billion are typically made for the development of a new engine.

Although internal combustion engines are the focus of automotive research and development, alternatives have been considered and occasionally developed. Taking the lead in fuel cells research and development might have a significant effect on success and future competitiveness in certain markets [not least because they provide a threat to the core competence in internal combustion engines]. The size of the global market justifies more and more investments in innovative products. In fact, having a very little share in this very large market tends to justify such investments. In addition, being among the leaders in the fuel cell technology would differentiate the company and enhance its "innovation" and technological leadership image.

Major investments are made in alternative propulsion technologies, as in the case of the Partnership for a New Generation of Vehicles (PNGV). The PNGV has an approximate annual budget of $250 million, with an equal amount spent by industry partners in a cost-sharing program for developing alternative vehicle propulsion and lightweight materials in the United States. This includes $21 million annually for federal fuel cell research.

On the environmental side, Corporate Average Fuel Economy (CAFE) standards in the United States have existed since 1970 and were progressively tightened through 1985. Large-size cars are particularly exposed to such regulations. In addition, the development of alternative fuel vehicles was mandated by the US Energy Policy Act of 1992. Fuel cells are also viewed as a potential solution to eliminate exhaust emissions.

The development of regulations in California indicated stringent emission requirements for future passenger cars. The implementation of the Low Emission and Zero Emission Vehicle regulations (ZEV) in the strategically important market of California in 1990 is regarded as a key event due to its progressive technology-push approach. The ZEV regulations initially required that automobile manufacturers selling more than 35,000 vehicles annually in California must produce two percent of these vehicles as ZEVs for sale in 1998, increasing to 10% in 2003. Under this provision, both Ford and DaimlerChrysler were affected by the regulations. Due to lagging technological progress, regulations were modified in 1996, and the requirement for 1998 was eliminated, leaving only the later requirement for all manufacturers.

One can argue that all the possible fuels potentially used in fuel cells, except from pure Hydrogen, will have other emissions than water and heat (CO2 is an example). However, by looking at Life-cycle emissions it can be proven that the fuel cell technology is better than most of the other "clean" technologies such as electric vehicles, Hackney (1998)

On the consumer side, buyers are more and more concerned about the environment and would be willing to switch to cleaner technologies for a reasonable premium if performance, practicability and reliability characteristics are not compromised. A fully developed fuel cell vehicle would satisfy these characteristics, as opposed to the electric vehicle, for example, but price still remains an issue.

b. Other applications:

While transportation has received the most attention, stationary power generation is perhaps as large an opportunity as transportation. Ballard has taken the same alliance approach in that industry. Its subsidiary, Ballard Generation Systems, has partnerships with GPU International in the U.S., the large French power producer ALSTHOM and Japanese manufacturer EBARA to produce and market stationary fuel cell power plants on three continents.

In February 1998, Ballard Generation Systems received a purchase order from Cinergy Technology Inc. for a 250 kW class natural gas fuel cell power plant for US$ 1.625 million (C$ 2.275 million). This power plant will be the first field trial unit manufactured by Ballard Generation Systems and it is scheduled for delivery in mid-1999. Ballard Power Systems will supply the fuel cell used in the power plant.

Ballard is also pursuing markets for fuel cell applications for portable power, marine and aerospace applications. In this context, Ballard Power Systems Inc. received in February 1998 a C$ 2.5 million (US$1.7 million) order from Honda R&D Co., Ltd. of Japan, a subsidiary of the Honda Motor Company, for the supply of one kilowatt, low pressure, portable Ballard Fuel Cell systems. Honda will integrate the fuel cell systems into portable power and specialty applications operating on hydrogen for demonstration, testing and product development. This fuel cell order from Honda for portable applications is in addition to previous deliveries for automotive applications.

These examples illustrate the importance of non-automotive applications of the fuel cell technology. They highlight the fact that even if we might never drive a fuel cell car in the future, the technology can benefit other industries. This needs to be taken into account in the final evaluation of the option being considered here.

4. Rationale Behind the Alliance

The "Alliance" seems to be one of the best strategies to achieve the common goal of having fuel cell powertrains available to support commercialization of fuel cell vehicles by 2004. On one hand, Ballard Power Systems is the world leader in the development of proton exchange membrane fuel cells. On the other hand DaimlerChrysler has unique expertise in research into alternative drive systems and automotive fuels. In addition, Ford is highly regarded for its advanced electric vehicle powertrain technology. Besides the complement of skills, all three partners reduce the financial consequences of a possible failure of the project by sharing the losses. This strategy of joining the forces when it comes to investing in a risky, irreversible project is widely used in the oil industry. In fact, oil companies tend to create joint ventures to explore new oil fields.

All three companies welcomed the alliance as commented below:
" Ford sees this partnership as a natural complement of the talent, skills and technology among the three companies... We have been working on the technology to support fuel cell vehicles for many years and view fuel cells as one of the most important technologies for the early 21st century. With our collaborative efforts, we think we can accelerate the commercial viability and implementation of fuel cell vehicles." Ford's Chairman Trotman (1997)

Schrempp (1997), Chief Executive Officer of Daimler-Benz, now DaimlerChrysler, expressly welcomed the new alliance and stated, "This cooperation is impressive evidence of the fact that the fuel cell represents a serious and promising alternative to the conventional combustion engine."

Rasul (1997), President and Chief Executive Officer of Ballard, said, "Through Ballard's relationship with Ford and Daimler-Benz, we have the strength, resources and commitment to bring the fuel cells to volume commercial production."

The question that remains unanswered is: Why did Ford Motor Company decide to join the "Global Alliance" now rather than wait for further developments of the technology? Annex IV goes through a detailed analysis of the answer to this question and uses the theory suggested by Grenadier and Weiss (1997) to justify the timeliness of Ford's investment in the DaimlerChrysler/Ballard JV.

VII. Application of the methodology to the Ford Case

1. Evaluation using the "isolation approach" (one application)

Since the objective is to value Ford's investment in the joint venture, the evaluation will be limited to the option of implementing the fuel cell technology in the automobile industry. Financial consequences of other applications are expected to be reflected in Ballard Stock.

All possible benefits that could be generated from other applications of the fuel cell technology are assumed to be reflected in the appreciation of Ballard Power Systems stocks. Ford Motor Company will benefit from this appreciation through their 15% stake in Ballard. One way to isolate the investment in the technology itself for automotive applications would be to deduct the value of the stocks they own from the initial amount invested.

Step 1: ***Location of the Ford case in the Real Option space:***

a. **Possible applications of the technology:** As discussed in the previous chapter, there are three major applications of the technology: automotive, stationary power generation and portable power. For the purpose of the present evaluation, only automotive applications will be considered.

b. **Identification of the corresponding markets:** The way that the market will look at fuel cell vehicles will largely depend on what will be achieved in the R&D phase. In fact, if a high technological success is achieved, those vehicles will face the same market characteristics as the internal combustion engine (ICE) vehicles face. This is due to the fact that buyers will value both technologies in more or less the same way. It is appropriate to use Ford Motor Company's stock as a proxy. However, if the results of the R&D phase are medium to low, the market will look at the eventual product as an innovation that is unequal to the ICE technology. This market uncertainty will be better reflected in Ballard's stock rather than in Ford Motor Company's stock. Two markets will consequently be considered requiring the investigation of two parallel options.

c. **Needed steps in the development of each application:** The general framework introduced by figure IV.2 will be considered in this analysis. The development of a fuel cell powered car will consequently go through three steps. The first corresponds to the laboratory research phase, the second to the development and testing phase while the last to the implementation phase. By making the first investment to initiate the research phase, Ford acquired the option to proceed with the development and testing phase which itself is an option on the implementation phase. This is an example of two combined or nested options.

(a), (b), and (c) allow to locate this specific case in the Real Option space. (Figure VII.1)

Figure VII.1 Location of the present Ford Case in the Real Options space

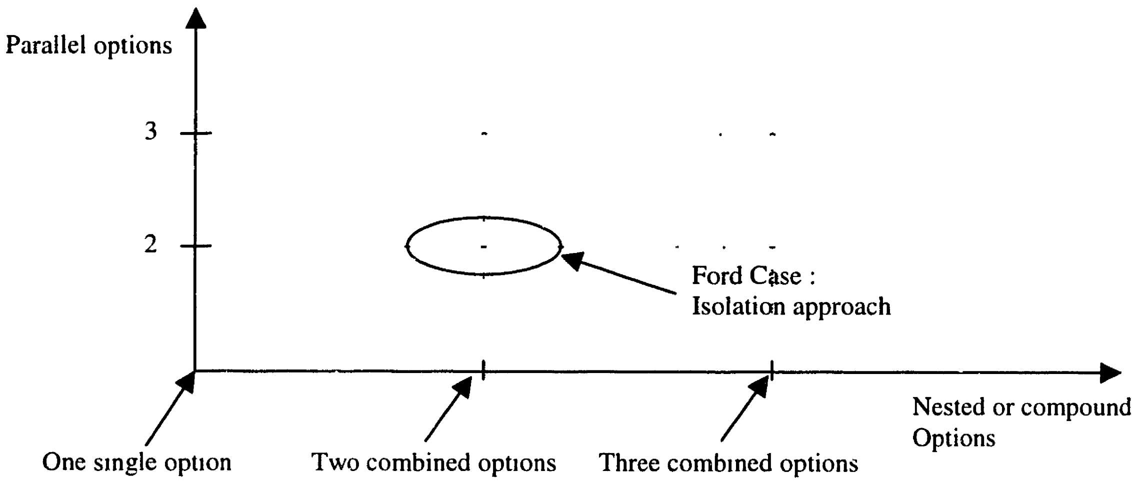
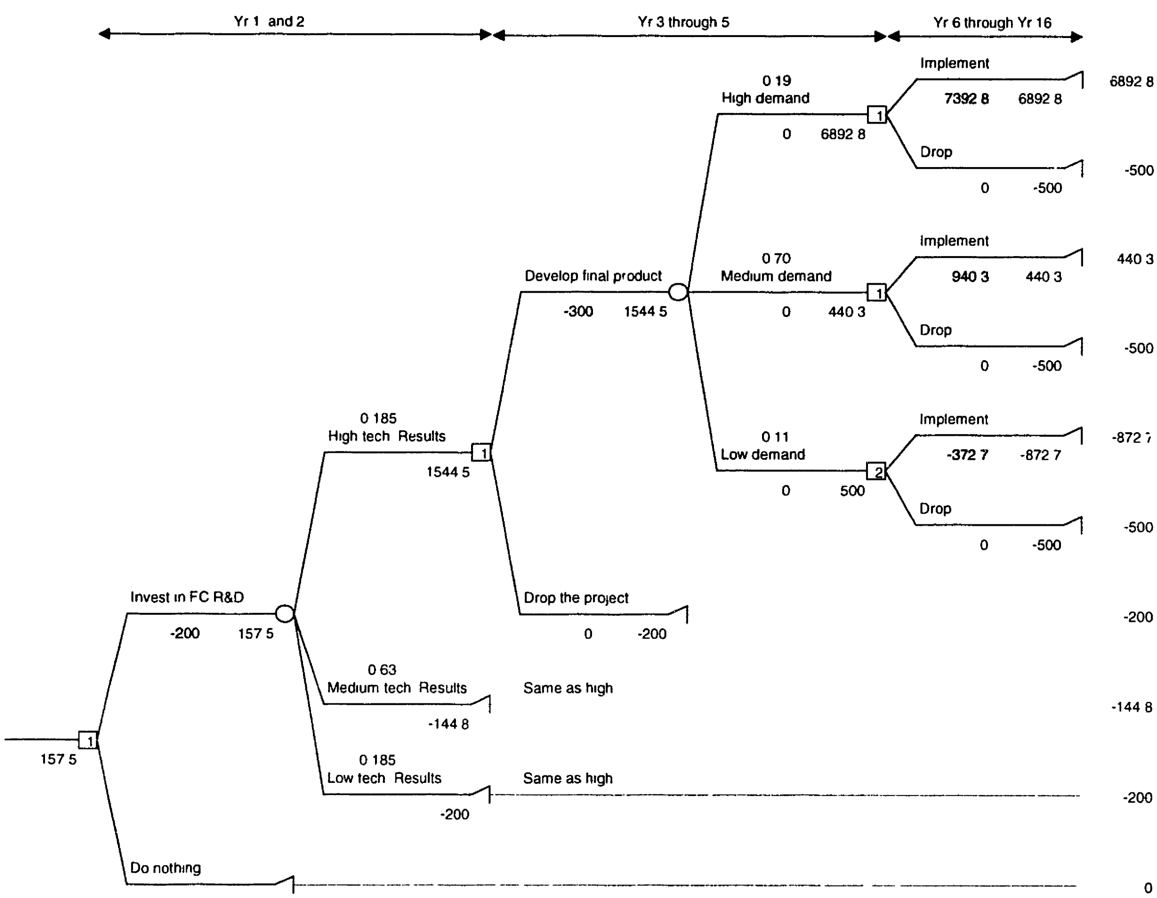


Figure VII.2 Illustration of the used decision tree



d. **Exploration of the different scenarios:** Three possible outcomes from the R&D phase were considered :
   1. Relatively high technological success: design of a flexible and reliable reformer, design of better fuel cells, reduction of the overall cost of the system.
   2. Relatively medium technological success.
   3. Relatively low technological success: failure of the R&D venture.

   At the end of the research phase, Ford will face the decision to follow up or not with phase II. In case they do, three possible outcomes from the development and testing phase were considered:
   1. High demand: The market reacts favorably to the introduction of this model
   2. Medium demand: Medium acceptance of the new technology
   3. Low demand: The product is not competitive

   By the end of Phase II, Ford Motor Company will face the decision whether or not to implement the new technology in their automobiles.

   All these different scenarios are summarized in the decision tree drawn in Figure VII.2. It illustrates the methodology used for the evaluation of the part of Ford investment that is not related to their 15% stake in Ballard Power Systems. It is meant to represent the investment in the Fuel Cell technology for automotive applications. Year one corresponds to 1998 since the transaction was announced in Dec. 15th 1997. The same decision tree could be applied to the evaluation of non-automotive applications of the technology.

Step 2: ***Selection of the appropriate tools for the application of the option thinking:***

a. **Identification and classification of the major risks/uncertainties:** Two major sources of risk can be identified while analyzing Ford investment in the Joint Venture. The first is relative to the technological advances that the "Global Alliance" would be able to achieve in a reasonable timeframe. This technical uncertainty falls under the private risk type described in Section II.4. The second type of risk is relative to market acceptance of this innovation and to market conditions in general. It is known as market-priced risk.

b. **Selection of the appropriate set of tools:** The coexistence of both private and market risk justifies the use of the composite method. In fact it is inappropriate to use market priced assets in the evaluation of the technological risk, and the market risk can be modeled through the use of a combination of Ford and Ballard stocks as the underlying asset.

   The major difference between the composite methodology introduced by Neely (1998) and the one that will be used here is in the choice of the underlying assets. Two assets will be used here (Figure VII.3):
   - Ford stock will be used as a proxy in the branch corresponding to high R&D results,

- Ballard stock will be used as a proxy in the medium and low branches.

