Evaluating Early Stage Technology Valuation Methods; What is Available and What Really Matters

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Abstract – This paper reviews methods to value technology in an industrial context. Decisions on early stage technologies are ill-supported and need to be seen as part of an iterative process including more qualitative techniques.

I. Introduction

Decision makers in technology-based firms face a significant challenge: how to make appropriate business appraisals for early stage technologies. This challenge includes gaining an understanding of the uncertainty associated with new technologies. Such an understanding supports a realistic determination of the value that a specific technology can bring to the organization, in comparison to the cost of developing or acquiring that technology. However it is remains difficult for technology managers to make assumptions on which to base their decisions, as future applications of an early stage technology have yet to be identified.

A number of technology valuation methods are already available. Most techniques are quantitative in nature and are derived from financial valuation techniques and decision theory, such as the use of discounted cash-flows [1], decision trees and real options e.g. [2, 3, 4]. Quantitative techniques enable decision makers to systematically structure the potential outcomes and their underlying uncertainty. Although widely accepted when technologies have a certain level of maturity and applications have been defined, for early stage technologies these approaches can be mathematically sophisticated but contextually naïve [5]. Another category of techniques focuses more on the qualitative aspects of valuation. These techniques generally attempt to structure reasoning and serve as an aid to decision makers in shaping their judgment, such as the use of score cards [6] and roadmaps [7]. Yet little is known about how these approaches specifically address the issues related to early stage technology. In fact many firms refrain from using formal valuation methods until the technology becomes more mature (and hence more certain) and rely on "gut feel".

This paper aims to describe the practical implications of prevailing approaches for early stage technologies. In order to understand the implications from a theoretical perspective, an overview of some widely applied methods and tools will be provided. Based on this overview we will then evaluate these methods and techniques on their practical merits. Initial results are taken from three ongoing case studies in technology-based companies, in terms of the limitations and constraints with respect to these existing methods and techniques. The paper will conclude by providing recommendations for future research in development of methods and techniques for early stage technology valuation.

II. Valuation Methods for Early Stage Technologies

Although the term "early stage" technology is often used, there are no clear cut definitions readily available. Early stage technology can be determined by assessing the technical and market uncertainty of a specific technology [8]. If these are high then the technology is in an early stage. Another way of assessing if a technology is in the early stage, or in more mature or late stages, is by means of technology readiness levels (TRLs) [9] used by the United States General Accounting Office to establish best practice in technology management for defense projects. These TRLs focus on the development of the technology and for our purposes we define an early technology as a technology that is operating in levels 1-3, which is the stage before it is introduced to sub-systems or components to new product development.

A. Discounted Cash Flow

The use of discounted cash flow (DCF) for early stage technologies is difficult due to high uncertainty levels. DCF techniques are easy-to-use, intuitive, widely applicable, credible and accepted [7]. However, myopic use of the technique can lead to poor decision making [1]. For early stage technology the high levels of uncertainty results in poor accuracy [2, 7] and hence assumptions are hard to make. Decision making during these stages requires flexibility. The DCF however does not allow for this flexibility.

In these cases many analysts have sought to justify their 'gut-feel' and industry experience by manipulating the valuation process and raising cash-flows to unlikely levels [7]. The result is a decision-making process that lacks credibility [9]. Additionally it is argued that this caused many US firms to miss significant growth opportunities in their industry [10]. For early stage technology methods are required that can handle more intangible aspects such as "managerial flexibility" [10].

B. Real Options and Decision Trees

The option to invest if appropriate is not something that is given a value by DCF. DCF methods tend to penalize uncertainty by using higher discount rates, even when there is flexibility in a project to profit from this uncertainty. There is sometimes value to be obtained through waiting for more complete information, and this value is also not incorporated in the DCF [11].

This issue of flexibility has been addressed by Real Option (RO) theory. Real options provide an essential framework for sequential decision making, extending current practices in decision theory [12, 13].

Three levels of real options thinking can be distinguished [7]. The starting level is to realize that some investments can be understood as options, that what is being paid for is the "right to play", and that there is no guaranteed pay-off [14, 15]. For early stage technologies this seems a fruitful contribution in terms of valuing the technologies.

The second level focuses on quantifying the value of the flexibility in projects by using decision trees and estimated probabilities [2]. These approaches encourage the exploitation of uncertainty rather than fear of it. Decision trees do not often carry the options label as there is some difficulty in estimating probabilities, since the events in a decision tree are typically one-off [7]. For example there may be value in delaying investments until the market value becomes clearer. Conversely in early stage technologies development projects there may be value in performing research projects to generate the information necessary to accurately value an opportunity.

