Integrated method for assessing and planning uncertain technology investments

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Abstract: We propose a method for assessment and planning of uncertain technology investments, in the context of corporate venture capital. It addresses three main issues. It is an integrated approach that starts from the technology, and proceeds to exhaustively cover the entire process that precedes valuation; it explicitly supports the identification of synergies between parent corporation and technology venture; it provides an improved treatment of uncertainty, adopting a broader view on the identification of uncertainty and sources of managerial flexibility, and starting to address it sooner, in the opportunity development phase. It is facilitated by a suite of practical tools. We provide a detailed description of the method and demonstrate its application with an illustrative case study.

Keywords: technology; investments; uncertainty; corporate venture capital; project assessment; project planning; flexibility; options thinking; entrepreneurship; engineering management and economics.

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1 Introduction

Companies seeking to grow, or to keep a competitive edge, operate in an increasingly competitive and fast-changing economic environment. Technological advances are one of the major drivers of those changes, challenging established corporations to enhance their efforts in technology innovation.

Companies can use a variety of approaches to pursue innovation, drawing on internal and external sources. Corporate venture capital (CVC) is an approach that tries to build on the synergies between both types of sources. By taking positions in technology ventures, the investor is able to leverage or enhance its competences, secure options to explore new technologies or new opportunities for commercialisation, or develop key partners in its value system.

Selecting technology ventures requires a sound, practical method to help the investor identify and direct its investments to opportunities with great upside potential, while controlling downside losses. We propose such a method, developed with the integration and adaptation of a set of state-of-the-art tools and concepts, from practice and from literature.

The method has four phases:

1 identification of technology based business opportunities

2 development of the components of the opportunities

3 dynamic planning and valuation of the opportunities

4 dynamic business plan preparation.

Its design addresses the following three key concerns:

- It is an integrated process that starts directly from the technology and proceeds through opportunity identification, development, planning and then finally valuation.
- It explicitly supports the identification of synergies between the parent corporation and the technology under assessment.
- It provides an improved treatment of uncertainty, extending its scope from opportunity *valuation* to opportunity *design*, by adopting a broader view on the identification of uncertainties and sources of flexibility, and by starting to address it sooner, in the stage of opportunity development.

The integrated nature of the approach clarifies the relationships between distinct phases of the technology-to-valuation process. This will help the assessment teams better direct their focus to what is knowable and required at each step of the process, and better deal with the feedback and iteration in the process, by providing a way to understand the impact that insights gained in later steps may have on the constructs of earlier steps.

The explicit identification of synergies between the corporation and the technology venture supports systematic creation and evaluation of the strategic linkages, and provides shared focus and vocabulary for R&D and business units.

The improved treatment of uncertainty will allow corporations to better evaluate and develop investments with large upside opportunities, while controlling downside losses.

This method will support assessment teams in developing appropriate appraisals of technology opportunities. This will contribute to the company's ability to be more competitive in its strategic choices regarding technology innovation, and ultimately to its overall ability to sustain growth and competitiveness.

The remainder of the paper is organised as follows: Section 2 presents an overview of related work and contributions; Section 3 consists of a detailed presentation of the method; Section 4 describes an illustrative case of application of the method; Section 5 presents the key conclusions.

2 Related work and contributions

The method that we propose aims at supporting CVC investors in assessing and planning uncertain technology investments. As such, it must address the identification, development, planning and evaluation of the business opportunities that may be created around the technology, as well as the distinctiveness of CVC investments and the high uncertainty intrinsic to these opportunities.

We therefore review related work in this area, identifying requirements for such a method, as well as tools that have been previously proposed to address some of those requirements: we start by looking at research on the specific objectives of CVC investments; next, we review work on concepts and models of opportunities; third, we present sources of structured sets of issues to consider for a detailed development of opportunities; finally, we review concepts and tools to address uncertainty in the development, planning and evaluation of opportunities. The section closes with a summary of the relationship between that work and our main contributions.