Step 3: ***Search for (estimation of) the required set of inputs***

a. **Estimation of the length of the different phases:** The research phase is assumed to last for two years. Since the start date of the analysis is January 98, this phase will come to an end by the end of 1999. (DaimlerChrysler publicly announced that they will make the decision to move forward with the development and testing phase by the end of 1999). The second phase is assumed to cover the period from 2000 to 2003 and consequently to last for four years since the "Global Alliance's" objective is to commercialize those vehicles in 2004. The length of the commercialization phase was arbitrarily set to ten years.

b. **Selection of the probabilities:**
   1. **For the Decision Analysis part:** (technological uncertainty) The probabilities were estimated using the Pearson-Tukey Method described by Keefer and Bodily (1983). It is a simple approach of estimating discrete probabilities and outcomes that works for both symmetrical and asymmetrical distributions. This three-point method assigns discrete probabilities of 0.185 to the 0.05 and 0.95 fractiles of a distribution and a probability of 0.63 to the median.
   By considering a range of outcomes that fits a standard normal distribution (mean = 0 , variance = 1), the extended Pearson-Tukey method would assign a probability of 0.63 to the discrete outcome of 0. This is because the mean of the normal distribution is also the median.
   Both the 0.95 and 0.05 fractiles of a normal distribution lie 1.645 standard deviations from the mean. This makes the method assign probabilities of 0.185 to the discrete outcomes of -1.645 and 1.645.

   Table VII.1 summarizes those results.

   2. **For the real option part:** (market uncertainty) Use of risk-neutral probabilities. Unlike other R&D ventures, the investment in the fuel cell technology does not allow to completely isolate the technological risk from the market risk. In fact, what will be observed in the commercialization phase will largely depend on achievements on the research side. For high results in the R&D venture, Ford Motor Company's stocks will be used as a proxy. However, in the medium and low R&D scenario cases, Ballard Power Systems stocks will be used.

   The following paragraphs illustrate the methodology for one year and then give the results relative to a total period of four years. Only the analysis relative to Ballard Power Systems stocks was detailed here. Ford Motor Company stock's analysis is attached in Annex I.

   A binomial approach was used to develop a risk-neutral distribution of stock prices. Since three alternatives (low, medium and high) were considered, a binomial tree with at least two periods was needed (for simplicity, the analysis was limited to two periods of six months $n = 2$). The stock price of S = \$27.5 (Stock price in Dec.98) was used as a starting point in the analysis.

For this traded security, the Cox and Rubinstein's (1985) method for estimating the volatility and dividend yield was used. This method assumes that the price path follows a time-dependent lognormal distribution.

Table VII.2 illustrates an application of this method to Ballard's stock. In the first stage, Ballard stock prices and dividends distributed over 13 quarters were collected (from Dec-95 to Dec-98) from Yahoo Finance.

In order to estimate the average growth (X), one should add back the dividends to the stock price ($S + D$) then divide this period's stock price by last period's ($S + D$) in other words:

$$X_t = S_t / (S + D)_{t-1}$$

No dividends were distributed during the period considered in the analysis ($D_t = 0$ for every single t).
The next step was to compute the natural logarithms of those growth ratios and to estimate the average log-ratio. Finally, the quarterly variance was computed as follows:

$$Variance = \sum (Y_t)/(n-2) \quad \text{Where} \quad Y_t = [LN(X_t) - Average(LN(X))]^2$$

and n is the number of quarters considered

The Annual volatility is estimated as being the square root of four times the quarterly variance.

At the end of period 1 ($t = 1$), the stock could go up to Su or down to Sd with probabilities of p and p' respectively. The values of u and d are estimated using the following equation:

$$u = \frac{1}{d} = e^{\sigma\sqrt{t/n}}$$

Using the value of the volatility we computed before: $\sigma = 0.584$. The values of u and d are as follows:

$$u = 1.51 \ and \ d = 0.66$$

Table VII.1 Extended Pearson-Tukey probability distribution

Point	Probability	Scenario of Technological Success
P(-1.645)	0.185	High
P(0)	0.63	Medium
P(+1.645)	0.185	Low

Table VII.2 : Estimating Dividend Yield, Stock Growth and Volatility for Ballard Power System's Stock Using Cox and Rubinstein's method (1985)

Date	*Stock Price*	*Quarterly Dividend D(t)*		[S+D](t)	X=S(t)/[S+D](t-1)	LN(X)	Y=(LN(X)-Ave.(LN(X)))^2
	US$	*US$*	*%*	*US$*			
Dec-95	3.75	0	0	3.75			
Mar-96	6 58	0	0	6.58	1.76	0.56	0.157
Jun-96	7.33	0	0	7.33	1.11	0.11	0.003
Sep-96	7.44	0	0	7.44	1.01	0.01	0.023
Dec-96	6.79	0	0	6.79	0.91	-0.09	0.066
Mar-97	8.33	0	0	8.33	1.23	0.20	0.001
Jun-97	11.17	0	0	11 17	1.34	0.29	0.016
Sep-97	13.31	0	0	13.31	1.19	0.18	0.000
Dec-97	25.38	0	0	25.38	1.91	0.65	0.229
Mar-98	37.83	0	0	37.83	1.49	0.40	0.054
Jun-98	32.56	0	0	32.56	0.86	-0.15	0.100
Sep-98	22.50	0	0	22.50	0.69	-0.37	0.287
Dec-98	27.50	0	0	27.50	1.22	0.20	0.001

Source Yahoo finance

Number Of Values (*n*) 13

Average Quarterly Div	0.00%	
Annual Dividend	0.00%	
Ave. Quart. Growth	16.60%	**Ave.(LN(X))**
Annual Growth	66.41%	
Quart. Variance	0.085	**Sum(Y)/(n-2)**
Annual Volatility	58.45%	

Figure VII.3 Selection of the underlying asset for different R&D Outcomes

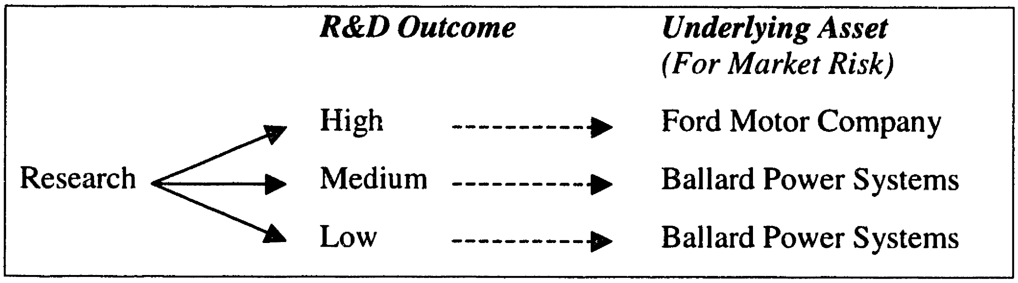
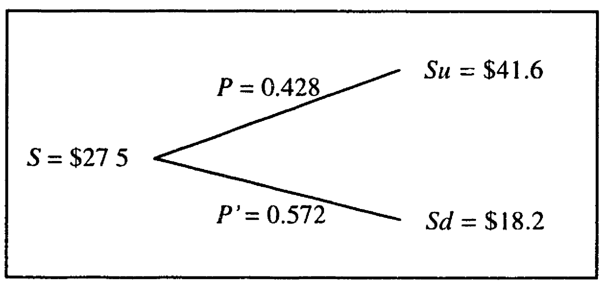


Figure VII.4 First period only risk-neutral evolution of Ballard stock (over 6months)



During the entire analysis, a risk-free rate of 5% was used. The letter *r* represents 1.025 = (1 + semi-annual risk-free rate) = *r*

The risk-neutral probabilities were computed as follows:

$$p = (r - d)/(u - d) = (1.025 - 0.66)/(1.51 - 0.66) = 0.428$$
$$p' = 1 - p = 0.572$$

Figure VII.4 plots the expected evolution of Ballard stock over a period of six months.

Where $Su = S \times u \times (1 - Div.\%)^{1/2}$ *and* $Sd = S \times d \times (1 - Div.\%)^{1/2}$
The dividend adjustment has no effect in this case since no dividends were distributed.

Once the range, within which the stock will vary during the first period was determined, the same reasoning for the second period should be done. Three possible stock prices result from the possible combinations of upward and downward price movements in two steps: *Suu*, *Sud* = *Sdu* and *Sdd.* The respective probabilities are *pp*, *2pp'* and *p'p'*. It is important to note here that since there are two paths for the outcome *Sud* = *Sdu,* the corresponding probability is twice the probability of an upward (1) then downward (2) event.

The results from using the two-period Binomial Tree to estimate the three-outcome, risk-neutral, Ballard's stock price distribution are summarized in Table VII.3 and plotted in Figure VII.5

Table VII.4 gives the results relative to the extention of the binomial method to 4 calendar years. Since the decision tree used in the option evaluation takes into account only three states of the world: high, medium and low, it was necessary to combine the nine results that figure in Table VII.4. These results are summarized in Table VII.6.

The probability of having a high price is computed as the sum of the probability of the three highest outcomes. The probability of having a medium price is equal to the sum of the three in the middle and so on.

The high, medium and low prices are computed as the weighted average of the three prices in the corresponding class. The weight being the probability of the outcome (one of the nine probabilities) divided by the probability of the class (high, medium, low).

As explained above the three sets of probabilities were used in the medium and low R&D results scenarios. For the high R&D scenario, the probabilities associated with the analysis of Ford Motor Company stocks were used.
Ford's stock prices were adjusted for dividend payouts.

Table VII.3 Three outcome, risk-neutral estimation of Balard's stock price distribution (over one year):

Risk-Neutral Price Outcome	Probability (P)
$Suu = S \times u \times u \times (1 - Div.\%) =$ \$62.85	$pp = 0.183$
$Sud = S \times u \times d \times (1 - Div.\%) =$ \$27.50	$2pp' = 0.489$
$Sdd = S \times d \times d \times (1 - Div.\%) =$ \$12.03	$p'p' = 0.328$

Figure VII.5 First and second period (combined) risk-neutral evolution of Ballard stock (over one year)

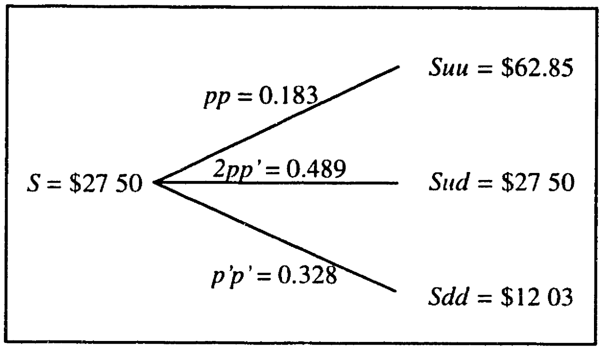


Table VII.4 & 5 Possible risk-neutral evolutions of stocks (over four years)

VII.4 Ballard

Possible values US$	Probability (%)
743.27	0.1
324.87	1.2
142.00	5.6
62.07	15.1
27.13	25.1
11.86	26.9
5.18	18.0
2.27	6.9
0.99	1.1

VII.5 Ford

Possible values US$	Probability (%)
165.16	0.6
117.97	4.4
84.27	13.7
60.19	24.3
42.99	27.0
30.71	19.1
21.94	8.5
15.67	2.1
11.19	0.2

Table VII.6 & 7 Summary of Compacted Data (over four years)

VII.6 Ballard

	Possible Values US$	Probability (%)
High	183.4	6.9
Medium	28.8	67.1
Low	4.2	26.0

VII.7 Ford

	Possible Values US$	Probability (%)
High	94.9	18.7
Medium	45.6	70.4
Low	20.5	10.9

Table VII.8 Ford's estimated needed investments for the design of a fuel cell vehicle

	1998	2000	2004	
Beginning of Year	1	3	6	Total
Investments ($million)	200	300	500	1,000

Table VII.5 and VII.7 summarize the same results obtained through the analysis of Ford Motor Company's stocks.

c. Estimation of the Costs/Benefits

Part One: Estimation of the development costs:

The total development cost for a new internal combustion engine amounts to about $1billion. It seems reasonable to use this number as a benchmark, especially if Ford itself is expected to invest somewhere around this amount in the alliance. In fact, the other two partners will be investing more or less the same amount. Meaning that the total development cost of the fuel-cell car will be around $3billions.

Ford Motor Company invested a total of C$650 million in the "Global Alliance". Among other things, they acquired 4,079,055 stocks of Ballard Power Systems. When the transaction took place, the stock was worth $20.83 in other words the investment that was made in the technology itself amounted to only US$200million (refer to VI.2 for more details).

US$200million have already been invested in the research phase. Ford Motor Company is expected to make at least two additional investments. The first one is expected to take place by the end of 1999 when they will be starting the development phase. The last one will eventually take place when the implementation / commercialization decision will be made.

Table VII.8 gives the dollar values that were considered in the base case scenario (The value of all Ballard stocks owned by Ford has been deducted from the initial investment in 1998).

Part Two: Estimation of the benefits:

The benefits will be estimated using a DCF analysis of the future cash-flows that would be generated from the implementation of the Fuel Cell technology in Ford Vehicles.

1. General trends:

The following paragraphs introduce some general characteristics of the car industry which were used as a basis for the evaluation of benefits.

Range of profits that could be generated from the sale of FC powered cars:

Through the analysis of the profits that car manufacturers were able to make on successful models, it is reasonable to accept the idea that Ford Motor Company would be able to charge a premium of up to $5,000 on a successful fuel cell model (maximum value reached during the lifecycle of the product). For example, Chrysler had the lead in the minivan segment for a large number of years. They managed to sell more than 200,000 minivans the first year and charge a high premium on them. As a matter of fact, they spend $ 13,157 to build a Town and Country model and sell it to dealers for $21,370. That yields a gross margin (before overhead or development costs) of $8,213, or 62%. When high-profit options are included, it's easy to see how Chrysler's profit on minivans can reach $ 10,000 (Source: Brock Yates interview in Forbes Oct28, 1996)

Time dependence of the benefits:

Like any innovation, the alliance is expected to face some problems gaining market share in the beginning. The main reasons behind this are the following:

- Development of the needed infrastructure for non-conventional fuels distribution and technical assistance
- Consumers reluctance to buy an unproven technology
- Existence of alternatives

The "Global Alliance" might be forced to charge a relatively low or even a negative premium in the beginning. However, since the automobile industry is characterized by the coexistence of important learning effects and economies of scale, the benefits per car sold are expected to increase in the first period. After this period of growth, margins tend usually to decrease because of competition. This "Bell" scenario will be compared to a linear benefits scheme. The benefits per fuel cell car sold are assumed to follow the trend represented in Figure VII.6.

The values of $*X* and $*Y* depend on the advances that could be achieved in the research and development phase and on the market acceptance of this technology.

Time dependence of the "Global Alliance's" market share:

The considered market, is of the fuel cell powered cars (it could be that this market would never exist). The market share of the "Global Alliance" will depend on the relative technological advances that they will be able to achieve. In the case of high technological advances, they are expected to enjoy a dominant position in the FC powered vehicles market. Their position in the market is expected to gradually decline because of competition.