The third level of real options thinking refers to the mathematical modeling techniques [16, 17] that have proved successful in the financial markets. It brings in the ideas of *replicating portfolios* and of *arbitrage pricing* i.e. what should the price of this option be so that no-one can make "excessive" guaranteed profits [7]. In the financial world this is also referred to as risk-free portfolios. This approach circumvents the problem of estimating probabilities, but in its place substitutes the problem of estimating how much the market prices are going to fluctuate i.e. the volatility of the prices.

The main problem in utilizing this technique for technologies is that, unlike financial options, with technologies there are no underlying assets. One way of dealing with this is to create more sophisticated stochastic models, but the question of whether it is valid still remains. [7].

A further pragmatic point to consider is the limit of accessibility for the users under consideration: venture capitalists and management teams. The "lumpy" nature of information release in technology might make decision trees a better model than commonly used random walk processes [18]. Hunt et al. [7] point out that the loss of intuitive understanding of the model may significantly undermine the value of the technique for non-expert users.

C. R&D Portfolio Methods.

Portfolio management is a decision process where a business's list of active new products and R&D projects is constantly updated, reviewed and revised. In this process, new products are evaluated, selected and prioritized; existing products may be accelerated, killed or de-prioritized [19].

R&D portfolio management methods aim to provide a balanced approach to risk and reward. The visual representation of the existing portfolio gives a starting point for the consideration of the impact and potential value of early stage technologies.

Portfolio methods can use both qualitative and quantitative (e.g. financial) data and assumptions. Financially oriented analyses suffer from the fundamental problem that the data required may be unavailable, or of dubious quality, especially in the critical early stages. For this reason many companies prefer to replace, or at least supplement quantitative models with techniques that incorporate qualitative assessments. Examples are the use of bubble diagrams, strategic "buckets", and scoring models [19].

These portfolio management approaches all contribute to technology valuation in that they provide various ways of depicting a set of assumptions across a variety of dimensions. This visualization can benefit early stage technologies by depicting the need, for example, for a balanced portfolio with both blue sky and incremental development projects. However in cases where the portfolios are small, portfolio methods are more difficult to apply.

D. Roadmapping

Roadmapping is a technique to structure and support brainstorming based on the future potential of technologies. It is being used in industry, both at the company and sector levels, to support a variety of strategic goals [20, 21].

Roadmapping supports the valuation of early stage technologies as it plots the potential future of the technology against a timeline and clarifies the enablers and barriers to value creation. Thus a better judgment on the future value of the technology can be extracted from the roadmap.

An example of a customized version of the technique is the value roadmapping (VRM) being developed by the authors of this paper. The VRM aims to provide a framework to explore, communicate, calculate, maximize and manage value. This technique is used to explore and improve the value of technology projects at a very early stage [7]. As well as supporting communication within the project team, roadmaps can be post-processed to emphasize key messages and can then be used as a tool for communication with senior management. A roadmap is typically used to collect and digest qualitative information over a time period of several years. It is particularly suited to ensure that the longer-term orientation of the business is adequately served by the selected projects.

The VRM approach is aimed at individual projects or programmes, and is not directly applicable to a portfolio of disparate projects, although the output from the VRM could

be an input to a portfolio management approach. Furthermore, VRM is the first technique that not only considers the external technology and market factors in order to determine value, but also provides space for an internal assessment of the firm's capabilities, thus addressing organizational uncertainty. Previous perspectives on technology valuation predominantly take an external focus, either on the technological aspects or the market aspects of technology valuation. However, estimating the future market potential for a specific technology, or the likelihood that a certain development will be successful, still does not guarantee that the organization assessing the technology will in fact be able to reap value from the technology.

E. Expert Judgment and "Gut Feel"

Decision makers rely on expert judgement and gut feel in a range of technology valuation situations. For example, Pavia [22] studied the criteria used to screen potential new products in entrepreneurial, hi-tech firms and found that the majority of the respondents did not use financial measures and preferred gut feel. In addition, Bannister & Remenyi [23] discuss "acts of faith" in terms of instinct and value for information technology investment decisions. They argue that in spite of the focus on evaluation methodologies there is a lack of understanding of the complex issue of value and a limit to what can be achieved. They suggest that "This limit becomes evident when decision makers fall back on gut feel and other non-formal/rigorous ways of making decisions".