2.1 Corporate venture capital

A recent survey (MacMillan et al., 2008) defines CVC as "programs in established firms that make investments in entrepreneurial companies". The report differentiates between *internal* and *external* programs, depending on whether the technology sources are internal or external to the parent corporation.

Chesbrough (2002) classifies CVC investments according to their objective and the strength of operational ties between the parent company and the entrepreneurial company. The objective can be *strategic* – the company tries to take advantage of synergies to grow the profits of its businesses – or *financial* – the company's resources may enable it to outperform VC firms and appropriate value that is not chiefly related to its businesses. The operational ties can be *strong* – resources are shared – or *loose*. Crossing these dimensions provides a framework with four types of investment: driving investments (strategic objective with tight links), appropriate to sustain the company's current strategy; enabling investments (strategic objective with loose links), aiming at growing a company's value system or improving the efficiency of its value chain; emergent investments (financial objective with tight links), to have access to options on new markets or products; passive investments (financial objective with loose links), where the company is just a regular investor.

According to MacMillan et al. (2008), CVCs generally combine strategic and financial objectives and will analyse investments by first examining their strategic value, and then carry out financial evaluation only if the strategic assessment is positive. This requires from the CVC a thorough understanding of technology and business strategies in the parent company and a close communication and interaction with both R&D and business units. The financial evaluation requires a rigorous approach that will greatly benefit the investments. Additionally, a CVC operation that is not financially self-sustainable will find it difficult or impossible to secure support from management in the parent company.

Concerning the strategic dimension of CVC investments, the view of this work is similar to that of Henderson and Leleux (2005), who identify three strategic objectives for CVC:

- leverage or enhance competences through the combination or transfer of resources
- secure options to explore new technologies or new opportunities for commercialisation
- develop implementors and complementors in the company's value system.

2.2 Identifying opportunities

Holmén et al. (2007) review the literature on opportunities and identify a set of limitations that led them to introduce the concept of *innovative opportunities*, consisting of three elements – economic value, mobilisation of resources and appropriability – that are to be present in order for actors to have the possibility of identifying, acting upon and realising the potential inherent in an idea. Perception and uncertainty are two fundamental challenges in the conceptualisation of opportunities emphasised in that work.

Opportunity identification belongs to the first part of the innovation process, called the fuzzy front end (FFE). Contrary to what happens in the following parts, best practices for the FFE are not well known, and as a result, it presents one of the biggest opportunities for improvement in the innovation process. With this motivation, Koen et al. (2002) address the absence of a common terminology and vocabulary for the FFE through the development of a new concept development (NCD) model, which consists of three parts: uncontrollable influencing factors (organisational capabilities, outside world, internal and external enabling sciences), the controllable engine that drives the activities in the FFE (leadership, culture, and business strategy), and the five activity elements of the NCD (opportunity identification, opportunity analysis, idea generation and enrichment, idea selection, and concept definition).

Markham and Kingon (2004) propose the use of the concept of technology-product-market (TPM) linkages as a systematic process for developing new technology product concepts and logic. Central to the logic and technique of turning technical advantages into product advantages is linking unique technical performance capabilities with enduring customer needs. This linkage requires specifying product features based on new technology capabilities and testing them for receptiveness with potential customers. A single technology can be used to create multiple product ideas for multiple markets. This articulation of the basics of the logic of an opportunity as providing a unique solution to a problem is shared by some of the most popular references in the field of technology entrepreneurship: Moore's (1991) *elevator test*, Christensen and Raynor's (2003) *job-to-be-done*, Dorf and Byers's (2005) *new venture concept summary*, or Kawasaki's (2004) *art of positioning*.

For the purposes of CVC – indeed, in general – a larger view of the situation is required. Accordingly, we propose a technology-implementation-commercialisation

(TIC) process that distinctively focuses on implementation and commercialisation. This TIC process builds upon and is indeed structurally similar to the conventional TPM process. However, it recognises the reality that the focus on ‘product’ and ‘market’ often is either inappropriate or too narrow. Indeed, a corporation may ultimately not want to market the results of a technological innovation, but may wish to use it in their business to enhance their competitive advantage. In short, the corporation may ultimately be interested in commercialisation and not ‘markets’. Similarly, the company may want to apply the technology to its processes, and may be interested in implementation and not ‘products’ as commonly understood. For these reasons, our proposed method refers to and uses the TIC perspective.