Figure VII.7 plots the trend that the "Global Alliance" market share will follow in good states of the world. It also plots the expected total number of fuel cell vehicles that will be sold in case of success. The *D*% value corresponds to a high share that is

Figure VII.6 Expected evolution of the Benefits per fuel-cell car sold

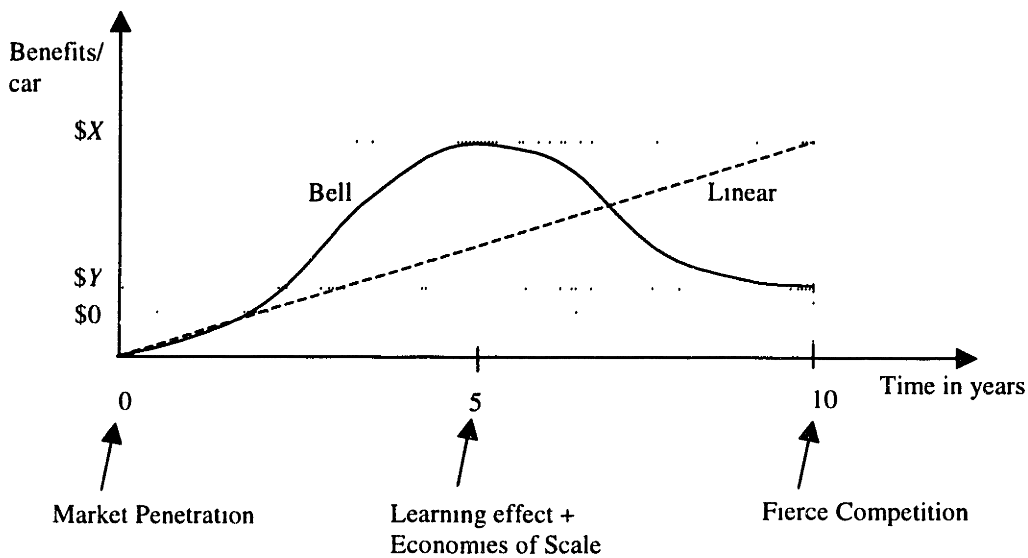
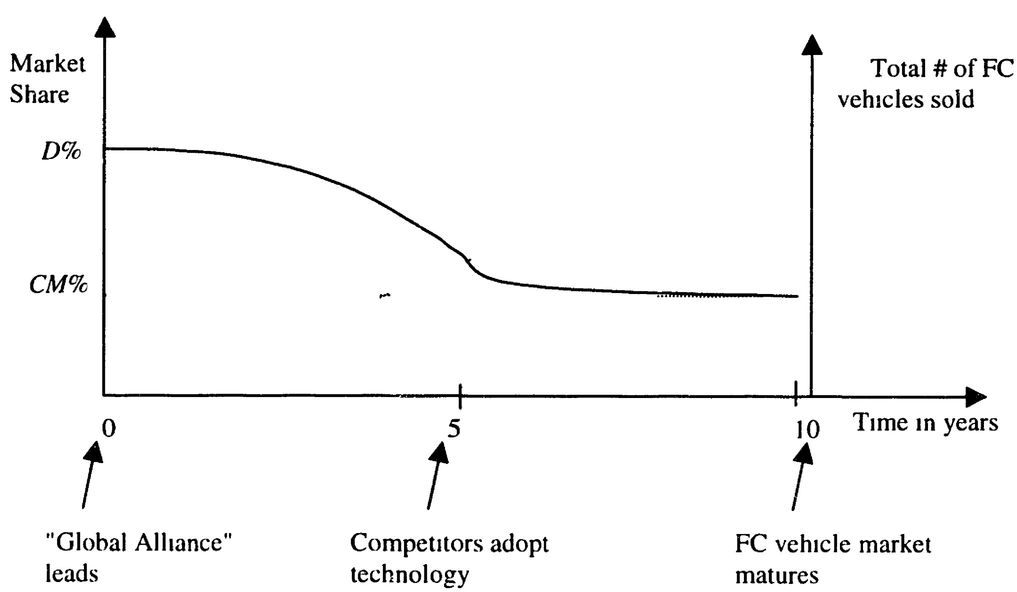


Figure VII.7 Expected evolution of the alliance's market share



likely to be observed if the alliance dominates the Fuel cell market while the *CM%* is the equilibrium share that will be reached on the long run.

2. Estimation of the total number of FC vehicles that could be sold in the US:

By looking at the evolution of the total number of passenger cars sold in the US in the last five years, one can notice that this number fluctuated very little between 8.2 and 8.9 million vehicles. The 1997 number of 8.27million vehicles will be used as a starting point.

One acceptable assumption would be to apply a 1% growth rate to 8.27 million to estimate future sales of passenger cars. The effect of variations in the total number of cars sold per year is not of major importance here. In fact, the most important variable is the rate of penetration of Fuel Cell Vehicles.

In a second stage, the total number of fuel cell vehicles that could be sold in the future was estimated. Three different penetration scenarios were considered:

- High penetration: This is likely to happen if the technology reaches a satisfactory development stage, the needed infrastructure is available and if consumers accept to switch from the internal combustion engine. This scenario also assumes that the technology will be implemented in different models,
- Medium penetration: This might happen in case one or more of the conditions listed above is not completely satisfied,
- Low penetration: This could happen in case the market for the fuel cell technology remains as a niche market and does not develop further.

Table VII.9 gives the assumed total number of new fuel cell vehicles sold under these three different scenarios.

3. Estimation of Ford Motor Company's future margins and sales of FC vehicles in the US:

In order to derive those numbers, one should first focus on the "alliance's" share in the Fuel Cell market. This could be correlated to the success of their research and development effort. Many other factors could affect their market share including how quickly they will be entering the market, how competition will react to their entry, etc... Table VII.10 gives the assumed shares of the "alliance" in the FC market under three different scenarios.

The "alliance" could have a low share in the fuel cell market even if the technology itself is widely accepted by consumers. Such a scenario can happen if GM and Toyota design a better Fuel Cell powered drive train.
In total, three technological scenarios representing the alliance's success/failure in their R&D effort and three market scenarios reflecting future market acceptance of the technology were considered. Those two sets of three scenarios could be combined in 9 different ways giving a total of nine scenarios.

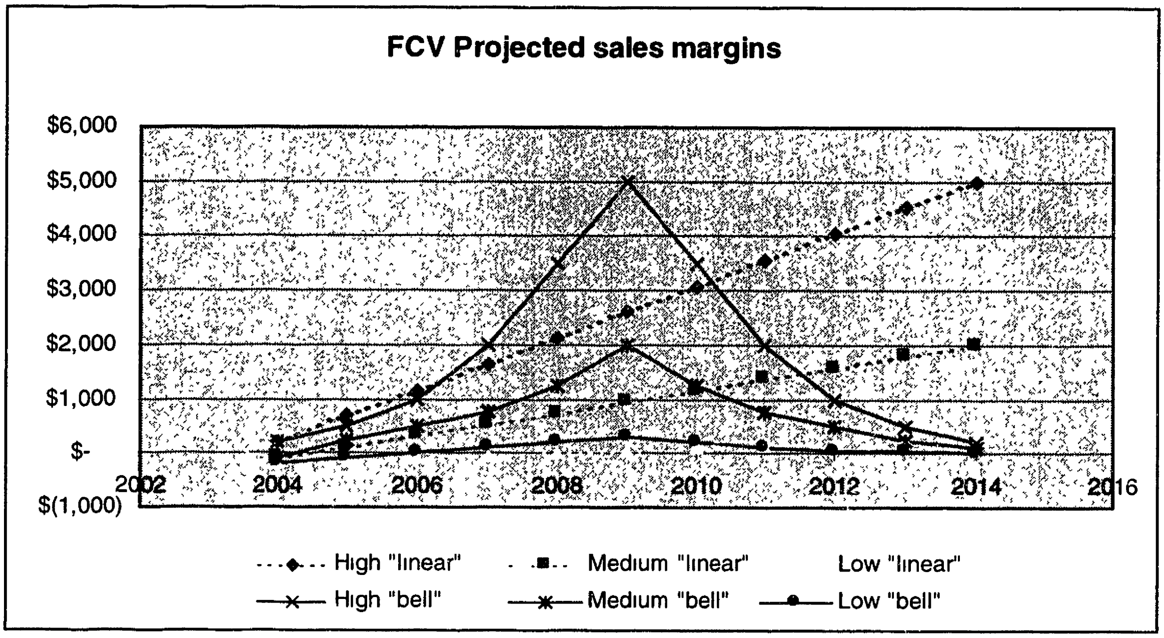
Table VII.9 Fuel cell vehicles sales projections

Year	Scenario		
	High	Medium	Low
2004	8,869	5,321	355
2005	17,915	10,749	717
2006	90,470	54,282	905
2007	365,499	219,300	1,371
2008	922,886	461,443	1,846
2009	1,491,383	745,692	1,678
2010	2,071,158	941,436	1,412
2011	2,662,380	950,850	951
2012	3,265,219	960,359	768
2013	3,879,848	969,962	582
2014	4,506,444	979,662	490

Table VII.10 Percent share of the "alliance" in the fuel cell vehicle market

Scenario	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Low	10	11	12	13	15	16	17	18	19	20	20
Medium	50	47	44	41	38	35	32	30	30	30	30
High	90	88	86	84	82	80	75	70	65	60	55

Figure VII.8 Ford's estimated sales margins on FCV



In the second stage the number of vehicles that are expected to be sold by Ford Motor Company itself are computed. These numbers are derived from the previous figures assuming that the share of their sales in the alliance will be in the same range as what has been observed in the past in the ICE market. Using historical data regarding past volumes of sales, their share could be as high as 65.6% of total alliance sales.

Once Ford's future sales of Fuel Cell vehicles are estimated under the nine different scenarios, one should focus on the margins they are likely to charge. Figure VII.8 gives the margins used in the analysis under the three market scenarios. The Base Case scenario uses the "Bell" shape scheme.

These estimates were based on two assumptions:

- Margins are correlated with market acceptance of the technology,
- Under any of the three different scenarios, Ford Motor Company will be able to charge a margin in the same range as what has been observed in the car industry in the past.

d. Estimation of the discount rate:

One of the advantages of using the hybrid method is that it bypasses the problem of choosing the appropriate discount rate to compensate for risk. In fact, The private risk or technological risk can be diversified and therefore requires no compensation for risk. In addition, the market risks are transformed by the options analysis so that no further compensation for risk is required in the discount rate.

All the cash-flows will consequently be discounted at the risk free rate.

Step 4: ***Evaluation of the investment***

a. Evaluation of the option (Base Case):

Summary of important assumptions:

- Schedule:

Phase	**I**	**II**	**III**
Year	1 and 2	3 to 5	6 to 16

- Needed investments:

	1998	**2000**	**2004**	
Beginning of Year	1	3	6	*Total*
Investments ($million)	200	300	500	1,000

- Probability distributions

Decision Analysis part (research phase outcomes)

Scenario	**Low**	**Medium**	**High**
Probability (%)	18.5	63	18.5

Real Options part

Numbers in %	**Scenario**	**Low**	**Medium**	**High**
R&D Results	**High**	10.9	70.4	18.7
	Medium or Low	26.0	67.1	6.9

- Benefits Computation

  The Bell benefit distributions plotted in Figure VII.8 have been used. Computations were made based on the numbers that figure in Tables VII.9 and VII.10.

- Discount Rate

  The risk free discount rate was set equal to 5%.

Base Case results:

The value of the project computed using an "option thinking" and all the assumptions/numbers that have been discussed exceeds the initial investment of US$200million by US$157.5million (all the required investments being already deducted). This means that apart form the strategic value of their partnership with the DaimlerChrysler/Ballard joint venture, Ford's investment has a sound financial value. Figure VII.2 plots the corresponding simplified decision tree.

b. Sensitivity Analysis on critical inputs:

1. Choice of the probabilities of Technological success/failure

Figure VII.9 plots the effect of the choice of the probabilities of high and medium research results on the value of the project. The probability of low research results is computed as : $P(\text{low}) = 1 - [P(\text{high}) + P(\text{Medium})]$. The graph shows that as long as the probability of high research results is higher than 11.15% and for values of the probability of medium results ranging between 10% and 60%, the project has a positive NPV. It also shows that the decision to invest is very sensitive to the choice of the probability of high technological results.

2. Choice of the number of underlying assets:

Figure VII.10 shows that the use of Ford stock only, overvalues the project while the use of Ballard stock only, undervalues it. As explained before, the results of the research and development phase will considerably affect the characteristics of the market in which the fuel cell vehicle will compete. It is consequently necessary to use both stocks as underlying assets.

3. Effect of the distribution of future benefits:

The project is re-evaluated using the "linear" distribution of future benefits plotted in figure VII.8 (dotted lines). The value of the project is even greater than in the Base Case: $798.7 million as opposed to $157.5million for the "bell" distribution.

c. Search for Break-even points:

1. Probabilities of Technological success/failure:

As discussed in the previous section, the value of 11.15% for the probability of high technological results can be considered as a break-even point. In fact, this is the minimum value that *P*(high) can take without affecting the decision to invest for *P*(medium) ranging between 10% and 60%.

2. Value of future benefits:

"Bell" Shape:
By focusing on the high market acceptance scenario, one could reduce the expected benefits per car from the implementation of the FC technology by as much as 45.6% (flat multiplier) and the decision to invest would remain unchanged. This sensitivity decreases the highest value of expected benefits from $5,000 to approximately $2,720. The corresponding benefits are given in Figure VII.11.

The breakeven values of the benefits seem to be relatively high but the following points should also be considered:

- Associated development costs are already deducted,
- Sales projections have been selected in a conservative fashion.

"Linear" Shape:
By using a linear distribution of future benefits, the investment decision appears more robust. In fact, by assuming that the medium case numbers will be half the high case ones and that the low case numbers are half the medium case ones, the average break-even distribution is obtained (plotted in Figure VII.12). The highest value of the average projected benefits can go as low as $1000 before braking-even. Only the numbers relative to the medium case scenario have been plotted. In fact, both the high and low case numbers can be derived from the medium case numbers by multiplying and dividing them by two, respectively.

Figure VII.9 Sensitivity to the Probabilities of Success/Failure

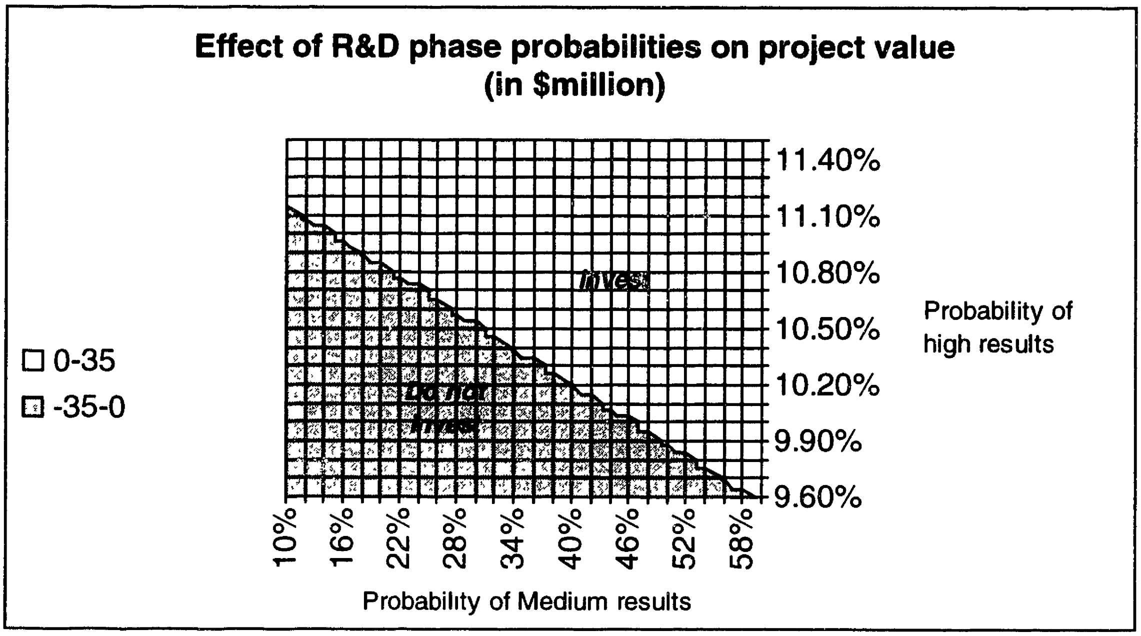


Figure VII.10 Sensitivity to the Choice of Underlying Assets

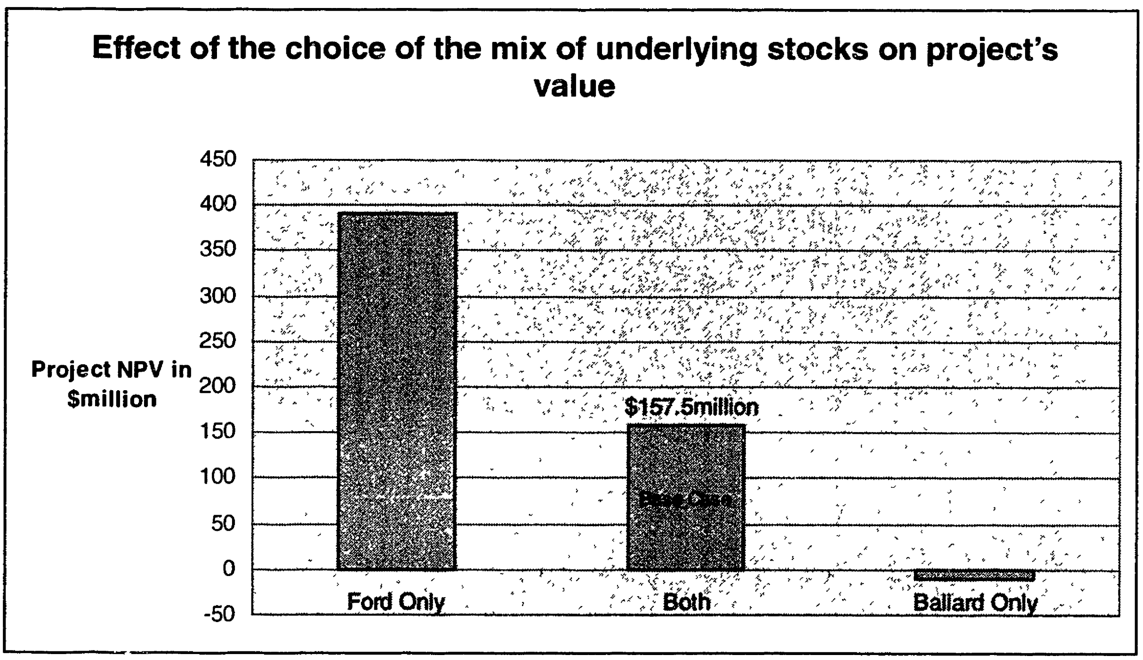


Figure VII.11 Search for Breakeven, High Market Acceptance, Sales margins ("Bell" shape)