However efforts have been made to quantify both gut feel and expert judgement in related fields. For example, Jagle [24] developed an options-based approach which aimed to incorporate much of the gut feel of experienced industry practitioners in the valuation of hi-tech and life sciences companies. In addition, Otway and vonWinterfeldt [25] categorised expert judgement and presented illustrative case studies of problems that can be encountered with its use in the regulation and management of hazardous industries. They used an influence diagram to model the decision problem, which was then quantified by expert judgement, and also calibrated the experts.

In summary, it is necessary to recognize the importance of experience in complex situations such as technology valuation, but this does not necessarily dictate a lack of rigor.

F. Overview of Methods.

When considering some of the prevailing methods that are currently in use to value technologies for investment decisions, different types of technique seem more appropriate at different stages of the technology development. For example DCF seems most appropriate when the technology is relatively mature and products or applications as well as market potential are clear. Option thinking can be beneficial in the stages preceding DCF, where a certain amount of flexibility is required. Portfolio methods are used to balance a portfolio and thus incorporate both mature as well as less mature technologies. However, the use of quantitative methods in portfolios is more difficult for early stage technologies. Conversely roadmapping techniques seem more appropriate in the earlier stages in order to map the future value streams of a particular technology. Finally, literature shows that "gut feel" and expert opinions underpin most valuation approaches, and that it may be possible to structure such experience.

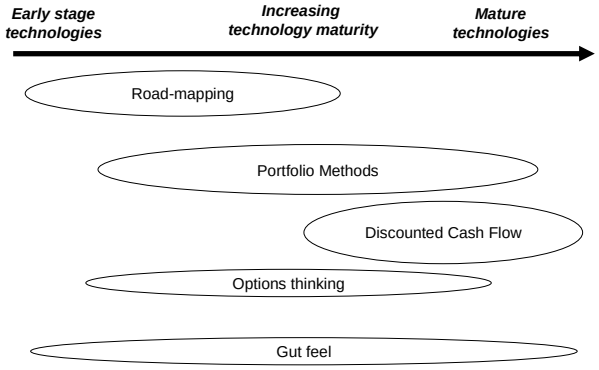

Fig. 1. Valuation Methods and the various stages of technology development

III. CASES STUDIES IN EARLY STAGE TECHNOLOGIES

The next section will evaluate the tools and methods from a pragmatic perspective using illustrative case studies.

A. Research Methodology

Due to the exploratory nature of the research we have used a case study approach in order to further the understanding of the use of business appraisal techniques for technology valuation. The data stems from an ongoing study on business appraisals for new technology potentials. We focus on OEM and 1st tier suppliers and have currently looked at three industries: aerospace (3 companies), electronics (4 companies) and printing technologies (1 company).

Data has been collected by means of 12 semi-structured interviews using a standard questionnaire and a dedicated workshop with a representative of each firm. Furthermore, we have used observations and company reports. The purpose of the interviews was mainly to understand the process of technology valuation and to map what tools and techniques were used within the various stages technology development. In addition we have made an assessment of their requirements. The results presented here should be seen as preliminary, used mainly to illustrate the implications of the technology valuation techniques and potential future research directions.

B. Process of Technology Valuation

In order to understand the use of valuation techniques and the limitations and gaps, it is important to understand the process. Based on the case studies we have been able to

construct a first version of a generic process that encompasses valuation of technology.

The first step is the gathering (deliberate or spontaneous) of data, information and opinions that fuels the next step – valuation or evaluation. In the next step the actual evaluation takes place. Here the tools are often used to either digest the financial data and information, the market or technical information or opinions to ultimately come with an indication of likely value(s) that fuels the decision. The decision (go/no-go) then leads to an implementation. The process is cyclical, and is repeated throughout the life cycle of the technology/product development. At different phases of the technology development funnel, the generic process has different characteristics and uses different criteria. During the concept evolution stage, qualitative analysis is essential. The next phase focuses more on the integration of the technology in new products, whereas the final phase focuses on the quantification of the business case.

The remainder of the paper will focus on the results from the case studies and describe the implications of the techniques and tools used in the technology valuation process at the concept evolution stage.

C. Case Analysis on Technology Valuation Methods

Our study shows that although many (hybrid or customized) versions of the tools that we have presented in this paper are being used, for early stage technology valuation none of the companies in our study have a clear cut, refined approach. For the later stages, more quantitative approaches are deemed useful.

