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Early valuation of technology: real options, hybrid models and beyond

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abstract

There are fundamental challenges in valuing technology, in particular dealing with uncertainty, complexity and aggregation issues. In this paper we identify desirable properties of valuation tools and then review existing tools against these criteria. We then establish a need for a tool to explore and communicate the value of technologies at the earliest stage of development, and propose a tool, the value roadmap, that fills this gap. We report on initial learning from piloting this tool at a multinational corporation.

1 Introduction

Valuing technology is a critical business activity in many companies. For example. selecting the best portfolio of R&D projects is often key to the long-term future of the company (Hicks 1999). It is usually this R&D that creates the new businesses that generate future revenues. And it is usually this R&D that finds solutions for businesses whose systems are operating at the limits of performance. With the rise in technology trading and licensing, the valuation of technology has taken on new importance. The ability to correctly value technology is useful to many: R&D employees structuring their projects to maximise value; managers selecting among projects; higher management wishing to understand the benefits of spending on technology development; employees responsible for acquiring or selling technology.

This paper reviews a range of tools and techniques available to do this technology valuation for individual projects, and proposes a new one, value roadmaps, to fill an identified gap with early stage valuation techniques. Before embarking on this, we consider in this introduction the fundamental challenges that valuation tools face, and the desirable characteristics of a good tool. We then go on to outline the structure of the rest of the paper. First, we consider the challenges.

The challenges in valuing technology are significant. The starting point is that technology has no inherent value: it has value when combined into a complete solution and delivered to a customer who is willing to pay a certain amount for it in their particular application. Major challenges in attributing a value are: uncertainty, complexity, and aggregation effects. We start by considering uncertainty. All predictions of future value are uncertain, but those involving early stage technologies are particularly so. There is more technical uncertainty as to what is physically possible, and when doing things for the first time there is also far more scope for unseen problems to emerge. Even if the technical problems are resolved there remain market uncertainties. These are often considerable since the conjectured market for an early stage technology will lie some way into future. All these uncertainties make it difficult to produce useful estimates of the value of an early stage technology, particularly since the actual financial *profit* derived from a technology will be the difference between an uncertain revenue and an uncertain development and marketing cost.

These uncertainties lead naturally onto the problems of complexity. The more uncertainties there are, the greater the number of possible futures that need to be

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considered. If, for example, a technology proves ineffective for one application, there may be other applications where it could still be valuable. If an insuperable problem occurs with a technological solution, there may be parts of the solution that can be salvaged and usefully exploited. Further complications to consider are that the route to obtaining value may involve other partners who, for example, control distribution channels or other complementary assets. Bounded rationality means that it is impossible to take into account all the potential interactions that occur as a technology is developed and exploited. In short, valuing early stage technologies is complex.

This complexity leads in turn onto issues of aggregation. As mentioned above, a technology needs to be encapsulated into a solution for a customer before it generates revenue. This solution often combines other technologies. Thus aggregating technologies has in this case increased their value. How should we value technologies linked in this way? How much of the combined value should be attributed to an individual technology? It may conversely be that two parallel technology projects are less valuable than a single one, due to the loss of focus.

In summary, valuing technology faces fundamental challenges, particularly with respect to uncertainty, complexity and aggregation. Different valuation tools tackle the challenges in different ways.

What are the desirable characteristics of such tools? Obviously a key desirable is accuracy of valuation, with the accuracy of the model matched to the accuracy of the available input data. Beyond this for practical reasons the tool needs to be easy-to-use. Clearly a balance needs to be found between the desires for accuracy and for simplicity.

Another desirable characteristic is that the tool be intuitive and generate understanding – managers and engineers want to be able to discuss the project in light of the valuation, to understand where the value comes from and particularly to be able to see ways to improve the value. Ideally the tool should be widely applicable to a variety of projects and be scalable. Finally the tool needs to be credible and accepted as useful. There is little point in a tool that is easy-to-use, intuitive and accurate, if no-one believes the answer or if no-one is willing to implement the process.

This paper has four further sections. The next section reviews decision trees and real option techniques that address the well known weaknesses of discounted cash-flow techniques in the presence of uncertainty (and intelligent informed management). The section then looks at scoring techniques before identifying the need for a tool to complement scoring techniques. Section 3 describes the value roadmap, a tool aimed to fill this need, and reports on preliminary learning from applying them. Section 4 concludes by identifying areas for further work.

2 Decision trees, real options and scoring techniques

Discounted cash flow (DCF) techniques score well on the desirable tool characteristics identified in the introduction. They are easy-to-use, intuitive, widely applicable, credible and accepted. However their accuracy can be poor if there are high levels of uncertainty, and if the project can be actively managed to reduce the impact of bad outcomes or boost the impact of good ones. This point is well made in a very simple example of Faulkner (1996), shown in Figures 1 and 2.