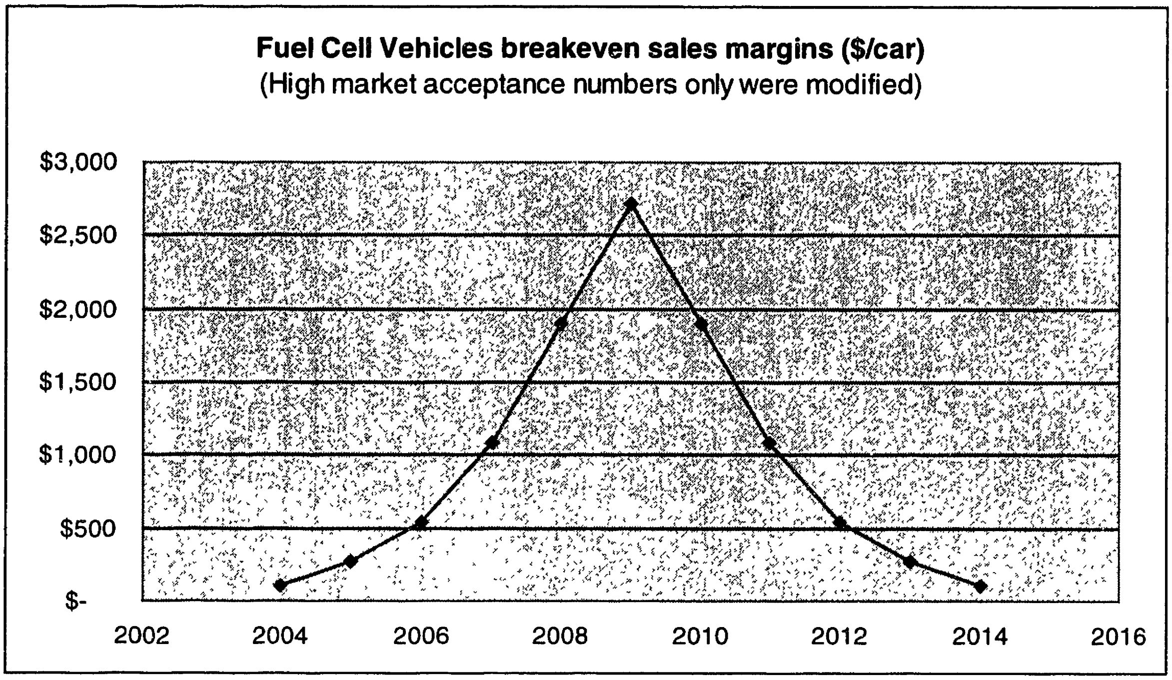
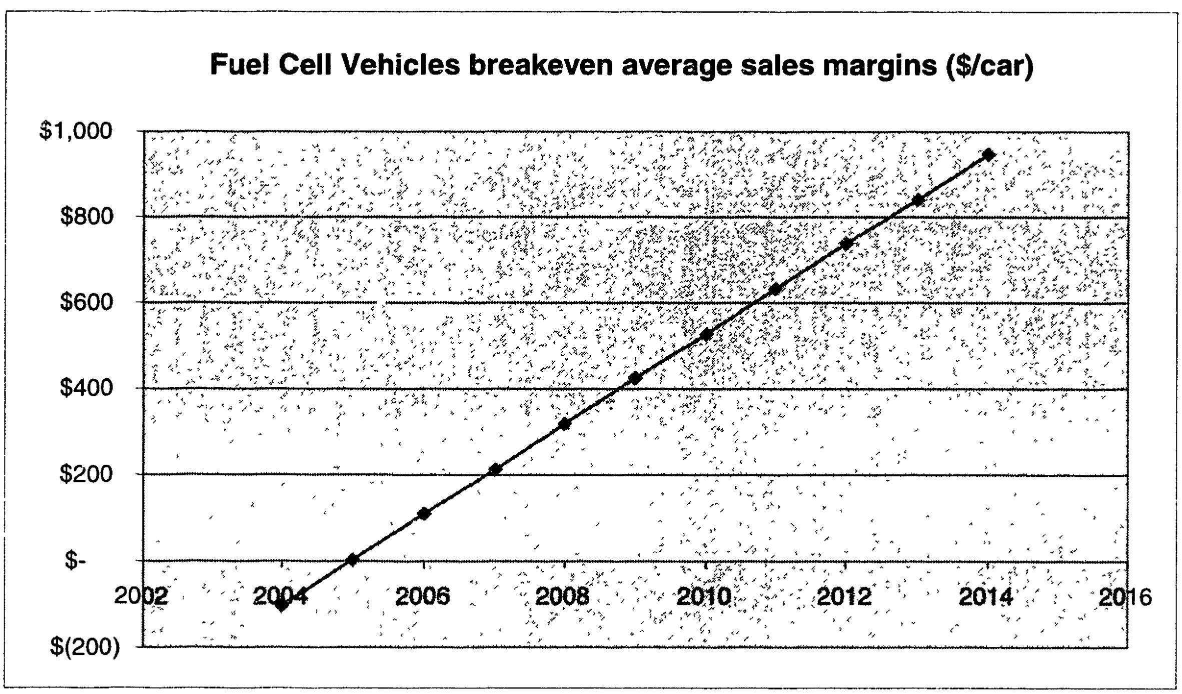


Figure VII.12 Search for Breakeven Sales Margins ("linear" shape)



2. Evaluation using the "portfolio of options approach"

In this part of the analysis, Ford's investment in the joint-venture will be analyzed as a combination of different options. In fact, the fuel cell technology could have many applications. The most direct applications that are considered by Ballard are the following:

a. Automotive applications,
b. Stationary power,
c. Portable power.

One can look at the value of investing in the fuel cell technology as the sum of three different options (see Figure IV.1). Each option corresponds to the implementation of the technology in a specific market. The problem faced at this point is the following: is the value of the investment equal to the sum of the value of each option computed in isolation or does the interaction between these options affect the overall value?

The interaction between these three options is expected to increase the overall value of the investment. In fact, the research effort made in the improvement of the fuel cell stacks that are used for automotive applications could benefit one of the two other options. In addition, all the efforts to reduce the cost of the fuel cell stacks could benefit any of the three options. This implies that the interaction will be positive in this case.

Since a detailed analysis of the automotive applications has been included in the first part of this chapter, only the two other applications will be discussed here.

a. The market for portable power:

Some manufacturers like the Japanese Honda see some prospects in the development of small fuel cell stacks for portable use. One can imagine the development of Honda devices that will use Methanol or another fuel to generate the needed amount of electricity. The technology is still in the stage of "developing an idea" meaning that no information on how the market will be affected by the technology is available.

To get an idea about this market, one can look at the market for portable tools that use different kinds of energy and assume that the fuel cell technology will be introduced in one of its segments. Two underlying assets will be needed:

- The first one will be used in the high R&D results scenario. Black&Decker stock is a good example,
- The second one will be used in the medium and low R&D results scenario. The stock of a start-up in the design and manufacturing of portable tools or Ballard stock could be used as a proxy.

An approach similar to the one detailed for automotive applications will lead to a value of the option relative to portable power applications. The very little information available on this specific application makes it very hard to come-up with a reasonable estimate of the value of this option.

b. The market for stationary power generation:

Even if it is unlikely that in the near future, the fuel cell technology enters the large power generation units market (around 500 MW), this technology has many prospects in the small to mid-size market. In fact, increasing environmental constraints and the large number of transmission constraints that are observed in big cities are pushing the development of clean distributed loads. The fuel cell technology could efficiently solve this problem through the development of clean generation units that would accept conventional fuels. The two constraints presented earlier could justify a reasonable price premium paid for this clean technology.

By looking at the contract signed between Ballard and Cinergy power for the delivery of a 250kw fuel cell generation unit, it can be seen that cost remains the main issue for this technology. In fact the price of this unit was of $ 6,500/kw compared to the $500/kw charged by manufacturers of combined cycle gas turbines (CCGT). This means that if no tax credits or subsidies are introduced, the price of fuel cell units will have to drop by a factor of ten before any take-off in their sales could happen.

In order to estimate the market within which this technology will be competing in the future, one should look at a minimum of three different factors:

- Projected growth in the demand of electricity
- Planned replacement of existing units
- Projected cost of transmission in major congested cities

The two first points provide an estimate of the new generation capacity that will be needed in the coming years while the last point gives an idea about the possible share of the Fuel Cell technology in this market. Power producers will be willing to pay a premium for generating units that could be distributed and that could have extremely low emission levels.

As previously explained in the automotive applications section, two sets of stocks are needed. The first one will be used as a proxy in the case of high technological success while the second one will be used in the case of low or medium technological success. The stock of a manufacturer of small to mid-size generating units can be used in the first case while the stock of Ballard would be more appropriate in the second case.

c. Value of the option (Combination of the different options):

Once the evaluation of each one of these options is completed, the task would be to come up with the value of the total option. A simple estimation of this value could be obtained by computing the sum of the three parallel options. However, it is easy to predict that the value of the global option is greater than the sum of each isolated option. The results that can be reached while exploring one application can be used in another application.

Another approach would be to design a global decision tree that would include the three different applications. This valuation of the option is more likely to be on the upper side since it is more costly to investigate three different applications at a time.

Even if a method for combining the three parallel options was not given here, both an upper and a lower boundary to the value of the option were suggested. This can be satisfactory if the range between both values is not too large.

VIII. Policy Analysis

After exploring the Ford investment in the DaimlerChrysler/Ballard Joint Venture from a financial point of view, it is important to look at other dimensions that influence the choice of this option. In order to do this, a large car manufacturer like Ford Motor Company usually goes through a corporate policy process. Such analysis would allow to isolate the problem, identify all the available options, analyze external and internal factors, and design a strategy that would help implement the best option.

This chapter presents a model of how to do a policy analysis based upon the procedures developed in the MIT Technology and Policy Program (Tabors, 1996). The chapter first presents the overall procedure, and then applies it to the specific case of Ford's policy toward the development of fuel cells. The conclusion is that Ford's strategy toward fuel cells is optimal in general terms.

1. Corporate Policy-Making Process for the design a fuel cell strategy

Definition of a Corporate Business Policy

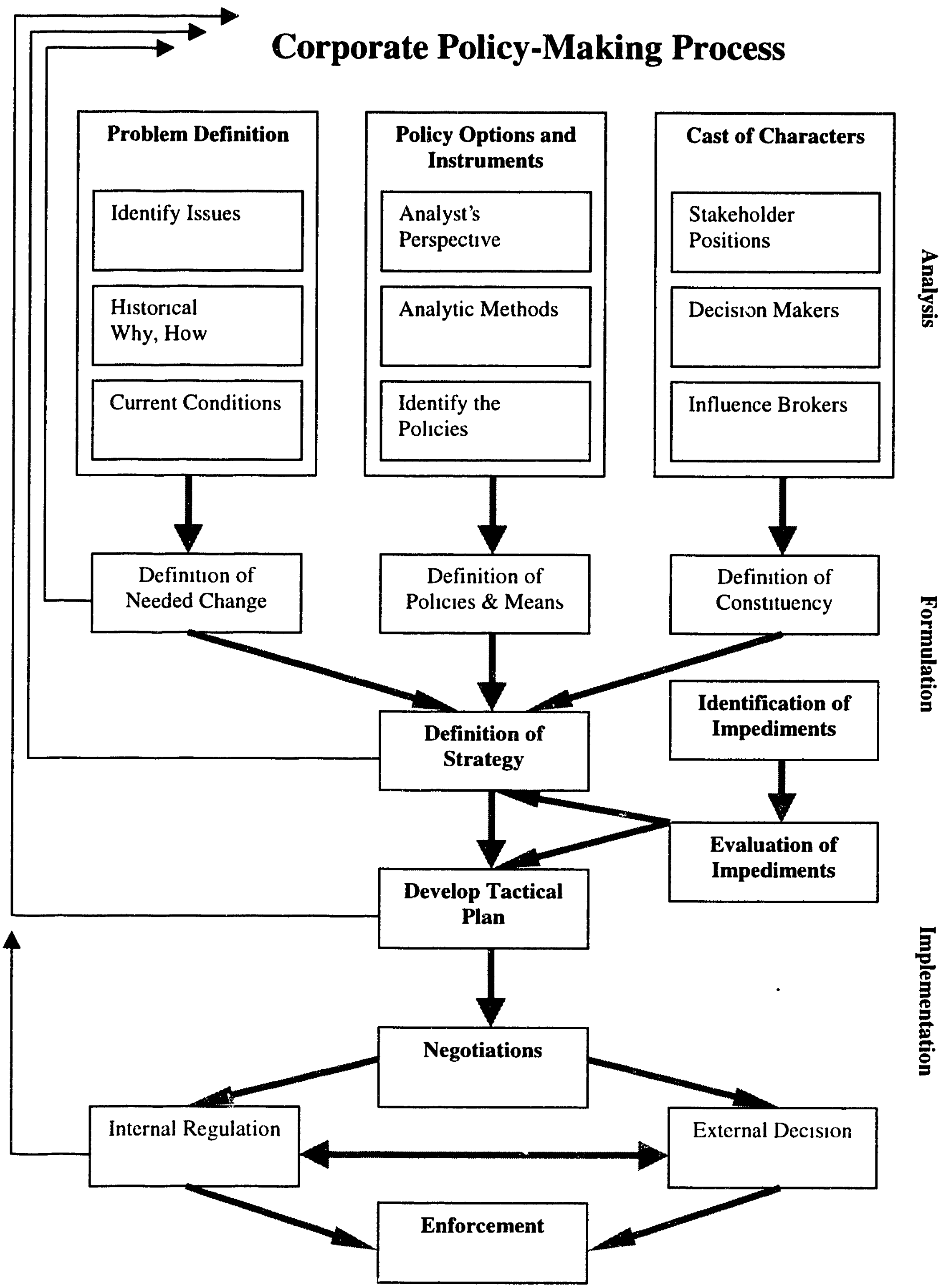
A business policy is "the analysis of an organization in its totality" (characterized by) "its internal structure, its resources and processes, and the constraints and opportunities posed by its environment" Buono (1985). In fact, every organization has fundamental needs to define its own business policy and clearly state its objective.

