Timing the adoption of a new technology: an option-based approach

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Deals with the problem of timing the adoption of a new technology. This is a very important question of strategy which directly affects the firm's competitive capability and whose analysis cannot be adequately faced by conventional capital budgeting techniques. Aims to provide a procedure for deciding on the appropriate adoption time, which is based on the option pricing approach. In particular, since innovative technologies generally disclose a set of strategic opportunities, makes the assumption that adoption occurs when it is possible to profit better from these opportunities. The decision procedure introduced also provides the starting point for developing a practical, option-based framework to formulate a technology strategy. In this perspective, a proactive attitude of firms towards the planning and looking for future technology opportunities is proposed.

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Because of its recurrent role in influencing the strategic alternatives open to competing firms, technology is one of the main forces which operates in the business arena. Certainly, technology is a formidable strategic weapon which deeply affects the nature of the five competitive forces, and pervades the whole firm's value chain[1], far beyond those techniques directly associated with the manufacturing process. As a consequence of the more important role ascribed to technology in business strategy, in recent years strategic management of technology has emerged as a distinctive managerial field[2]. It is concerned with how the firm might use technology to get a sound competitive basis[3], or in other words how technology has to be integrated throughout the organization as a source of competitive advantage[4]. In this perspective, companies are requested to link technology to corporate strategy; the resulting technology strategy is a plan which guides firms' decisions on technology identification, development, acquisition and application[5].

An effective and proactive strategic management of technology involves various decisions: from the formulation of a global technology plan to the selection and the adoption of a specific new asset. The basic question regarding the latter concerns which new technology has to be adopted and when. Time, in particular, is a crucial point, and deciding on the appropriate time is a critical issue[6] which raises substantial questions coming from: the intrinsic uncertainty surrounding each new technology; the inherently intangible nature of many of the expected benefits; the long-term perspective involved by a technological commitment; the current and future availability of technical and economic information about the new technology; the need to develop new competences and skills; the role played by learning processes; the partial or complete irreversibility of the innovative investment.

Since traditional capital budgeting techniques tend to ignore all these questions, they do not seem to be of particular help in deciding on the adoption time. Recently, however, a valuation approach which tries to overcome these limitations has emerged from the theory of financial option pricing. The resulting real option approach seems to provide a powerful tool for the assessment of technology investments because it allows one to account for irreversibility and uncertainty, and explicitly recognizes that time affects the investment returns.

The aim of this paper is to provide a procedure for timing technology investments which is based on the option theory. According to this procedure, the decision to invest is treated as the decision to exercise a financial option. In this sense, the new investment is evaluated on the basis of the present and future opportunities it discloses and the adoption decision is taken when one can most profit from all the embedded options.

The real option approach to investment

The use of conventional capital budgeting techniques and, in particular, the discounted cash flow (DCF) analysis in evaluating innovative projects has been widely criticized. In particular, the opinion has recently spread that, when innovative investments are concerned, traditional procedures may understate their true economic value and hence induce the firm not to pursue them[7-9]. This not being the place to recall all the criticisms, we will limit ourselves to remembering that the conventional investment analysis ignores:

- the strategic growth opportunities connected with the new investment;
- the fact that the project can be discontinued before the end of its economic life;
- the possibility of delaying the investment decision;
- the arrival of information throughout the project life;
- the option temporarily to stop its execution[10].

More specifically, traditional analysis generally treats investments as isolated opportunities about which decisions must be made immediately[11] and encourages concentration on the individual decision[12]; also, having a systematic bias towards the short term, it fails to evaluate the long-term and strategic

factors involved in innovative investments[8]. In short, what is important to our aims is that within this framework time is not a matter of choice, given that the investment is viewed as a now or never decision.

Highlighting some shortcomings of the traditional approach, in 1984 Kester[13] used the term "growth options" to denote future opportunities that (in his opinion) each investment project unfailingly carries out. Afterwards, the option concept was enriched and more often suggested for issues such as uncertainty and flexibility, where the latter means the ease to modify a project during its execution in order to adapt it to changing business conditions. Now this conceptual device is providing several analytical and explanatory hints in the field of strategy evaluation, given that it brings out the potential of future action linked to current decisions.