In figure 1, a standard DCF approach is taken on a hypothetical printer project. The net present value of this project is negative. In figure 2 however, by distinguishing the

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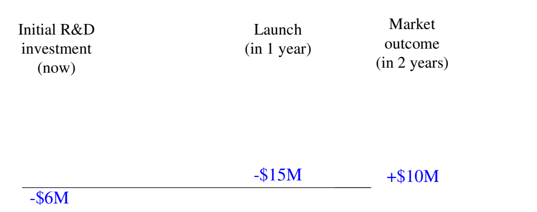
different R&D outcomes and assigning probabilities to them, and deciding to launch the product only in the case of an "excellent" R&D outcome, the expected discounted value is positive.

This decision tree method of valuation produces a more accurate reflection of the value of the project, assuming the estimates of probabilities and the corresponding market values are reliable. This is simply due to it being a more accurate model of the staged investment process – a reasonable manager will not launch a product that is likely to make a loss (unless there is some other benefit to be obtained).

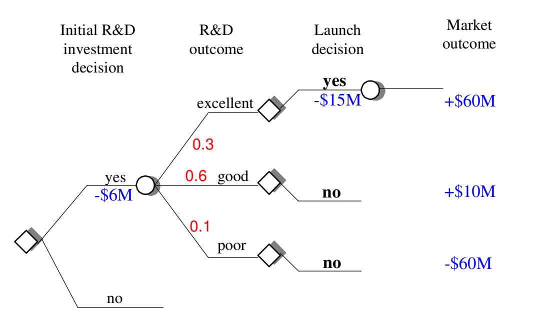
Transferring this simple example to the real world immediately leads to the question of where probability figures such as "0.3" came from. It may be that there is a database of previous similar projects and thirty percent of them had excellent outcomes. This is the approach adopted for generating probability figures for a pharmaceutical decision tree reported by Loch and Bode-Greuel (2001). Another approach is to view probabilities as representing subjective judgments of experts based on experience as to how much should be bet on an outcome. Neither of these approaches gives great confidence and thus can undermine the credibility and acceptance of decision trees. To counter this, sensitivity analysis can be performed on the parameters, seeing how the value changes as the R&D outcome probabilities change. The logical extension of this yields Monte Carlo valuation methods.



NPV@12% =
-\$6m -\$15m/1.12 +\$10m/1.12^2 = **-\$11.4m**

Figure 1: Simple DCF valuation (Faulkner 1996)

The advantages of the decision tree approach is that it generates a more accurate value than DCF in the case where there is uncertainty and informed management flexibility. It achieves this at the expense of being slightly less easy-to-use and slightly less credible, due to appearance of probability estimates. However it is still intuitive and understandable. It can be used as the focus of a discussion and managers can consider if there are other configurations of the project that have more value, and whether it is possible to do particular de-risking pilot studies to determine the likely value of the project earlier, hence before major investments have been made. A key observation is that it is often more useful to understand the range of



value =
-\$6m - 0.3 × \$15m/1.12 + 0.3 × \$ 60m /1.12^2 = **\$2.2m**

Figure 2: Decision tree valuation (Faulkner 1996)

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likely outcomes and have plans to handle these outcomes, than it is to simply have a single figure representing the value averaged over these different outcomes.

This decision tree approach has similarities with the so-called real options approach. The fundamental idea that uncertainty is good if the downside can be mitigated is common to both. For example it may be worth doing a pilot study into a technology to establish if it will work or not. If the answer is yes then a large investment can be made to reap an even larger benefit. If the answer is no, then only the small cost of the pilot study has been incurred. This is in contrast to the DCF approach where uncertainty is typically penalized by raising the discount rate.

The term real options valuation is often reserved for approaches which derive from the Black-Scholes-Merton (Black and Scholes 1973) model for valuing options contracts on the financial markets. An option contract gives the right but not an obligation to e.g. buy a certain amount of an asset at a particular price on a future date e.g. in 3 months time. The model assumes the asset price moves according to a random walk process. It is then possible to theoretically construct a portfolio of some of the asset and some options which is isolated from the random fluctuations. The value of this "risk-free" portfolio can then be calculated, and from this the value of the option (Wilmott et al. 1995).

The real options valuation approach makes the analogy between an option contract and a research project. In the world of financial markets, by paying a small amount for an option, you can buy an asset if the price is favourable and abandon the option otherwise. In the world of research and development, by paying a small amount for some research, you can launch a technology if the result is favourable, and abandon the research otherwise. However the details of this analogy are open to question (Perlitz et al. 1999). In particular it is unclear whether the risk-free portfolio argument carries across, and to what extent the value of the output of a research project follows a random walk. It intuitively seems that a decision tree with discrete events corresponding to the end of different stages of research is a better model (Loch and Bode-Greuel 2001).