To achieve its goals, a corporation must:
- Understand what it hopes to accomplish,
- Assess what it has to work with,
- Decide how to use its resources within its environment to accomplish its purposes,
- Translate these concerns into specific plans,
- Implement those plans, and
- Measure and evaluate the results.

This process, which is referred to as policy, planning, strategy, implies a broad scope of relationships of the major elements, internal and external, in an organization's situation.

Figure VIII.1 describes one view of the different steps that policy makers could follow while developing their governance plans (Tabors, 1996). This process has three different parts:
- Analysis: To help the company understand what it hopes to accomplish and assess what it has to work with.
- Formulation: To translate the overall policy into specific plans for a company to use its resources within its environment to accomplish its purposes.
- Implementation: To move to the actual accomplishment of these plans, including the measurement and evaluation of the results. Naturally, these steps are iterative. Development in the formulation and implementation stages, for example, lead to new analysis of the overall strategy.

Figure VIII.1 Description of the Corporate Policy-Making Process



1.1. Analysis

The analysis starts with a definition of the problem. One should first identify all the issues that relate to the problem, go through its historical development and state the current conditions.

1.1.1. Problem Definition

The definition of the problem to be addressed by a policy derives from a combination of the basic issues, the historical background, and the current situation. This constitutes the first phase of the analysis.

a. Issues Identification:

Environmental constraints and corresponding government regulations have forced car manufacturers to look at new technologies that would considerably reduce or even eliminate tailpipe emissions. Many alternatives have been considered, but few are economically viable and technologically feasible.

The fierce global competition that characterizes today's automobile industry does not allow any player, even as big as Ford Motor Company, to be indifferent with regard to competitors' objectives. In addition, any modern car company has to manage its technological and environmental image to appeal to consumers. It is consequently necessary for them to look into less polluting technologies. Major auto-makers like General Motors, Toyota and DaimlerChrysler are looking at the possibility of replacing the Internal Combustion Engine by Fuel Cells and are making heavy investments in this direction.

b. Historical background:

The race for the development of technologies with lower emissions was stimulated by different regulations which, in most cases, originated in California. The Los Angeles Basin is known for its poor air quality due to the local geography and its high number of cars.
The California Air Resource Board (CARB) has been behind most of the regulations, usually adopted by the federal government later on. Regulations included specifications of the share of Low Emission Vehicles that each major car manufacturer would have to introduce by specified dates. In 1990, CARB ruled that in 1998, each of the seven major carmakers selling in California -GM, Ford, Chrysler, Honda, Toyota, Nissan and Mazda-, would have to make 2% of annual sales emission free. In 2001 and 2003, the minimum share would be raised to 5% and 10% respectively.

Since there were no Zero Emission Vehicles (ZEV) ready for the market, car manufacturers started a dual effort:

- Lobbying to cancel the plan that was voted,

- Speeding the research and development effort relative to the most advanced ZEV technology at the time: Electric Vehicles.

General Motors was the only car-company that tried to build an electric vehicle from the "ground up" before the 1998 deadline. Shnayerson (1996) describes the steps GM took to commercialize its first electric vehicle known as the EV1. Ford and Chrysler focused their efforts on the conversion of gasoline models.

The major problem was to design a battery stack that would both have an acceptable range and achieve reliability, cost, and longevity targets. This was impossible in the given timeframe even with the creation of the USA Battery Consortium (USABC). This consortium included the three US car manufacturers and some companies involved in battery research and development. Its objective was to improve the existing battery technology for automotive applications. The 1998 target set by CARB was finally abandoned after extensive lobbying efforts from both car-makers and oil producers.

The EV experience highlights a number of points that need to be considered in formulating technology policy for future automotive innovations such as fuel cells:

- Alliances such as the USABC can be beneficial but present a number of negative points as well. For example, GM, Ford and Chrysler were in competition and did not want to share all the information relative to their own electric vehicle programs. This led to inefficient cooperation. This suggests that a company should look for complementary cooperation rather than work with others on the same piece of the puzzle.
- It is impossible to schedule the arrival of a technological breakthrough. It was impossible to have the battery technology ready by 1998. A car company should not, consequently, commit to the commercialization of a new model before being sure that the necessary technology will be ready.

c. Current Conditions:

Air quality in American cities is still a concern, even if new US automobiles pollute far less than previous ones. In addition, car manufacturers face the threat that the ZEV requirements would be enforced in the future or that the new required emission levels would be set so low that they would have to sell ZEVs to meet them.
Fuel cells are one of the most promising "zero emission" technologies. Three alternatives are under consideration depending on the type of fuel used: hydrogen, methanol or gasoline. Strictly speaking fuel cells are not "zero emission" however, what comes out of fuel cells is innocuous[1].

Fuel cell technology is not commercially ready. The system needed, including both the fuel cell stacks and the needed infrastructure to fuel them is not ready:

- Hydrogen fuel cells are well developed and can be ready for mass production in a relatively short time but the needed hydrogen distribution infrastructure is not

[1] Hydrogen fuel cells produce water. Both Methanol and Gasoline fuel cells also emit some CO2.

available. There are also safety concerns relative to the hazard associated with the handling of hydrogen.

- Methanol fuel cells are still not production ready. Moreover, the distribution infrastructure is not ready.
- Gasoline fuel cells still face many technical problems.

d. Definition of Needed Change:

There is a need to respond to environmental mandates and to develop cleaner technologies. The fuel cell technology is among the most promising ones. Therefore major car manufacturer should consider joining the fuel cell research and development race in a way or the other in order to:

- Protect or improve its environmental image,
- Improve its technological leadership image,
- Be able to react to competitive threats,
- Be prepared to meet future regulation requirements.

1.1.2. Policy Options and instruments:

Once the problem has been defined, the next step in a policy analysis is to identify the different options and instruments available to deal with it. In this phase, it is first necessary to be clear about the perspective of the group for which the policy is being formulated. Different groups will have quite different points of view. Once this is done, one can select the methods of analysis, apply them to the available options and define the possible policies.

a. Analyst's Perspective:

The current analysis looks at fuel cell policy from the perspective of car manufacturers. This perspective, or "frame", contrasts with other possibilities, such as that of regulators.

Even within the car industry, perspectives differ from one car company to another. These frames are linked to the corporate culture of the company. The way General Motors, Ford, DaimlerChrysler or Honda views the need for technological innovations are different. For example, Daimler-Benz has a reputation of technological innovation in the automobile industry. In order to protect this image, they need to be aggressive in making investments in research and development. They are also trying to build up the environmental image that pushed them to speed up the research in the field of fuel cells through their alliance with Ballard. Size also matter. A large company like General Motors has the tendency to develop new technologies in-house whereas smaller ones like Honda would prefer to wait and buy the technology from others once it is developed. The environment in which a company operates is also important: Honda has very strong ties with the Japanese government which influence its managerial decisions.

b. Analytical Methods:

To evaluate an investment in technology innovation in the automobile industry, one should take into account managerial flexibility. Analytical tools that take into account both the effects of uncertainty and flexibility should be used. A Real Options thinking would be appropriate, as described in earlier chapters of the thesis.

Since the Discounted Cash Flow method (DCF) is based on the forecast of future cash-flows according to a fixed plan, it is impossible to model the benefits of flexibility using this approach. A DCF approach is likely, moreover to undervalue any project with risk and flexibility.

To account for managerial flexibility one could use decision analysis. However, the coexistence of many decisions that affect the overall value of the investment increases the number of inputs. A decision analysis approach would require that financial analysts estimate the probabilities of the different outcomes and the discount rate for each stage. It is hard to justify the choice of those values in a decision analysis approach.

A Real Option approach is the only remaining methodology. It is, for example, relatively easy to look at Ford's investment in the DaimlerChrysler/Ballard Joint-Venture as an option. Through its investment, Ford Motor Company holds the right and not the obligation to use the Fuel Cell technology in future models if the economics of the implementation justify the investment at the maturity date.

c. Identification of Possible Policies:

Car manufacturers face essentially six possible policies in the design of a fuel cells strategy. As Table VIII.1 shows, these represent different levels of commitment and complexity. These are to:

- Develop the technology internally (GM and Toyota strategy),
- Commit to production by oneself (GM adopted this strategy in the design of EV1),
- Commit to production within a group (DaimlerChrysler might adopt this strategy by the end of 1999),
- Create alliances for the development of the technology (Ford/DaimlerChrysler/ Ballard)
- Buy actual and future developments of the technology from others (Honda)
- Do nothing for now (Small manufacturers like Kia).

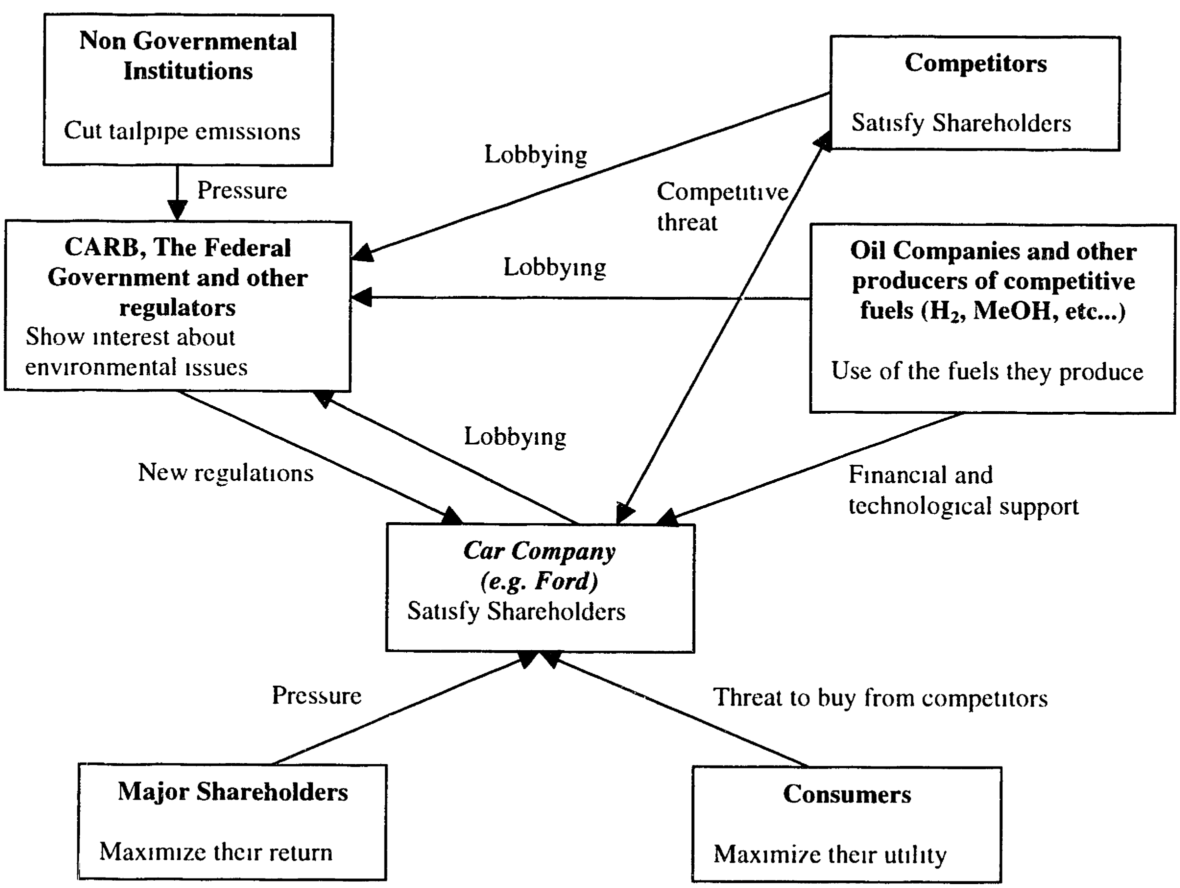
Table VIII.1 Possible Policies towards Fuel Cell available to car manufacturers

Level of Commitment →

Level of Complexity ↓

	Passive	**Research**	**Production**
Alone	Kia	GM/Toyota	(GM for EV)
Joint effort	Honda (Buy the technology from the winner)	Ford/Daimler-Chrysler/Ballard ---▶	DaimlerChrysler (end of 1999)

Figure VIII.2 Stakeholder interaction in the car industry



1.1.3. Cast of Characters:

Once the problem defined and all the different options identified, it is important to analyze stakeholders positions and identify decision makers and influence brokers before designing the strategy. By knowing the key players in the problem, one can design a strategy that will eventually be acceptable to key participants who could block or prevent the execution of a policy. The objective is to implement the best available policy.

In formulating a policy that has a chance of success, it is imperative to build and sustain sufficient coalitions that will overcome political obstacles.

Figure VIII.2 identifies the major stakeholders, decision makers and influence brokers as well as their interactions from the perspective of an American car manufacturer. Tables VIII.2 and VIII.3 give an overview of their position, objectives, an estimate of their power in influencing the choice of an option, and a reference to when during the policy making process they will be able to influence the policy.

1.2. Formulation

As opposed to the Analysis part of the Policy Process, both the Formulation and Implementation parts are specific to the group that would apply a policy. Hence only a brief general introduction of each of them is suitable at this point.

This part uses the three definitions of: needed change, options and means, and constituency to identify the best option available to the considered corporation and define the strategy that will efficiently implement it.

1.3. Implementation

Implementation of a policy usually involves both internal and external negotiations. External negotiations are needed, for example, to influence environmental regulations if the technology could not be made available in time. Internal negotiations are needed to reaffirm the commitment to the policy and adjust it as conditions evolve.

The decision process General Motors went through during the design of the electric vehicle EV1 involved many internal negotiation rounds. Each time the strategy failed, the team reviewed its strategy, defined a new tactical plan and initiated a new round of negotiations (Shnayerson, 1996). This finally lead to the commercialization of the first "from the ground up" built electric vehicle.

Table VIII.2 Inside Stakeholders Position

Inside Stakeholders	Position/Objectives	Influence on policy selection	When can they influence things
Management	To satisfy shareholders.	They make the decision.	At any time.
Finance group	To invest only in projects with a positive NPV. They are reluctant to invest in risky projects such as research and development. Management should encourage them to use modern evaluation tools such as real options.	Indirect. They estimate the financial value of each available option.	When investment decisions need to be made/revised
Marketing group	To have products that respond to consumer demands. They are not used to marketing new products unfamiliar to consumers.	Indirect.	In the last phase.
Strategy group	To enhance the position of their company in the automobile industry. They should push for the exploration of new technologies.	Indirect. They provide management with the best competitive strategy.	At any time.
Engineers/ Researchers	To progress within the corporation, to have more autonomy, and to see their designs approved by management. They should avoid pushing products that are not fully developed. In the case of the EV1, Shnayerson (1996), the excitement of a handful of engineers lead to GMs' commitment to manufacture an electric vehicle for which the technology was not ready.	Indirect. They can, to some extent, kill or push one option or the other.	At the very beginning (research phase).