With regard to the analytical procedure for giving the correct economic value to the aforementioned aspects, it simply consists in comparing them to financial options. Nevertheless, in spite of the effective logical correspondence between real and financial options, the financial methods (for an exposition see [14]) cannot be applied as they are when the former are involved. This, in fact, could require the estimation (or, better, the knowledge) of the value of market traded activities, while the project is not definitely the object of market evaluation. In addition, real investments generally involve more kinds of options at the same time (see Figure 1).

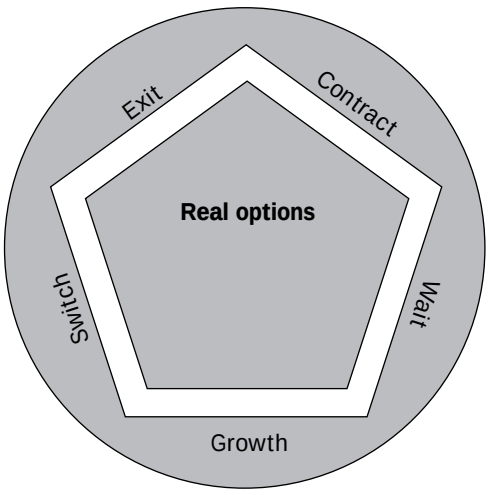
There may be opportunities for deferring the investment, especially when waiting for new information means reducing risk and uncertainty. On the other hand, a delay could be the source of economic losses if competitors avail themselves of the opportunity to gain first movers advantages. When uncertainty on future (market and technology) conditions is high, the inexpensive exit from an investment which is giving unsatisfactory results may assume great value. Also, the operative flexibility of a project, i.e. possible changes during its implementation, may take on considerable economic value. Generally speaking, different kinds of real options exist:

- Growth (or incremental) options give the opportunity to benefit from subsequent investments, as in the case of modular projects. In general, they are new capabilities which can be exploited by later investments. In several cases it is impossible to define them accurately until some time has passed, after the firm has assimilated the know-how provided for the initial investment.
- Abandonment options allow exit from (or liquidation of) a project with limited expenses. They essentially depend on irreversibility; most of the investment expenditures, in fact, are sunk costs, especially when they are firm or industry specific.
- Wait options give the possibility of deferring an investment in order to acquire new and better information; the passage of time may, in fact, contribute to the resolution of uncertainty. Generally, wait options mean profiting from price reduction. In all cases, however, benefits deriving from more accurate information and price reduction go hand in hand with costs, because of delay in the investment[15].
- Options to contract allow the costless reduction of the operating scale if business conditions turn out to be unfavourable.
- Switching (or flexibility) options imply effective and not very expensive changes to the investment. In other words, switching options mean the possibility of making a different use of the biggest part of the investment. Thinking about investment reversibility is very important for projects which are highly sensitive to changes in external conditions[12].

Returning to the assessment of these opportunities, Kester[13] claimed that the growth option value depends on:

- The length of time the option can be exercised and the project deferred. The ability to defer decisions allows a better examination of the course of future events, thus avoiding irreparable mistakes. Hence, the longer the interval, the more likely the choice of the most propitious time to exercise the option.

Figure 1
The various facets of a real option



- With project risk, i.e. the width of the stochastic distribution of the expected outcomes, the maximum potential gain achievable by exercising the option increases.
- The level of interest rates, since high interest rates lower the present value of future benefits.
- The exclusiveness of the owner's right to exercise the option, and hence the degree of appropriability of the project's outcomes.

Following this point of view, Kasanen and Trigeorgis[16] suggested a model which integrates an option-based approach to capital budgeting and consists in calculating the Expanded (strategic) net present value (NPV) of the investment:

$$ENPV = NPV + OP + IE$$

where:

ENPV = expanded net present value;
NPV = traditional (passive) NPV of expected cash flows;
OP = value of operating options;
IE = interaction effects (synergy, inter-project dependence).