The TIC linkages framework fits perfectly with NCD activities in the context of technology ventures, and addresses the key issues in conceptualisation of opportunities outlined previously. TIC linkages are informed by the team’s knowledge and perceptions, and address the three elements of innovative opportunities: creation of economic value from the fit between features of the implementation of the technology and real opportunities for commercialisation, mobilisation of technological expertise as the core resource for a technology venture, and uniqueness as a determinant factor for appropriability.

Additionally, the TIC linkages framework also plays a role in addressing uncertainty. The framework satisfies the two requirements for predictable commercialisation identified by Christensen and Raynor (2003): a plausible statement of causality – that providing a unique solution to a problem will enable the creation of economic value and basic conditions for its appropriation – and circumstance-based categorisation – identification of specific commercialisation opportunities is based on the problem that needs to be addressed. Also, the generation of multiple concepts of implementation for multiple commercialisation opportunities creates multiple options for the development of the opportunity. Finally, the TIC linkages can be assessed early in the innovation process, before a commitment to important investments in implementation of the technology.

2.3 Developing opportunities

The most widely used tool to communicate business opportunities is the business plan. Although there is no standard for the structure of a business plan, there is a *de facto* theme for that structure, consisting of an outline of chapters, sections and subsections to be developed. A typical business plan structure therefore offers an organised set of issues to be addressed when developing an opportunity. For representative structures, we suggest Ernst & Young (1997), Sahlman (1997) and Dorf and Byers (2005).

An alternative source of an organised set of issues to consider is the literature on investment criteria used by venture capitalists. Franke et al. (2008) reviewed prior research in this area, but with a restricted focus on the evaluation of the venture team component. Kakati (2003) reviewed this stream of research with a wider focus and compiled a set of 38 criteria, divided in six groups: four groups proposed by MacMillan et al. (1987) – characteristics of entrepreneurs, product characteristics, characteristics of potential uses, and financial considerations – and two groups suggested in more recent studies – resource-based capabilities and competitive strategies.

McGrath and MacMillan (2000) identify a detailed set of issues to address when examining each of a set of factors that influence the value of a technology project: the size and sustainability of potential revenue streams, speed or delay in market adoption, development costs, commercialisation and market access costs, company strengths, likely competitive responses, dependence on standards, and the degree of uncertainty.

McGrath and MacMillan (1995) propose a planning tool – discovery driven planning (DDP) – for new ventures, where relevant past experience does not exist and management will have to make decisions with a high proportion of assumptions relative to knowledge. This requires an appropriate method of planning – planning to learn, in particular to learn how to achieve the venture's objectives, maximising the conversion of assumptions to knowledge at the minimum possible cost. DDP involves:

a the specification of a goal position for the business – what it will have to look like to be successful and justify investment (financial performance, scope of the opportunities of commercialisation, competitive benchmark standards and operations)

b the identification of all assessments that are uncertain – best guesses used when data is not available, goals whose level of achievement is uncertain, etc. – and their characterisation regarding how critical they are, how their uncertainty can be reduced and what the corresponding cost will be

c the creation of a plan for the development of the business that includes checkpoints for the generation, as soon and with as low cost as possible, of information to reduce the uncertainty about the most critical assumptions.

2.4 Addressing uncertainty

Investments in technology are characterised by considerable uncertainty, essentially concerning the degree of success in the development of the technology, the magnitude of commercialisation costs, and the behaviour of demand and competitors (McGrath, 1997).

We address uncertainty without making a distinction between uncertainty and ambiguity, in line with a stream of research on the appropriateness of contingent approaches to uncertain and dynamic environments, as identified by Brun and Saetre (2009) (Eisenhardt and Tabrizi, 1995; Verganti, 1999; MacCormak et al., 2001; MacCormak and Verganti, 2003).