Table VIII.3 Outside Stakeholders Position

Outside Stakeholders	Position/Objectives	Influence on policy selection	When can they influence things
Major company stockholders	To realize an acceptable return on their investment. The company should remain competitive in the market and explore strategies that will achieve this, such us, investing in technological innovation.	Direct. Influence on the financial position of the company through the stock-market.	Very early in the process. (They can react to simple rumors).
Competitors	To mislead the company and to be among the first in introducing innovative products.	Indirect, through public statements.	At any time.
Government Institutions	To serve US interests.	Direct influence through regulations.	At any time (especially during reviews of regulations).
Consumers	To maximize their utility, equivalent to obtaining a competitively priced, reliable and practical vehicle.	Very little ex-ante.	At the very end by refusing to buy new products.
Oil Companies and other fuel suppliers	To sell their products. They should adopt a more flexible approach and increase their cooperation with car-makers for the development of cleaner technologies.	Relatively important because they are part of the supply chain.	Especially in the beginning.
Non governmental Institutions	To push for the cleanest technologies regardless of any feasibility concerns.	Indirect. Their importance varies.	At any time.

2. Application of the Policy-Making Process to the Ford Case

2.1. Analysis

The analysis part is similar to the one made in the general case. Its main conclusions are that:

- It is necessary to look into less polluting technologies including fuel cells,
- The fuel cell technology is not, as of 1999, ready for the market.

The formulation and Implementation parts are more specific to the case of Ford and need to be addressed.

2.2. Formulation

The formulation of a practical policy joins the analysis of what is desirable with an assessment of what is politically feasible. This is done by assessing how each of the key stakeholder groups would react to each possible policy under consideration. If key stakeholders might block a policy, then it needs to be rejected as infeasible, regardless of how desirable it might be. Conversely, a policy is feasible if it can be assured sufficient support by key stakeholders at critical moments.

The formulation of a feasible policy is not a direct process. Part of defining a feasible policy consists of the identification of impediments (see figure VIII.1), and the formulation of ways to overcome them. The means to overcome obstacles typically consist of changing the proposed policy to include features to make them acceptable to stakeholders that might otherwise be opposed.

The experience in developing the US national policy on clean air illustrates the interactive nature of the policy formulation process. As described by Cohen (1995), The development of the Clean Air Act Amendments of 1990 (CAAA) required provisions to take care of various stakeholders adversely affected by this CAAA. For example, the restrictions on sulfuric emissions reduced the market for sulfur-rich coal from West Virginia, and the economy of that region. To gain acceptance of the CAAA, the persons formulating this policy had to include measures to compensate that region. This kind of reformulation was, and normally is, repeated many times for different stakeholders in the policy formulation process.

Key decision-makers are also often key elements in the process. They can enhance or detract from the power of stakeholder groups. For example, the influence of West Virginia coal mines on the CAAA was significantly increased due to the web of friendships and personal influence of Senator Byrd (Cohen, 1995). Likewise, the personal desires of Roger Smith as head of General Motors largely determined that company's policy on electric vehicles (Shnayerson, 1996)

A thorough policy formulation should thus consider both the groups of stakeholders and also key personalities. Such an extended analysis is beyond the scope of this chapter however.

Ford Motor Company had to choose among six different options related to the fuel cell technology. Tables VIII.4 and VIII.5 distribute the stakeholders, from inside and outside the company, over their preferences for the policy possibilities introduced in Table VIII.1

By going through the list of stakeholders inside the company, one can do the following analysis:

- It is hard to predict managers' choice. They consider all different possible policies and try to make the best decision. The placement of the management team in Table VIII.4 was made based on the fact that Ford Motor Company invested in a joined effort to do research in the fuel cell technology.
- Marketing groups are usually concerned with satisfying consumer demand. Since the technology is unknown to most consumers and it is still not competitive, this group will push for a passive approach.
- Finance groups are concerned with the return on investment. The uncertainty behind the future of the fuel cell technology in the automobile industry would push them towards a passive approach. However, they are also concerned about future sales and would hope that competitors do nothing about the technology. If they use a "Real Option Thinking" to evaluate the option of joining the DaimlerChrysler/Ballard Joint Venture, they may discover that under some reasonable assumptions this option is extremely valuable.
- Strategy groups are concerned with the positioning of the company in the market. They will push towards the exploration of future technologies being considered by competitors. They would prefer for in-house research programs rather than doing research within a group.
- Engineers usually want to develop new products internally and to see their designs produced.

Table VIII.4 demonstrates how different preferences for various policies can be, even within the same car-company. Parallel analysis (Table VIII.5) shows how external stakeholders can influence the choice of policies:

- Both government agencies and non-governmental institutions want to see each car manufacturer produce a fuel cell vehicle. They usually prefer individual efforts hoping for the creation of a competitive market of environmentally friendly vehicles.
- Major Stockholders usually expect the company to do research in promising technologies and in the same time minimize the needed investment. This could be achieved through joining an existing research group or through creating a new one.
- All other external stakeholders may not have a direct influence on the initial choice of policy.

Table VIII.4 Policy preferences of inside stakeholders

Level of Commitment →

Level of Complexity ↓

	Passive	Research	Production
Alone	Marketing	Strategy	Engineers
Joint effort	Finance ------▶	Management	

Table VIII.5 Policy preferences of outside stakeholders

Level of Commitment →

Level of Complexity ↓

	Passive	Research	Production
Alone			Government/ Non Gov. Institutions
Joined effort		Major Stockholders	

Putting together the analysis of the six major possible policies with respect to the stakeholder groups (Tables VIII.4 and VIII.5) highlights the fact that cooperative research would be beneficial in this case. In addition, Ballard was and is still the leader in the development of PEM fuel cells. If Ford did not choose to join the already existing Daimler-Benz/Chrysler Joint Venture, they would have had to pursue the same technological advances that have been achieved by others. The combination of these elements make the partnership the most attractive technology policy for Ford with respect to fuel cells.

In formulating this technology policy, Ford naturally has had to consider special arrangements with a range of key stakeholders. In particular, Ford may:

- Approach competitors and other companies involved in the research and development of fuel cells to create a joint venture. Each company should focus on the element of the project they master. By doing so, synergies will be created and the total R&D cost will be shared among all the participants. (Ford achieved this point by joining the "global alliance").
- Approach oil companies and different fuel producers to negotiate joint efforts, to raise funds and smooth implementation. (Ford is working with Mobil Oil Company)
- Work closely with regulators to design technologically and economically feasible plans for the future. (establish long term contacts)
- Respond to consumer needs but also try to influence their choices (i.e. the marketing strategy followed by Daimler-Benz and Swatch for the "Smart" car).
- Adopt a flexible strategy. If another strategy proves more appropriate, the company should be able to speed up the research associated with this other alternative and put the first one on hold.
- Investigate competitors' moves and try to respond appropriately and quickly.
- Require a validation of the properties of a new technology before implementing it in a new model.

2.3. Implementation

The ultimate objective of a policy is to implement the strategy. This is a long-term effort that requires constant negotiation around difficulties that arise.

Many internal and external impediments will be faced during implementation. The same methodology of going through the list of stakeholders, identifying the impediments they can create, and a suggested strategy to get around those problems is appropriate. Tables VIII.6 and VIII.7 suggest the obstacles that may arise for Ford in implementing its fuel cell strategy, and ways Ford could negotiate around them.

Table VIII.6 Inside Stakeholders Impediments

Inside Stakeholders	Impediments they can create show that	Suggested countermeasures show that
Management	How does it serve shareholders?	It is a good insurance policy against competitive threats.
Finance group	Prove through the use of financial evaluation that investing in the fuel cell technology is risky and presents a negative NPV	Make an independent evaluation that takes into account the value of some imbedded options.
Marketing group	There is no demand for such product and hence Ford has to avoid investing in such venture.	Introducing innovative products can help market existing products by improving image and that it is possible to create demand for innovation (the "Smart" car marketing strategy)
Strategy group	Ford should work on its own Fuel Cell Project	Cost sharing in R&D is important and that joining the leader in the technology can speed up research.
Engineers/ Researchers	Ford should commit to the production of Fuel Cell vehicles on its own.	This strategy can hurt the corporate image in case of failure and that it is excessively costly and risky.

Table VIII.7 Outside Stakeholders Impediments

Outside Stakeholders	Impediments they can create show that	Suggested countermeasures show that
Major company stockholders	They will sell their shares if Ford does not react to competitive threats or over invests in research.	The strategy is the best insurance policy that Ford can buy to react to competition.
Competitors	They can block Ford's access to new technological advances through contracts or alliances.	Ford has to move quickly with regard to creating alliances.
Government Institutions	The Fuel Cell technology is not a zero emission technology.	On a life-cycle basis the Fuel-Cell technology can be cleaner than electric vehicles.
Consumers	They are not willing to pay a large premium for a "cleaner" car.	Their demand will not be satisfied, on the long run, if they stick to the current technologies.
Oil Companies and other fuel suppliers	Building a Hydrogen or methanol distribution network is both costly and requires time.	The current condition is not sustainable and that they should gradually adapt their infrastructure in case fuel cell vehicles are produced.
Non governmental Institutions	Require a commitment from car manufacturers to producing fuel cell vehicles in a near future.	The inefficiency of such policy by going through the CARB (ZEV) mandate example.

3. Conclusions

This chapter presents how a policy analysis can be carried out to:

- Identify possible policies,
- Formulate a feasible policy, and
- Implement a policy through negotiations over time.

The application of the policy analysis to Ford's choice of technology policy with regard to fuel cells, suggests that its preferred approach is to an initial joint research program that can be expanded later on as appropriate. This policy is in fact the one being pursued. Ford seems to be making the correct policy choice for itself.

ANNEX I

Application of Cox and Rubinstein's (1985) Method to Ford Motor Company's Stocks

Table A.1 illustrates an application of Cox and Rubinstein's (1985) method to Ford Motor Company's stocks. In a first stage, stock prices and dividends distributed in 17 quarters (from 26-Oct-94 to 28-Oct-98) were collected from Yahoo Finance. In a second stage, the dividends as a percentage of the period's stock prices were computed and averaged. This gave an estimate of the expected quarterly dividend yield and subsequently an annual estimate of the dividend yields.

In order to estimate the average growth (X), the dividends were added back to the stock price ($S + D$) than this period's stock price divided by last period's ($S + D$).

$$X_t = S_t / (S + D)_{t-1}$$

The next step was to compute the natural logarithms of the growth ratios and to estimate the average log-ratio. Finally the quarterly variance was computed as follows:

$$Variance = \sum (Y_t) / (n-2)$$ Where $$Y_t = [LN(X_t) - Average(LN(X))]^2$$

and n is the number of quarters considered

The Annual volatility is estimated as being the square root of four times the quarterly variance.

The analysis of Ford Motor Company's stocks provided an estimate of the annual dividend yield of 6.36% and an annual volatility of 23.78%.

Estimating a Risk-Neutral Distribution of Stock Prices

A binomial approach was used to develop a risk-neutral distribution of stock prices. Since three alternatives (low, medium and high) were to be considered, a binomial tree had to be built, with at least two periods (for simplicity, limiting the analysis to two periods of six months $n = 2$). The stock price of $S = \$54.25$ (28-Oct-98) was used as a starting point for the analysis.

At the end of period 1 ($t = 1$), the stock could go up to Su or down to Sd with probabilities of p and p' respectively. The values of u and d are estimated using the following equation:

$$u = \frac{1}{d} = e^{\sigma\sqrt{1/n}}$$

Table A.1 Estimating Dividend Yield, Stock Growth and Volatility Using Cox and Rubinstein's method (1985)

Company Ford Motor Company
Source Yahoo finance
Number Of Values (n) 17

Date	*Stock Price*	*Quarterly Dividend D(t)*		[S+D](t)	X=S(t)/[S+D](t-1)	LN(X)	Y=(LN(X)-Ave.(LN(X)))^2
	US$	*US$*	*%*	*US$*			
26-Oct-94	16.92	0.26	1.54%	17.18			
24-Jan-95	14.63	0.26	1.78%	14.89	0.851	-0.161	0.047
26-Apr-95	15.89	0.31	1.95%	16.20	1.068	0.065	0.000
31-Jul-95	17.17	0.31	1.81%	17.48	1.060	0.058	0.000
30-Oct-95	17.23	0.35	2.03%	17.58	0.985	-0.015	0.005
29-Jan-96	17.89	0.35	1.96%	18.24	1.018	0.018	0.002
30-Apr-96	21.97	0.35	1.59%	22.32	1.205	0.186	0.017
31-Jul-96	20.07	0.38	1.89%	20.45	0.899	-0.106	0.027
30-Oct-96	19.61	0.38	1.94%	19.99	0.959	-0.042	0.010
28-Jan-97	20.40	0.38	1.86%	20.78	1.020	0.020	0.001
30-Apr-97	22.33	0.42	1.88%	22.75	1.075	0.072	0.000
30-Jul-97	26.53	0.42	1.58%	26.95	1.166	0.154	0.009
29-Oct-97	28.63	0.42	1.47%	29.05	1.062	0.060	0.000
28-Jan-98	33.70	0.42	1.25%	34.12	1.160	0.149	0.008
29-Apr-98	45.08	0.42	0.93%	45.50	1.321	0.278	0.049
29-Jul-98	56.48	0.42	0.74%	56.90	1.242	0.216	0.026
28-Oct-98	54.25	0.46	0.85%	54.71	0.953	-0.048	0.011

Average Quarterly Div	1.59%	
Annual Dividend	6.36%	
Ave. Quart. Growth	5.66%	**Ave.(LN(X))**
Annual Growth	22.63%	
Quart. Variance	0.014	**Sum(Y)/(n-2)**
Annual Volatility	23.78%	

Using the volatility computed in Table A.1: $\sigma = 0.238$, the values of u and d are:

$$u = 1.183 \text{ and } d = 0.845$$

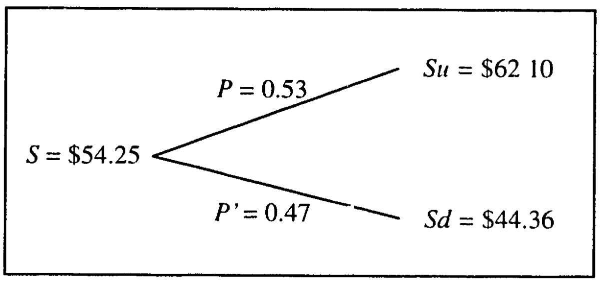
In all the analysis, an annual risk-free rate of 5% was used. The letter r represents the semi-annual discounting multiplier: 1.025 = (1 + semi-annual risk-free rate) = r

The risk free probabilities are computed as follows:

$$p = (r - d)/(u - d) = (1.025 - 0.845)/(1.183 - 0.845) = 0.53$$
$$p' = 1 - p = 0.47$$

If the focus is on the first period only, the evolution of the stock will be as follows:

First period only risk-neutral evolution of the stock (over 6 months)



Where $Su = S \times u \times (1 - Div.\%)^{1/2}$ and $Sd = S \times d \times (1 - Div.\%)^{1/2}$
Note that stock prices are adjusted for dividend payouts.

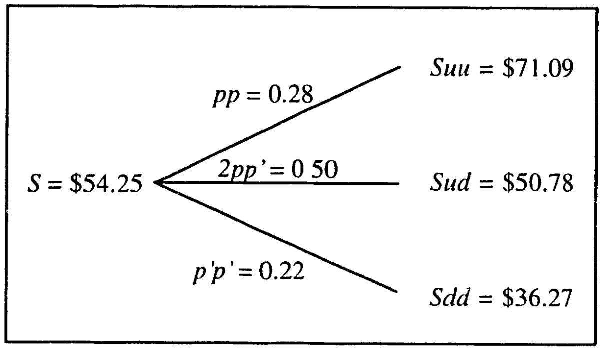
Once there is an idea about the range, within which the stock will vary during the first period, the same reasoning for the second period is redone. Three possible stock prices result from the possible combinations of upward and downward price movements in two steps: *Suu*, *Sud* = *Sdu* and *Sdd*. The respective probabilities are *pp*, *2pp'* and *p'p'*. It is important to note that since there are two paths for the outcome *Sud* = *Sdu*, the corresponding probability is twice the probability of an upward (1) then downward (2) event.