Hybrid models have been constructed which use decision trees for modeling the early stages of research and development and then link these to models of the market value that follow particular stochastic processes (Perdue et al. 1999; Neely and de Neufville 2001; Hunt et al. 2003). However the promise of real options valuation based approaches seems low when judged against the criteria suggested in the introduction. Direct application of the Black-Scholes-Merton model is usually flawed (Bowman and Moskowitz 2001), producing recommendations such as that delaying the product launch will necessarily increase the value. A more realistic model will be more complicated. Even if this more realistic model is accurate and easy-to-use, it is unlikely to be intuitive and help managers and researchers in find ways to increase the value. Since the mathematics underpinning the models are high level, and the underpinning assumptions are not self-evidently reasonable, it is hard for these models to become credible and accepted.

In conclusion, decision trees and Monte Carlo extensions of these seem to be the best tools for evaluations where the uncertainties make DCF inappropriate, but where it is still possible to identify likely development branch points and ascribe credible probabilities. Where the uncertainties are such that it is difficult to identify likely development branch points or ascribe credible probabilities, new techniques are needed. The most commonly used approach is scoring projects against a number of

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qualitative factors such as how broadly applicable the technology is, or how well it fits with company strategy, and then ranking the projects according to their total scores. As well as selecting the highest scoring projects, attention is paid to achieving a balanced portfolio, typically by a visual plot. Cooper et al. (1997; 1997; 2001) review a range of these tools and make the telling observation that companies who rely exclusively on financial measures to rank projects are less successful at new product development than those who also include qualitative factors.

One weakness of scoring methods is that it may be hard to justify why a particular score on a qualitative factor was given. For example, it is hard for senior managers to query a strategic fit score without some understanding of the project. Also the ability of managers and engineers to understand and improve the value of a project, which was possible with decision trees, has been lost. To address this gap we developed the concept of value roadmaps, extending previous work on technology roadmaps (Probert et al. 2003).

3 Value roadmaps

3.1 Value roadmap structure

Value roadmaps are a way to explore and improve the value of technology projects at a very early stage. As well as supporting communication within the project team, the roadmaps can be post-processed to emphasize key messages and can then be used as a tool for communication with senior management.

The structure of a value roadmap (VRM) is depicted in figure 3. Typically a roadmap

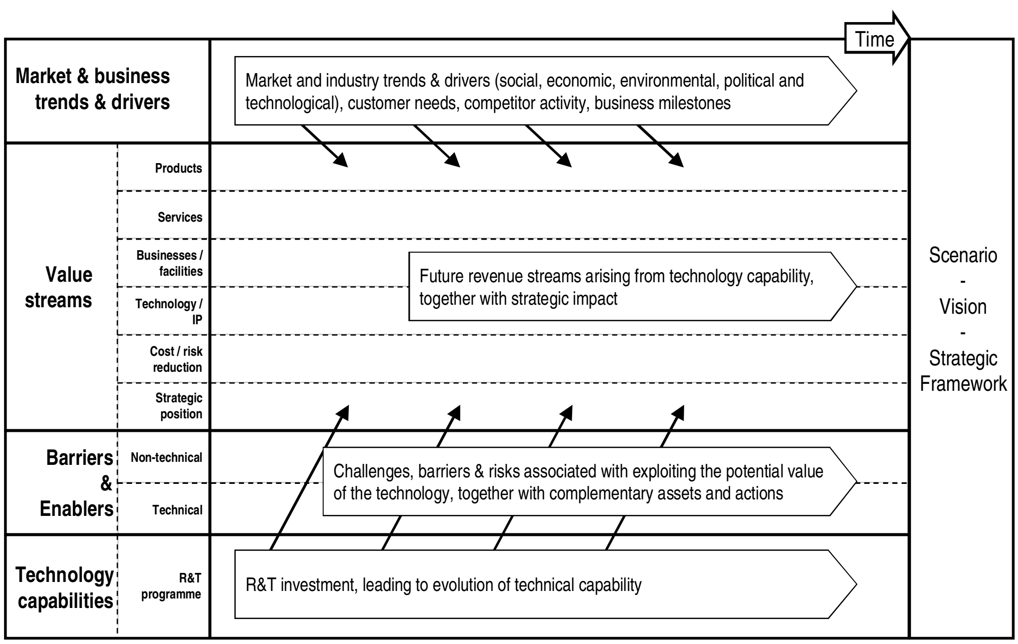

Figure 3: Value roadmap architecture

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is developed on a wall chart during the course of a half-day workshop. It comprises the following four layers:

- External market trends & drivers (social, economic, environmental, technological and political) and internal business factors that influence the development of products and technology in the area of interest, including strategic milestones and goals.
- Value streams (sources of future revenue and savings: products, services, business / facilities, technology / IP, cost / risk reduction, strategic position). All of these value streams relate directly to the generation of cash revenue, except for 'strategic position', which includes all non-financial factors that provide a foundation for future revenue generation.
- Enablers and barriers (technical and non-technical challenges and risks, together with complementary assets and actions needed to exploit the potential value of the technology or capability)
- Technology capabilities that result from R&D investment.