The relative importance of the three components – passive NPV, operating options and interaction effects – changes according to the conditions in which the firm acts. Certainly, the option value increases with the competitive dynamics and with the current or perspective firm's business opportunities. However, valuing these opportunities correctly is particularly complex and is further complicated by the co-existence of various kinds of options and the possible existence of options on options. With regard to the existence of joint effects between different options, it must be carefully noted that their quantification does not reduce to a simple arithmetic sum of the individual option values, since the single effects could be alternative or even annul each other.

Bearing these difficulties in mind, but thinking it correct to refer to a consolidated approach, we will develop a procedure for deciding the adoption time of a new technology on the basis of this model.

Deciding on the adoption time

As mentioned earlier, timing requires the evaluation of all the options involved. This is a very intriguing question, made more complex by the fact that different technologies entail different combinations of options with different economic effects. With the aim of facing this problem in quite a formal way, a simple procedure consisting of four stages is suggested. First, it is a matter of discovering and identifying the options embedded in the new technology. Second, the environment and the circumstances in which each option might be exercised have to be evaluated. Third, the most relevant options must be selected and their global value assessed. Finally, the adoption time has to be decided.

With regard to the latter, it must be considered that when a company adopts a new technology it "kills" some options, since it gives up the possibility of waiting for new, more propitious conditions, and creates some others, in that it opens the way to future opportunities[9]. Hence, the global options value is given by the value of generating new options minus the opportunity costs of killing some other ones.

Technology options identification

The first step involves the investigation of all the possible sources of technology options which are embedded in our technology. A major handicap in identifying and appraising options is that they are not only directly connected with the technical attributes of the new technology, but also affected by some individual features of the firm and its business. A useful starting point for making a complete identification could be found in the previous options classification, suitably specified to stress the technological issues (see Table I).

Table I
Possible sources of different technology options

Options' class	Sources of technology options
Growth	Learning processes, tacit know-how, cumulativeness of technical improvements, modularity of technology investments, first-mover advantages, synergetic effects
Exit	Sunk costs, investment reversibility, specialization of tangible and intangible assets
Wait	Uncertainty reduction, acquisition of valuable information, price decrease, weak appropriability of technical advantages
Contract	Economies of scale in the use of the new technology
Switch	Standard compatibility, transferability of technical knowledge, interconnectability of technical equipment

Uncertainty and risk, inevitably linked to the exploitation of each new technology, generally have a twofold effect. On the one hand, there is a considerable value in waiting before the new technology is proven. The greater the uncertainty, the greater the value of the possibility to learn or gather relevant information so that future investments might be made under more favourable terms. On the other hand, the greater the risk, the better the opportunities for a first-mover strategy. In fact, there could be benefits in investing today to gain experience with the new technology or to follow a pre-emptive strategy. In this sense, uncertainty and risk generally embody, to different extents, both wait and growth options.

Learning process and cumulativeness are other important sources of options. Learning time, in particular, should always be taken into account, because when a firm acquires a new technology, both it and its members gain new knowledge. Furthermore, where the innovative assets may be the indispensable basis for subsequent innovations, they have the potential to generate opportunities in the future. Cumulativeness also means that current projects can provide a window on forthcoming technology generations.

Emerging standards, appropriability conditions, and the presence of network externalities are all factors that may induce a more or less rapid commitment. In presence of high appropriability conditions, a quick adoption could ensure the achievement of quite protected competitive positions. On the other hand, in the case of positive network externalities, where adoption benefits increase with the number of previous adopters, it may be convenient to wait. Concerning standardization, several empirical findings have shown that the first mover may have the opportunity to define a specific standard, forcing the followers to adopt it.

Compatibility among different technologies and the transferability of technical knowledge are sources of switching options, since they can affect interchanges among different technical solutions. Switching costs arise when passing to a new technology implies the unlearning of old methods and procedures. In this sense, the more specific knowledge and assets are, the higher are the switching costs. Also, standards may be a relevant source of these costs.

Concluding with the incremental or radical nature of the new technology, it gives rise to different kinds of options, especially in terms of the involved opportunities. Radical innovations, particularly when competence destroying, can be formidable threats for an established organization. In this case, the new technology deeply modifies the status quo, thus eliminating the null alternative. This is a very important question because if, on the one hand, the adoption decision cannot be taken on the basis of the traditional evaluation techniques, on the other hand the resulting stimulus to innovate might find the correct economic justification, and not only stands on vague strategic considerations.