The results from using the two-period Binomial Tree to estimate the three-outcome, risk-neutral, Ford's stock price distribution are summarized in the following table.

Three outcome, risk-neutral estimation of Ford's stock price distribution (over 1 year)

Risk-Neutral Price Outcome	Probability (P)
$Suu = S \times u \times u \times (1 - Div.\%) =$ \$71.09	$pp = 0.28$
$Sud = S \times u \times d \times (1 - Div.\%) =$ \$50.78	$2pp' = 0.50$
$Sdd = S \times d \times d \times (1 - Div.\%) =$ \$36.27	$p'p' = 0.22$

First and second period (combined) risk-neutral evolution of the stock (over 1 year)



ANNEX II

Overview of examples of real option evaluations of investments

Type of Option	Case	Underlying asset	Rationale	Methodology	Reference
Simple option evaluated using **Black-Scholes**	Valuing a Startup in the Brewing Industry	Publicly traded microbrewers stocks. (Avoid firms with valuable growth options)	Same business, same risk.	1 Forecast Sales level in two years, as an established business 2 Calculate the average of the current value-to-sales ratio for established publicly traded microbrewers. 3. Estimate the current value of the market opportunity. 4 Estimate the average stock price volatility of the selected companies. 5. Use Black-Scholes formula to compute the value of the identified call option	Amram and Kulatilaka, 1999
Simple option evaluated using **Black-Scholes**	Valuing a Start-up Biotech company. The Merck methodology	Stocks of typical Biotech companies (financial information on those companies is also required)	Same line of business and compete in the same market	1 Estimate the capital investment that needs to be made (exercise price) 2 Compute the present value of the cash inflows from the project (Equivalent to the Stock price) 3 Select a range of times to expiration. 4 Estimate the standard deviation using the selected stocks 5 Compute the value of the identified call option using Black-Scholes formula	Harvard Business Review Jan-Feb 1994 PP89 - 99
Simple option evaluated using the **binomial method**	Valuing a Startup in the Software business	Software publisher Stocks	Market = retail segment of the internet market Once established, both selling expenses and profit margins will be similar to those of software publishers	1 Model the private (technology) risk using a 50%/50% chances of Success/Failure (no better estimates of probabilities are available). 2 Estimate volatility using the underlying stock. 3 Compute the average market to sale ratio of different software publishers 4 Forecast the sales 5 Use the binomial method to evaluate the option.	Amram and Kulatilaka, 1999

Type of Option	Case	Underlying asset	Rationale	Methodology	Reference
Combined or Nested options evaluated through the use of **dynamic programming**	Valuing An oil field	Option contracts on oil (Futures contracts give the expected range of future oil prices)	The value of the oil field depends on the future market value of the underlying commodity oil	1 Estimation of the volatility of oil prices using the option contracts traded on this commodity 2 Estimation of the convenience yield form oil future contracts 3 Assume that the distribution of reserves is lognormal, 4 Use historical/Statistical data associated with the geology 5 Run a dynamic programming model to estimate the value of the option	Amram and Kulatilaka, 1999
Combined or Nested options evaluated through the use of **single options evaluation tools** and a series of simplifying assumptions	Valuation of Claims on Offshore petroleum leases	• Variance of the rate of change of crude oil prices = variance of the rate of change of developed reserve prices • Traded securities such as the Permian Basin Royalty Trust (NYSE), which are financial claims to the net revenues of developed oil reserves They are used in the valuation of developed reserves.	• The value of the reserves increases or decreases in accordance with changes in oil prices. • The market value of explored reserves is best reflected by the value of the financial claims to the net revenues of developed oil reserves (that's what they are worth)	1 The extraction option is considered as being already incorporated in the current market value of a developed reserve 2 The value of developed reserves is estimated using the value of related traded securities and discounted for development lag 3 Evaluate the option of developing the undeveloped petroleum reserves as if it was an American call option With the variance of the rate of change of crude oil prices as underlying variance, the per unit development cost as exercise price and the relinquishment requirement as time to expiration 4 Use the statistical and geological information available to value the option of exploring the reserves. By exercising this option, the holder will pay the exploration price and obtain the development option	Paddock, Siegel and Smith, 1988

Annex III

Overview of the Fuel Cell Technology

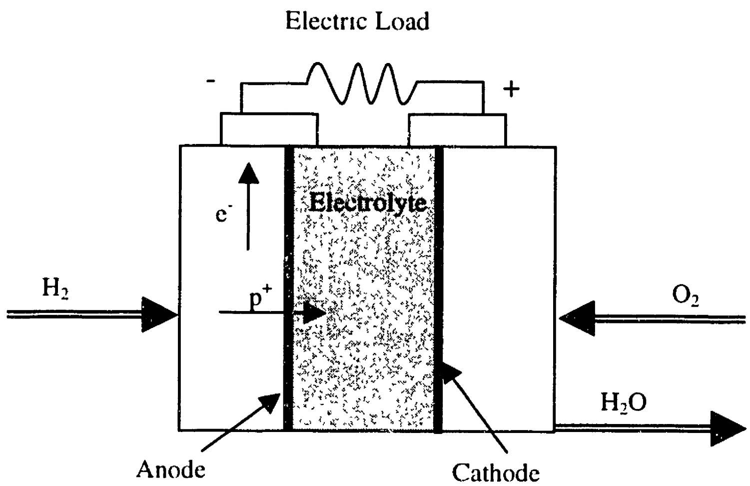
Definition:

Fuel cells are electrochemical devices that directly convert hydrogen, or hydrogen-rich fuels into electricity without combustion. This process is much more efficient than traditional thermal power plants, converting up to 80% of the chemical energy in the fuel into electricity (compared to a maximum of 40% for conventional power plants). Although their structure is somewhat like that of a battery, fuel cells never need recharging or replacing and can consistently produce electricity as long as they are supplied with hydrogen and oxygen. Fossil fuels (coal, oil and natural gas), biomass (plant material) or pure hydrogen can be used as the source of fuel. If pure hydrogen is used, the fuel cell does not emit anything except from water. Fuel cells are small and modular in nature and therefore fuel cell power plants can be used to provide electricity in many different applications, from electric vehicles to large, grid-connected utility power plants. First used in the U.S. space program in the 1950s, fuel cells are a developing technology with a few commercial uses today, but may emerge as a significant source of electricity in the near future.

Fuel Cell Electrochemistry

Fuel cells have a similar structure to a battery, with two porous electrodes separated by an electrolyte. Electricity is produced by a chemical reaction between a hydrogen-based fuel and an oxidant (usually oxygen) inside the fuel cell. Figure 1 diagrams the electrochemical reaction which takes place inside a fuel cell. Hydrogen (H_2) flows over the anode (the negative electrode) and splits into positively charged hydrogen ions and electrons which carry a negative charge. The electrons flow through the anode to the external circuit, performing useful work (this is the electric current generated) while the hydrogen ions pass through the anode and into the electrolyte, moving towards the cathode (the positive electrode). The electrons eventually return to the cathode which is supplied with oxygen (O_2). At this point the electrons, hydrogen ions and oxygen react to form water (H_2O) and heat. In stationary fuel cell power plants this heat can be captured and used for process heat in industries or space heating (co-generation). As long as the fuel cell is supplied with hydrogen and oxygen, this electrical production can continue indefinitely.

Figure A.1: Schematic representation of the operation of a simple acid-electrolyte fuel cell.



The general design of most fuel cells is similar except for the electrolyte. Several different substances have been used as the electrolyte in fuel cells, each with their own advantages and disadvantages. The five main types of fuel cells, as defined by their electrolyte, are:

1. Alkaline
2. Solid polymer (also known as proton exchange membrane fuel cells),
3. Phosphoric acid
4. Molten carbonate, and
5. Solid oxide fuel cells

Alkaline and solid polymer fuel cells operate at lower temperatures (50-260° C) and are mainly designed for use in transportation applications, while the other three operate at higher temperatures (up to 1000° C for solid oxide fuel cells) and are being developed for use in co-generation and large central power plants.

Sources of Fuel and Oxidant

Fuel cells operate at maximum efficiency, when operating on pure hydrogen and pure oxygen. Pure oxygen is very expensive, and thus air is used as the source of oxygen in most applications except where the extra cost can be justified, as in the space program. Pure hydrogen is also expensive and difficult to transport and store. Therefore, like pure oxygen it is only used in special cases. Gaseous mixtures of hydrogen (H2) and carbon dioxide (CO2) which can be created by the 'processing' of fossil fuels or biomass are used instead of hydrogen in most commercial uses of fuel cells. The most economical sources of the necessary H2/CO2 fuel mixture have been found to be: gaseous hydrocarbons such as natural gas and propane, light hydrocarbon liquids such as naphtha and methanol (from biomass), heavier hydrocarbon liquids such as fuel oil and coal.

There are three common methods of processing these hydrocarbon fuels to create the H2/CO2 mixtures required by fuel cells. 'Steam reforming' is a simple process involving the reaction of light hydrocarbon fuels with steam. 'Partial oxidation' is the incomplete burning of a fuel and is used to process heavier hydrocarbon liquids and coal is 'gassified' by reacting coal with oxygen and steam at high temperatures. Fuel processing can be performed at any stage before the fuel is added to the fuel cell, but it is most common to perform the processing at the 'point of use' as this eliminates the need for storage of the hydrogen rich fuel. Liquid hydrocarbons such as naphtha and methanol are preferable for transportation applications of fuel cells because they are easily transported and stored and can be steam reformed at the point of use. Large stationary fuel cell power plants are generally designed to use natural gas, fuel oil or coal as a source of fuel depending upon local costs and availability.

Uses of Fuel Cells

There are two main types of uses for fuel cell power plants. The first is as power for a vehicle driven by electric motors, the second is as a stationary power plant with or without co-generation. Fuel cells in vehicles can operate with efficiencies of 40-80% compared with 25-35% for "state-of-the-art" spark ignition engines. This means that fuel cell powered vehicles will get more 'kilometers per liter' than other cars. Unfortunately, current fuel cell technology is expensive and bulky. For this reason, today's fuel cells are more suited to larger, high use vehicles such as buses and trucks. Ballard Power Systems, a Canadian company which has pioneered the development of a solid plastic electrolyte fuel cell, installed a 100 kW demonstration fuel cell on a bus in Vancouver. Future breakthroughs in fuel cell technology could make them more practical for smaller passenger vehicles.

Fuel cells can also be used in any size of stationary power plant, with or without co-generation and with a variety of potential primary fuels. Fuel cell power plants are smaller, quieter and have fewer emissions of pollutants than other types of fossil fuel power plants and are therefore better suited to use in urban areas. Small local power plants in urban areas have a market for their waste heat and reduce the loss of power associated with long distance electrical transmission. Japan, the U.S.A and Canada have all tested demonstration fuel cell power plants attached to electrical grids.

Environmental Impacts

The environmental impact of fuel cell use depends upon the source of hydrogen rich fuel used. If pure hydrogen is used, fuel cells have virtually no emissions except water. As mentioned earlier, hydrogen is rarely used due to problems with storage and transportation, but in the future many people have predicted the growth of a 'solar hydrogen economy'. In this scenario photovoltaic cells would convert sunlight into electricity. This electricity would be used to split water (electrolysis) into hydrogen and oxygen, in order to store the sun's energy as hydrogen fuel. In this scenario, fuel cell powered vehicles or generating stations would have no real emissions of greenhouse or acid gasses, or any other pollutants.

It is predominantly during the fuel processing stage that atmospheric emissions are released by a fuel cell power plant. When methanol from biomass is used as a fuel, they have no net emissions of carbon dioxide (CO_2 a greenhouse gas) because any carbon released was recently taken from the atmosphere by photosynthetic plants. Any high temperature combustion, such as that which would take place in a spark ignition engine fuelled by methanol, produces nitrous oxides (NO_x), gasses which contribute to acid rain. Fuel cells virtually eliminate NO_x emissions because of the lower temperatures of their chemical reactions.

Using processed fossil fuels, fuel cells still have emissions of CO_2 and sulphur dioxide (another acid gas) but these emissions are lower than those from traditional thermal power plants or spark ignition engines because of the higher efficiency of fuel cell power plants. Higher efficiencies result in less fuel being consumed to produce a given amount of electricity or to travel a given distance.
This corresponds to lower CO_2 and SO_2 emissions. Fuel cell power plants also have longer life expectancies and lower maintenance costs than their alternatives.

Annex IV

Rationale behind the timeliness of Ford investment in the "Global Alliance"

Some companies buy new technologies when they are first available while others postpone their decision to acquire them until the technology is improved. In this part, we analyze the factors that drive the differences in such behavior and apply the model to Ford decision to invest in the fuel cell technology.

When Ford was contemplating investment in the early stages of the fuel cell technology, they were considering the purchase of an "option". In fact, Ford not only invested in the current innovation itself, but they also purchased an option to implement the technology in the future. Under these conditions, the challenge for Ford Motor Company was determining an optimal strategy. (Invest in Ballard or just buy the current Technology, buy all the upgrades or not, wait for further developments, etc.).

In the paper "Investment in technological innovations: An option pricing approach" Grenadier and Weiss (1997) develop a model of the optimal investment strategy for a firm confronted with a sequence of technological innovations. We discuss this model below and prove that it can be applied to Ford investment in Ballard.

Grenadier and Weiss base their analysis on four assumptions that firms:

- Choose whether or not to adopt a current version of the innovation, they consider the implications for their ability to respond to future technological innovations.
- Face uncertainty about both the value and the timing of future innovations,
- Who adopt innovations are allowed to "learn by doing",
- Are aware of realistic cost concerns.

Their model focuses on the four potential migration strategies listed in Table A.2.

In their model, they compute the probability that a firm will pursue each of the four migration strategies as well as the expected time at which a firm will invest in an innovation. These computations depend on market, as well as firm-specific, factors.

Discussion of the Model:

In their model, they consider a firm that faces a sequence of investment opportunities in technological innovations. The firm is initially confronted with an opportunity to invest in a current innovation. In addition, the firm also anticipates the possibility of a potentially more valuable technological innovation in the future. Both the arrival time and value to the firm of the future innovation are uncertain.

Table A.2 Translation of the different migration strategies to Ford Case's wording

Migration Strategy	Application to Ford's case
Compulsive strategy of purchasing every innovation	Invest in the leader in fuel cells research and development, Ballard for instance.
Leapfrog strategy of skipping an early innovation, but adopting the next generation	Buy the fuel cell technology when it is proven to be competitive for automotive applications
Buy-and-hold strategy of only purchasing an early innovation	Buy the technology today and do not buy more advanced versions in the future.
Laggard strategy of waiting until a new generation of innovation arrives before purchasing the previous innovation.	Buy today's technology when a new one comes to stream

The firm may choose to invest in the current innovation at any time it chooses (or bypass the current technology altogether). When the future innovation becomes available, the firm must then decide whether to migrate to the new technology. This decision is contingent upon its earlier decision regarding adopting the current innovation invoking a "path dependency".

The model relies on the following assumptions:

- $t = 0$ when the current innovation arrives,
- P_0 = value of the current innovation,
- C_e = cost of early adoption of the current innovation,
- $P_0 - C_e$ = payoff from early adoption (assumed to be positive),
- T = random time of arrival of the next generation of technology,
- P_T = Value of the future innovation,
- C_u = cost of upgrading from the current to the future innovation,
- C_l = cost of adoption of the future technology with no prior adoption (leapfrog),
- C_d = cost of adopting the old technology at $t = T$,
- $C_d < C_e$ and $C_l < C_e + C_u$ (it is cheaper to leapfrog to the future innovation than to purchase the current innovation and instantaneously upgrade to the future innovation).