In the aerospace cases we have discussed valuation with people from finance/commercial functions as well as R&D. In commercial groups there is use of portfolio techniques and DCF is being used on an iterative basis to evaluate the business case at hand. However for the valuation of blue sky research the most common method for technology valuation is individual expertise or "gut feel". Especially with respect to technical uncertainties, a heavy reliance is put on the technical expertise of a few "wise men" within the organization. It was indicated that during this early phase the available technology directions were thin and heavily reliant on visionaries, due to the long life cycle of aircraft. In one company the VRM has been piloted on a historical case and further tests are underway.

In the printing industry we witnessed a similar rigorous and detailed stage gate approach with clear milestones and an accompanying business plan using various derivatives of DCF. However, the printing OEM did not use this process for the valuation of an individual technology but for the valuation of a product. The technology was seen as subservient and if a product project has been approved then the technologies required for this project would be developed or acquired. Additionally a new technology for the project does not have to be a new technology to the world. Alternative applications of mature technologies are thus often favored.

In the electronics industry again it appeared that the bridge between the new technology and the application seems of high importance. The most important issue mentioned was that decisions in the early stages are often based on expertise, especially in the phase from early to "mid" stage, where the first applications have to be considered. As in Moore's "chasm" [26] the main problem appeared to be convincing the early majority, i.e. the business units, to invest in the technology. If they do not see a use for the technology (long or short term), it is likely that investment will cease. In one case it was reported that the technology was initially well received, but because the market was not ready, the technology was shelved, never to emerge again, although the market picked up a couple of years later.

D. Discussion

The first results from our cases examining the use of valuation methods and tools in industry can be summarized as follows. A major issue is that the method being used should be understood not only by the user, but also by the receiver. In the majority of our cases we found that the person responsible for the valuation was not responsible for the decision. The input requirements of the decision maker can be different to the outputs obtained from the method selected by the evaluator. This appears to be an especially important problem in the transition from early stage to "mid" stage technologies, as at this point the usability of the technology as a subsystem of a product becomes critical. This could suggest the importance of technology marketing oriented concepts in order to ensure that effective (internal) adoption of the technology occurs. Portfolio methods, in terms of visualization, and VRM could be used to communicate and build a joint understanding between different parts of an organization with respect to the potential value available and effort required.

Furthermore, our sample showed that real options theory has not yet caught on. Our analysis however shows that the acknowledgement of options thinking within the development funnel could be beneficial. For example, in the electronics case where the technical development was faster than the market development, the organization perceived the technology as a failure. When the market was finally ready, the technology was deemed "old", hence missing an opportunity. This suggests that market readiness levels are as important as technology readiness levels and that an options based view could be used to balance the two over time in concrete and real investment decisions. Portfolio methods and VRM could be used to integrate such options thinking.

Finally we have seen that expertise or "gut feel" still play a major role in the valuation of early stage technologies. The knowledge by which these are shaped however is often poorly structured or even unknown. Our study shows that there is potential in understanding these unstructured approaches in an attempt to make the knowledge transferable and sustainable. The advantages and disadvantages of the methods discussed in this paper are summarized in Table 1.

Technique	*Pros*	*Cons*
Discounted Cash flow	Generally accepted and used for later stages by commercial/finance	Too rigid for early stage technologies
Real Options	Option thinking potential in the valuation process e.g. roadmap	Mathematical models often seen as too complex – black box
Portfolio methods	Supplementary qualitative assessment, graphical representations	Can become too complex and overshoot purpose, or self-fulfilling
Value Road-mapping	Construction of mental model, applicable for early stage, assessment of org. uncertainty	Not directly applicable for portfolio of disparate projects
Expertise / Gut feel	Most commonly used method, especially for technical uncertainty	Often unstructured and so cannot be sustained over time.

Table 1. Pros and Cons of Prevailing Methods

IV. CONCLUSION

This paper describes an exploratory study on the relevance and practical requirements for techniques to support the early stage technology valuation process. Although many techniques exist for technology valuation, during the early stages often decisions are ill-supported. We have seen that in these stages transparency and usability are very important, as the technical, market and organization uncertainty is high. Furthermore we have begun to identify emerging patterns and implications that underpin the often hidden process of early stage technology valuation. Instead of attempting to get a reliable answer immediately, we argue that during the early phases it is important to introduce valuation as a process rather than a result to the organization.

Future research can be directed to collaborative work with companies, developing and testing qualitative techniques such as VRM and the integration of options thinking into existing valuation processes to retain flexibility. Furthermore, attention should be directed towards understanding the impact of the full technology lifecycle including product development, focusing on the reduction of technical, market and organizational uncertainty and taking all relevant stakeholders into account. Finally, more empirical research is required to increase understanding of the important yet poorly documented process of technology valuation.

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