Environmental analysis and options selection

Having identified all the options, the next step is the analysis of the environmental conditions and the specific strategic and operative circumstances where the firm acts. This is required to give a preliminary evaluation of the different options and to select the most relevant ones. It is worth noting that all the opportunities are, by nature, strongly firm specific, and consequently the value of the single option is deeply affected by the context on which it may be exercised. A way to understand the role which each option could play is to construct future alternative scenarios and assess the effects arising from taking the option.

Choice of timing

The final and decisive step consists of the global evaluation and adoption decision. The question lies in the fact that different options with different effects on time coexist. It is also emphasized by the fact that options may be interrelated and not precisely appreciable if individually considered. To decide on the adoption time, we suggest a decision procedure which is substantially based on the expanded NPV of Kasanen and Trigeorgis[16], with minor changes which take into account that adoption opens some opportunities and closes others. In this case:

Expanded NPV = Passive NPV + Net option value

where the net option value (NOV) is given by the value of the created options (COV) minus the value of the killed options (KOV).

For the sake of simplicity, the procedure does not face some of the aforementioned questions: in particular, the straightforward additions leave out the interactivity of the different options. It also considers the adoption decision as a repetitive process which occurs at established time intervals (see Figure 2). In this sense, the value of the killed options has to be considered with reference to a given time interval equal to a period.

The logic underlying this scheme is that, while a positive NPV does not imply the instantaneous adoption, at the same time a negative one does not imply the immediate

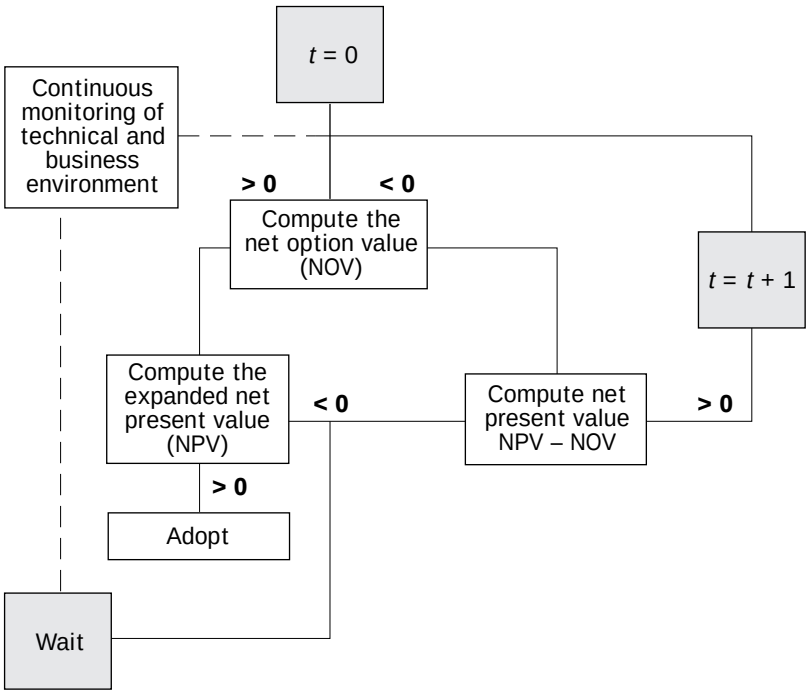
rejection of the new technology. On the contrary, the final decision is made in accordance with the net option value.

When positive, it means that the immediate adoption generates more opportunities than it kills. Under this condition, if ENPV > 0 one has to pass to adoption; otherwise, given that options are not able to reverse an unfavourable "economic" evaluation (in this case NPV < 0), it is a matter of waiting for some new event of either a technical nature (improvement in technological performances) or a strategic nature (changes in the competitive context), able to bring up the economic value of the new technology for discussion again. This leads to a return to the evaluation/adoption process.

When negative, it is convenient to wait. Also, in this case the decision may be delayed to the next period (if the "waiting ENPV" is positive) or suspended waiting for new information.