As discussed before, investing in the leader in the fuel cell technology is to some extent equivalent to a commitment to buy all the advances in this technology as they happen. However, there are two important points that need to be discussed:

- The expected payoff form investing in Ballard is higher than the expected payoff from buying all the advances in the Ballard fuel cell design. In fact, Ford Motor Company will receive benefits from Ballard success through its stakes in the company.
- If another company than Ballard designs the most competitive fuel cell technology, Ford would have to make an additional investment to externally acquire this technology. This scenario is not very likely to happen since Ballard is recognized as being the leader in this field.

The state of the technological progress is represented by the stochastic process $X(t)$. As $X(t)$ rises, the arrival of the future innovation approaches. If $X(t)$ rises to the upper boundary X_h, the future innovation arrives. Thus, the arrival of the innovation is the first passage time of $X(t)$ to the boundary X_h.

The optimal innovation investment strategy:

To derive the optimal technological migration strategy, they work backwards in dynamic programming fashion. They begin by assuming that the firm has already adopted the current innovation, and now holds the option to upgrade to the future innovation. Then, using this valuation, they derive the firm's optimal decision rule for adopting the current innovation. If $F(X)$ is the value of the option to upgrade from the current to the future innovation, where X is the current state of the progress, $F(X)$ must satisfy the following equilibrium differential equation (Lito's Lemma):

$$0 = \tfrac{1}{2}\sigma^2 X^2 F'' + \alpha X F' - rF$$
$$\textit{subject to:}$$
$$F(X_h) = E[\max(P_T - P_0 - C_u, 0)]$$
$$\textit{and}$$
$$F(0) = 0$$

The first boundary condition characterizes the expected payoff of the upgrade option at the moment the new innovation arrives. The second boundary condition reflects the fact that if $X(t)$ ever falls to zero, the option would never be exercised (since the new technology would never arrive).

If the firm decides to purchase the current innovation, it receives not only the current payoff from adoption (P_0 - C_e), but also the value of an embedded option to upgrade. Therefore, the firm holds an "option on an option " and must choose an optimal exercise policy.

The optimal time at which to invest in the current innovation is when the state variable $X(t)$ falls to a lower trigger X_l . This trigger will be chosen so as to maximize the value of the option $G(X)$ to purchase the current innovation. Intuitively, the longer the expected period before the future innovation arrives, the more beneficial the current innovation becomes, as it is less likely to be rendered obsolete in the near future. At the trigger X_l , the benefits of investing in the current innovation are precisely equal to the marginal benefits of waiting. The value of this option satisfy the following equilibrium differential equation:

$$0 = \tfrac{1}{2}\sigma^2 X^2 G'' + \alpha X G' - rG$$
$$\textit{subject to:}$$
$$G(X_l) = P_0 - C_e + F(X_l)$$
$$G'(X_l) = F'(X_l)$$
$$G(X_h) = E[\max(P_T - C_l, P_0 - C_d)]$$

The suggested technological migration strategy is the following: Prior to adopting the current innovation (and before the future innovation arrives), the firm holds an option to purchase the current innovation. The value of this option is $G(X)$. The firm's optimal exercise strategy is to adopt the current innovation the first moment that $X(t)$ falls below the trigger X_l , prior to the arrival of the future innovation. If the firm invests in the current innovation, it will receive an option to upgrade, $F(X)$. The firm will then upgrade if and only if P_T - P_0 - C_u >= 0. If the firm does not invest in the current innovation prior to the arrival of the future innovation, then it will *leapfrog* to the future innovation if P_T - C_l >= P_0 - C_d . Otherwise, it will purchase the older innovation at a discounted price.

The likelihood and speed of migration strategies

The model introduced before will be used to predict a firm's future innovation adoption choices. This section derives the probability that a firm will pursue any of the four potential migration strategies and the expected time in which a firm first invests in an innovation.

The following definition will be used in the analysis:

$$T_e = \inf[t \geq 0 : X(t) \leq X_l] \; and \; T = \inf[t \geq 0 : X(t) \geq X_h]$$

T_e is the first passage time of $X(t)$ to the early adoption trigger. A firm will adopt the current innovation early if and only if $T_e < T$. Therefore, the probability of early adoption is $\Pr[T_e < T]$. By revisiting the four migration strategies introduced before, we define the following probabilities:

The probability $PC(X)$ of a compulsive strategy, conditional upon $X(0) = X$ is:

$$PC(X) \equiv \Pr[T_e < T, P_T - P_0 - C_u \geq 0]$$

The probability $PB(X)$ of a buy-and-hold strategy, conditional upon $X(0) = X$ is:

$$PB(X) \equiv \Pr[T_e < T, P_T - P_0 - C_u < 0]$$

The probability $PL(X)$ of a leapfrog strategy, conditional upon $X(0) = X$ is:

$$PL(X) \equiv \Pr[T_e \geq T, P_T - C_l \geq P_0 - C_d]$$

The probability $PG(X)$ of a leapfrog strategy, conditional upon $X(0) = X$ is:

$$PG(X) \equiv \Pr[T_e \geq T, P_T - C_l < P_0 - C_d]$$

The model can also be used to characterize the speed at which a firm invests in technology. The time it takes a firm to adopt an innovation is $\min(T_e,T)$. The expected time of initial adoption is then $E[\min(T_e,T)/ X(0) = X]$.

The figure shows that the leapfrog and laggard strategies dominate for markets with rapid innovation (low $E(T)$), while the compulsive and buy-and-hold strategies dominate for markets with slow innovation (high $E(T)$). These results hold under a wide variety of assumed parameter values.

Figure A.2 Probabilities of the four migration strategies as a function of the expected arrival time, E(*T*).

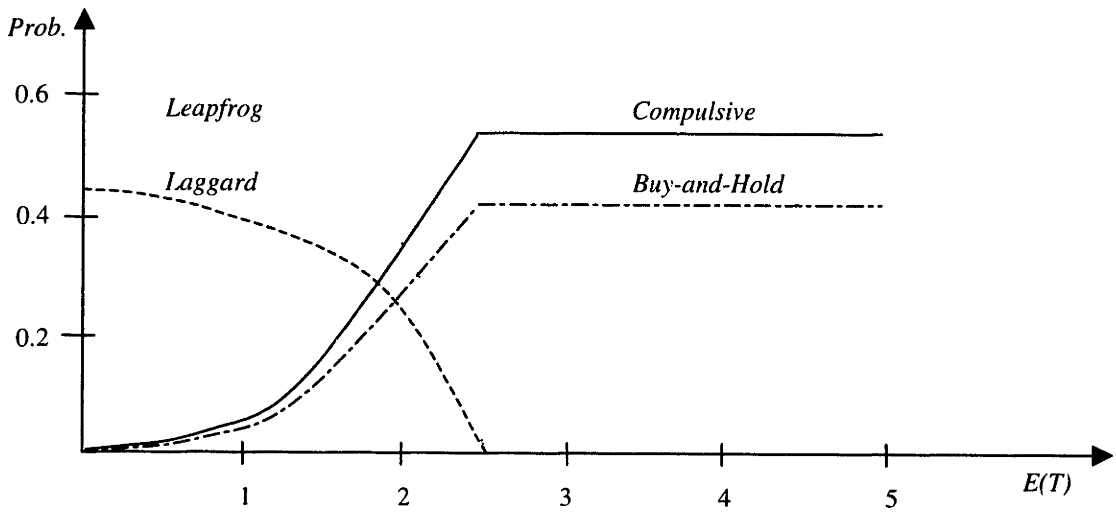
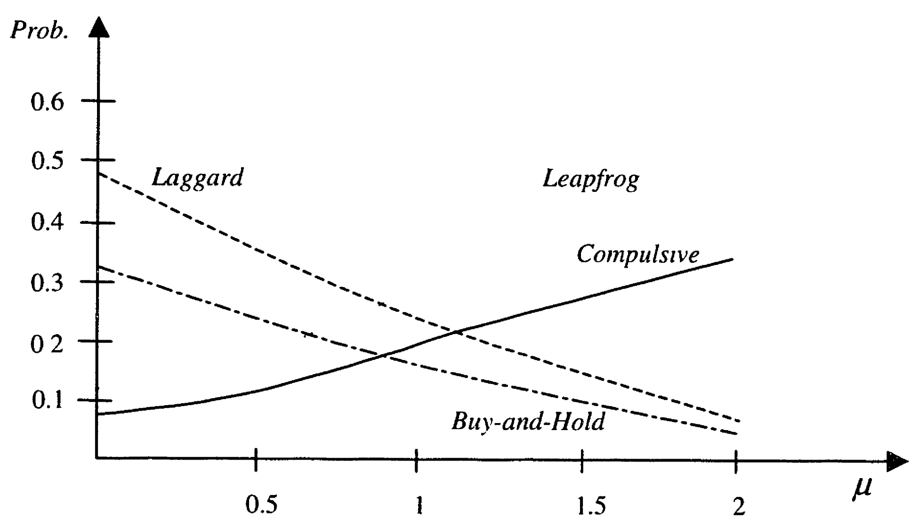


Figure A.3 Probabilities of the various strategies as a function of the expected profitability of the future innovation, μ.



Technological environments differ not only according to the speed of innovation, but also according to the significance of the improvements. If we consider the intuition of the model, the first and most direct impact of increasing the expected profitability of the future innovation is to increase the likelihood that the future innovation will be adopted. Thus, both the compulsive and leapfrog strategies become reasonable, while the laggard and buy-and-hold strategies become less compelling. The second impact deals with the effect of learning. Given that the future innovation is likely to be adopted, and given the benefits to learning by doing, firms have an incentive to purchase the current innovation. This effect increases the likelihood of both the compulsive and buy-and-hold strategies. Taking these two effects into account, the model suggests that for markets with greater expected benefits to future innovations, the compulsive and leapfrog strategies should become more likely, the buy-and-hold strategy can increase or decrease, and the laggard strategy should become increasingly rare.

Table A.3 summarizes the effects of both the expected arrival time and the profitability of the future innovation on the optimal migration strategy.

Table A.3 Strategy selection matrix

		Time between innovations ($E(t)$)	
		Short	**Long**
Expected profits (μ)	**Low**	*Laggard*	*Buy-and-hold*
	High	*Leapfrog*	*Compulsive*

Advances in the fuel cell technology happen very slowly meaning that Ford investment would fall under the High arrival time type. In addition the expected profits from a successful development of fuel cells are extremely high. The matrix introduced above suggests that Ford Motor Company should follow a compulsive strategy. They should keep on acquiring every single development in the fuel cell technology.

As discussed earlier, Ballard is the leader in the Fuel cell research and development making Ford investment in it equivalent to a commitment to acquire every single improvement in the technology. Ford Motor Company adopted a strategy that could be qualified as being appropriately compulsive.

References

Amram M. and Kulatilaka N., 1999, Real Options: Managing Strategic Investment in an Uncertain World, Harvard Business School Publishing.

Boer F.P., 1998, Traps, Pitfalls and Snares in the Valuation of Technology, *Research. Technology Management*, September - October 1998.

Brealey R.A. and Myers S.C., 1991, Principles of Corporate Finance, Fourth Edition, (McGraw-Hill, New York), pp. 155-175, 517.

Buono A.F., Nichols L., 1985, Corprate Policy, Values and Social Responsibility, Praeger Publishers, New York.

Childs P.D., Ott S.H., and Triantis A.J., 1998, Capital Budgeting for Interrelated Projects: A real Options Approach, *Journal of Financial and Quantitative Analysis* Vol. 33, No. 3, September 1998.

Cohen R.E., 1995, Washington at Work: Back Rooms and Clean Air, Second Edition, Allyn and Bacon.

Cooper R.G., Edgett S.J. and Kleinschmidt E.J., *Research. Technology Management*, July - August 1998.

Cox J.C. and Rubinstein M., 1985, Options Markets, (Prentice Hall, Englewood Cliffs, N.J.).

de Neufville R., 1990, Applied Systems Analysis: Engineering Planning and Technology Management, (McGraw-Hill, New York)

Dixit A.V. and Pindyck R.S., 1994, Investment Under Uncertainty, (Princeton University Press, Princeton, N.J.),

Faulkner T.W., 1996, Applying Options Thinking to R&D Valuation, *Research. Technology Management*, May - June, pp.50-56.

Geske R., 1979, The Valuation of Compound Options, *Journal of Financial Economics* 7, pp. 63-81.

Grenadier S.R., and Weiss A.M., 1997, Investment in Technological innovations: An Option pricing approach, *Journal of Financial Economics* Vol. 44.

Keefer D., and Bodily S.E., 1983, Three-point Approximations for Continuous Random Varaibles, *Management Science*, 29, 595-609.

Kester W.C., 1984, Today's Options for Tomorrow's Growth, *Harvard Business Review*, March - April, 153-160

Lintner J., 1965, The Valuation of Risk Assets and the Selection of Risky Investments in Stock Portfolios and Capital Budgets, *Review of Economics and Statistics*, 47:13-37 (February 1965)

Luehrman T.A., 1998, Strategy as a portfolio of Real Options, *Harvard Business Review*, September - October 1998.

Luehrman T.A., 1998, Investment Opportunities as Real Options: Getting Started on the Numbers, *Harvard Business Review*, July - August 1998.

Neely J.E., 1998, Improving the Valuation of Research and Development: A Composite of Real Options, Decision Analysis and Benefit Valuation Frameworks, (Ph.d. Thesis, Technology, Management and Policy Program, Massachusetts Institute of Technology, Cambridge, MA).

Nichols N.A., 1994, Scientific Management at Merck: An Interview with CFO Judy Lewent, *Harvard Business Review,* January - February 1994.

Paddock J.L., Siegel D.R., and Smith J.L., 1988, Option Valuation of Claims on Real Assets: The case of Offshore Petroleum Leases. *Quarterly Journal of Economics* 103 (August): pp. 479-508

Plant, 1998, Canada's Industry Newspaper, www.plant.ca

Sharpe W. F., 1964, Capital Asset Prices: A Theory of Market Equilibrium under Conditions of Risk, *Journal of Finance*, 19:425-442 (September 1964)

Shnayerson M., 1996, The Car That Could: The inside story of GM's revolutionary electric vehicle, Random House, New York.

Sick G., 1995, Real Options Paper presented at INFORMS International Singapore, June 25-28, 1995, 70 pp.

Smith J.E. and Mccardle K.F., 1998, Valuing Oil Properties: Integrating Option Pricing and Decision Analysis Approaches, *Operations Research*, March - April 1998.

Smith J.E. and Nau R.F., 1995, Valuing Risky Projects: Option Pricing Theory and Decision Analysis, *Management Science*, Vol.41, No.5, May 1995.

Steinemann P.P., 1998, Daimler-Benz Fuel Cell Vehicles: Research and Development Strategies, MIT Internal Working Document.

Tabors R.D., 1996, Class Notes, Technology and Policy Proseminar, MIT, Cambridge, MA

Trigeorgis L., 1996, Real Options: Managerial Flexibility and Strategy in Resource Allocations, (MIT Press, Cambridge, MA),

Trotman A., Schrempp J. E.,and Rasul F., 1997, Article in Canada NewsWire Ltd., December 15, 1997

Umedaly M. 1998, Article in "Plant" Maclean Hunter Publishing Ltd.

THESIS PROCESSING SLIP

FIXED FIELD: ill ______ name ______

index ______ biblio ______

► COPIES: (Archives) Aero (Dewey) Eng Hum

Lindgren Music Rotch Science

TITLE VARIES: ►☐

NAME VARIES: ►☑ Khalil

IMPRINT: (COPYRIGHT) ______

► COLLATION: 116 l

► ADD: DEGREE: ______ ► DEPT.: ______

SUPERVISORS: ______

NOTES:

cat'r: date.

page ► J168

► DEPT: T&PP

► YEAR: 1999 ► DEGREE: S.M.M.O.T.

► NAME: OUESLATI, Skander K.