A key feature of the VRM is the time axis, which links the short-, medium- and long-term perspectives for all of the layers since R&D investment now is intended to generate revenue in the future. The time horizon for the VRM will typically extend considerably further into the future than the R&D project plan, providing a forward looking 'radar'.

The value proposition that is explored and mapped in the VRM will typically depend on the strategic context or scenario that governs the discussion and defines the broad direction within which innovation is desired. It is important that the strategic context is clearly articulated, including assumptions, constraints and desired end result of the R&D investment.

3.2 Value roadmap process

The following process stages are used to generate the VRM:

1. Define strategic framework / vision / scenario (assumptions, boundaries, constraints).
2. Map market and business trends and drivers (social, economic, environmental, technological and political), milestones and goals.
3. Map R&D project milestones and investment (current and future / potential), in terms of the technical capabilities that will be achieved at key milestones.
4. Map barriers and enablers associated with technical capabilities, in terms of the challenges and risks associated with realizing the commercial value from the technology, together with the associated and complementary assets and actions that must also be in place. Consider both technical and non-technical factors.
5. Steps 1-4 provide the context (strategic framework, market pull and technology push) within which the potential value that may result from the R&D investment can be explored. The goal is to identify specific sources of potential future revenue, articulated as clearly as possible.
6. Review project plan and VRM, including key linkages between elements.

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7. Generally, for non-trivial projects it is expected that the information contained in the 'first-cut' value roadmap will be dense, complex and fragmented, with gaps and data of varying quality. Further effort will be required to tidy up the roadmap, although the end result will still probably be a complex roadmap – the VRM is designed to reflect the complex 'big picture'. This 'rich picture' VRM can be considered as a 'database', containing a great amount of relevant information at a fairly high level of detail, and is likely to be too dense to clearly communicate key messages about the project and its value. For this purpose, summary or communication roadmaps need to be developed. Consider carefully what the key messages are, and who the audience is, and then use the 'rich picture' VRM as a resource to construct suitable communication roadmaps and graphics. The VRM can also provide a useful resource for 'what if' and sensitivity analyses, and to assess the impact of events and new information on the plan as a whole.
8. Maintain the VRM and associated documentation on an ongoing basis, preferably as part of the business process (project management, new product development, research and technology strategy).

3.3 Value roadmap application

The value roadmap technique was successfully piloted at a multinational company. The feedback from users was positive particularly in that it forced researchers to think of communicating the value of a project rather than the interesting technical challenges or capabilities produced. It also caused them to rethink the order of the capabilities developed in the research.

The major difficulty encountered was in placing information on the chart without the chart becoming too densely packed with information. Experiments were performed in post-processing the final roadmap, having multiple versions at different levels of detail, and also the possibility of using IT support that enabled the interrogator of the VRM to dig down into items of particular interest. An alternative was to generate narrative roadmaps in which the researcher used the headings as prompts to enable them to communicate the value. However clearly the advantage of the one unifying visual representation of the project is lost by doing so.

4 Conclusions and further work

The value roadmap approach appears to be a helpful addition to the technology valuation toolkit, although it by no means solves the key central challenge of financial valuation of long-term R&D. However, it does provide a framework within which the full context of technology investment and exploitation can be explored and communicated.

The VRM approach is a particular type of the more general method of 'technology roadmapping', and much can be learnt from practice in that area. While the concept behind roadmaps is simple (a multi-layered time-based graphical framework), the reality of developing and maintaining roadmaps is much more challenging, reflecting the complexities of strategic planning more generally. Essential ingredients in a successful roadmapping initiative include: an effective process (linked to other key business processes), support (facilitation and potentially software), and ownership.

Our next steps in developing the VRM approach are to:

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1. Undertake further pilot studies for a range of R&D project types, capturing key learning points.
2. Develop solid historical cases to demonstrate application of VRM, and also to illustrate the non-linear path to commercialization that is typical of many successful research activities, which might well have not been funded at the time (without hindsight) if standard accounting approaches such as DCF were used in isolation.
3. For particular companies develop a unified 'top layer' of VRM, in terms of a set of trends, drivers and strategic milestones that can be provided to technical teams, for consistency across projects and also because this information is often not readily available.
4. Develop VRM process guide and support infrastructure (workshop facilitation and software), based on further trials and examples.

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