At this point, the problem lies in giving the correct economic value to the different options. In principle, as underlined by Sharp[7], it is not a difficult matter. The simplest valuation process, in fact, is to consider each option and ask: "How much are we willing to pay now for each one of the generated or killed options?". Unfortunately, the option pricing models do not always give a direct answer.

Figure 2
The adoption procedure



Qualitatively speaking, it seems reasonable to think that the various options and opportunity costs affect the adoption time differently, in the sense indicated in Figure 3. These indications could be a simple and preliminary, but very rough, guide in timing. Nevertheless, the decision cannot be left just to experience and wisdom of decision makers: formal techniques able to support them in validating their feelings or not[17] are needed.

If one wished to follow a more rigorous and quantitative appraisal process, one could resort to some of the available evaluation techniques. For example, the quite simple and widely known binomial pricing model[11,18] may be a good starting point, especially when it is possible to reduce future events to only two scenarios, for which one estimates the probability of realization and their economic consequences. This model, however, suffers from some of the main limitations of the classical Black and Scholes[19] formula, and hence is of little use.

Instead, other techniques exist, which do not always directly refer to the option approach, which can support the evaluation of a specific set of opportunities. We can briefly recall some of them, by distinguishing them according to the particular kind of options they could be used for.

- *Growth options.* Ang and Dukas[10] have suggested a model for capital budgeting decision in a competitive environment, where the firm's expected cash flows are affected by the entries of competitors. Given that this model can be applied in evaluating a first-mover or a pre-emptive strategy, it could be usefully employed for assessing the value of an early technology commitment. Furthermore, there are models which explicitly take into account how learning affects adoption time by influencing the profitability both of the current[20,21] and future investments[22].
- *Abandonment options.* A very promising technique for evaluating this kind of option is given by the exit net present value[23]. This technique, by quantifying the economic consequences of exiting an investment at different points in time, gives a measure of the costs associated with its premature abandonment. In the same direction, but within the option framework, the model developed by Schnabel[24] links the abandonment option value to the non-specific nature of the technology asset.
- *Wait options.* All the models that allow the determination of the value of better information (e.g. probabilistic decision trees) can be used for appraising the value of waiting. The problem is to estimate the

associated waiting costs. In this case one could refer to a simple operative model developed by Gottardi and Scarso[15] which links deferring benefits and costs when two alternative investments are involved. Further suggestions about the value of these costs can be derived from the dynamic costs and revenues analysis developed by Pettinato and Pignanelli[25].

Figure 3
Technology options and adoption time

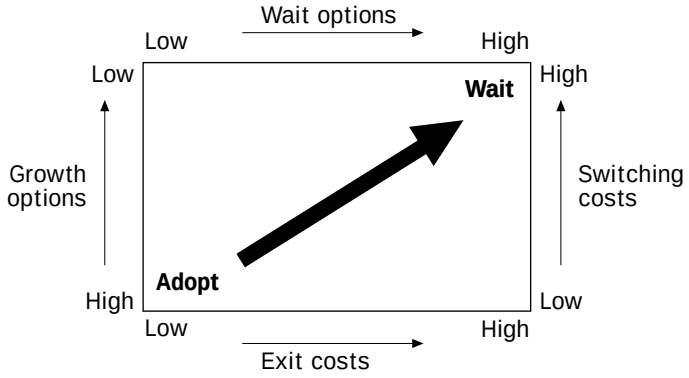
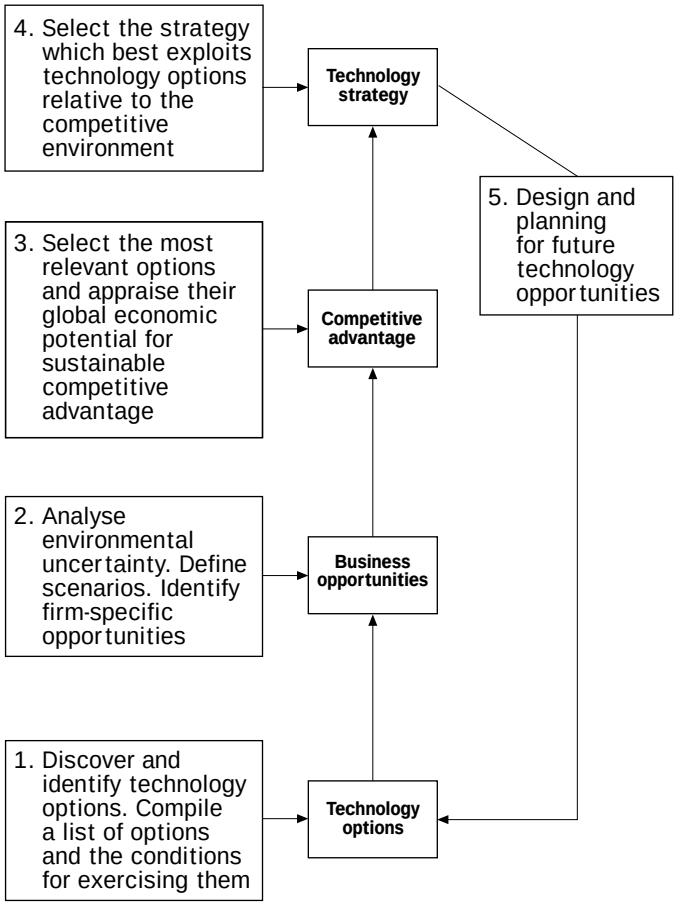


Figure 4
An option-based approach to technology strategy



- *Contract and switch options.* Some recent sensitivity models[26,27] provide fruitful indications in this field, given that they compute how much the investment profitability is affected both by the scale and other operative conditions. Other techniques can give satisfactory hints in assessing the project flexibility, as in the case of the model developed by Azzone and Bertelè[28].

Finally, it should not be forgotten that the diffusion literature[29] provides useful, even if rather qualitative, insights concerning the adoption time.

Two operative warnings may be useful at this point: since the global option value is generally not the simple arithmetic sum of the different options, at least the most relevant interrelations have to be carefully considered; and sometimes there are factors which can be included positively among options or negatively among opportunity costs. This is the case of deferring costs, some of which are the opportunities generated by an immediate adoption, which are killed by waiting. Attention must be paid to avoid a double accounting of them.

Before concluding, there are two important questions. First, the suggested procedure stresses the role played by continuous information-gathering. In order to time the adoption correctly, it is very important to keep a non-stop monitoring on the evolution of both the technological and business environment and their effects on the firm's competitive edge. As a matter of fact, we must say that recognizing the option value implicitly means recognizing the value of information in business strategy. Second, once the significance of technology options as a source of competitive advantage has been accepted, the question could move to another level, and precisely to how these opportunities can be designed and planned. This could require a changing perspective in the formal process of technology planning. In this sense, from the previously suggested procedure, an option-based approach to technology strategy can be derived (see Figure 4), which strictly recalls the resource-based theory of competitive advantage of Grant[30]. If technology options are the basis of business opportunities which constitute the background of the competitive advantage, firms have to follow the innovation strategy that best exploits available opportunities and poses the premiss for designing and planning new technology options.

In accordance with this point of view are Dixit and Pindyck [9], when they affirm that, if correctly understood, the nature of options

suggests placing great value on investments which create options and being more hesitant to finance those that exercise options.

Finally, returning to the strategic management of technology, we think that our approach is in total consonance with it. They both, in fact, not only emphasize a long-term perspective in implementing a technology strategy, but also explicitly link together technology and business strategy.

Conclusions

When the adoption of a new technology is considered, deciding on the appropriate time is an important strategic question. Time, in fact, can have a substantial influence on the competitive advantage offered by the innovation.

In this paper we have focused on the adoption decision, thus proposing a technique for its timing. It is a four-step procedure which substantially stands on an option-based perspective and considers adoption, not of a single decision, but a process of continuous monitoring of the business and technical environment.

The value of this approach is twofold. On the one hand, it stresses the importance of considering all the (present and future) advantages directly and indirectly involved with the new technology; on the other, it highlights the value of a persisting information-gathering activity. It is exactly in the direction of taking explicit advantage and continuously generating new opportunities that we have extended our reasoning, thus providing, from the suggested procedure, an option-based approach to technology strategy.

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Application questions

1 How is investment time addressed in your organization?
2 Do you think that technology deserves a specific strategy?