Traditional valuation methods, such as discounted cash-flows, have been shown to evaluate innovative developments inappropriately, as they are unable to account for the value of updated information and flexibility in future decisions (Dixit and Pindyck, 1994). Real options thinking (ROT) is an approach to the valuation of uncertain investments that takes into consideration the value of flexibility in future decisions to enable an increase of the upside profits or a reduction in downside losses. ROT brings a different mindset, a different way of stating problems and a different way of thinking about the future (Faulkner, 1996).

Nichols (1994), McGrath (1996) and Faulkner (1996) are early works suggesting real options approaches for the evaluation of technology projects. Dissel et al. (2005) provide an overview and a comparison of technology valuation approaches (discounted cash-flows, real options, decision trees, portfolio methods, value roadmapping and expert systems) and advocate for interdisciplinary approaches. Steffens and Douglas (2007) also review and compare several valuation approaches (discounted cash-flows, decision trees and real options), and recommend the use of traditional decision analysis, with subjective adjustments for firm specific risk.

Faulkner (1996), Steffens and Douglas (2007) and de Blasio et al. (2007) describe why the assumptions that underlie financial options models do not hold in uncertain technology investments, and propose using decision tree analysis (DTA) as an alternative to real options valuation (ROV). Amram (2005) also favours DTA, due to its ability to provide the essential insights about the investment and improve the communication of results.

Technology investment projects are predominantly treated in the ROT literature as black boxes. This leads to a limited view of the flexibility that is available or can be deployed in the projects. MacMillan et al. (2006) suggest combining DDP and ROV for planning and selecting among alternative investments. The combination partially addresses this issue by proposing an approach to plan the project for learning (as described in Subsection 2.3). However, at each checkpoint, only an option to continue is considered. Schneider et al. (2008) have suggested modelling the flexibility in the project with five types of options – continue, expand, switch, abandon and defer. However, the focus has not yet shifted significantly from opportunity *evaluation* to opportunity *design*. Technology ventures are complex socio-technical systems offering many sources of flexibility, in technology, product, operations or organisation design. This more complete appraisal of the impact of uncertainty and flexibility in technology ventures requires broadening the options perspective to include options 'in' projects (Wang and de Neufville, 2005).

Business plans play a key role in communicating opportunities and also in providing a discipline for a venture team to be specific about what it intends to do and what it hopes to accomplish. As such, they should reflect the critical importance of addressing uncertainty for new technology ventures. Sahlman (1997) argues that the best business plans address four interdependent factors that are critical to new ventures – people, opportunity, context and risk and reward – and discuss the venture as a moving target, confronted with the critical risks ahead – both downside and upside. The logical implication is that business plans should be *dynamic*, proactively incorporating the key uncertainties and the associated decisions on how best to proceed given each outcome, dynamically adapting the venture's development path.

However, references in this area typically pay little attention to uncertainty [Ernst & Young (1997) is an example] or focus mostly on downsides [as in Dorf and Byers (2005)]. Another common approach to dealing with uncertainty consists of performing a sensitivity analysis on the financial projections. With this approach, the effect of uncertainty is only considered after the business plan has been developed, and the plan itself does not consider alternative decision paths making use of updated information and managerial flexibility.

2.5 Contributions

Our first main contribution is related to the identification of technology based opportunities to a CVC context. The framework that we propose in Subsection 3.2 provides a more operational conceptualisation of the synergies between the parent corporation and the technology venture. From the standpoint of opportunity modelling, it extends previous frameworks to allow an explicit modelling of those synergies.

A second contribution is the integrated nature of the method. Literature and practice suggests several methods to address partial issues in assessing and planning uncertain technology investments. We adapt, build on, and bring together several concepts and tools from those methods, in order to provide an integrated method that covers the whole process from technology to valuation, including opportunity identification, development and planning.

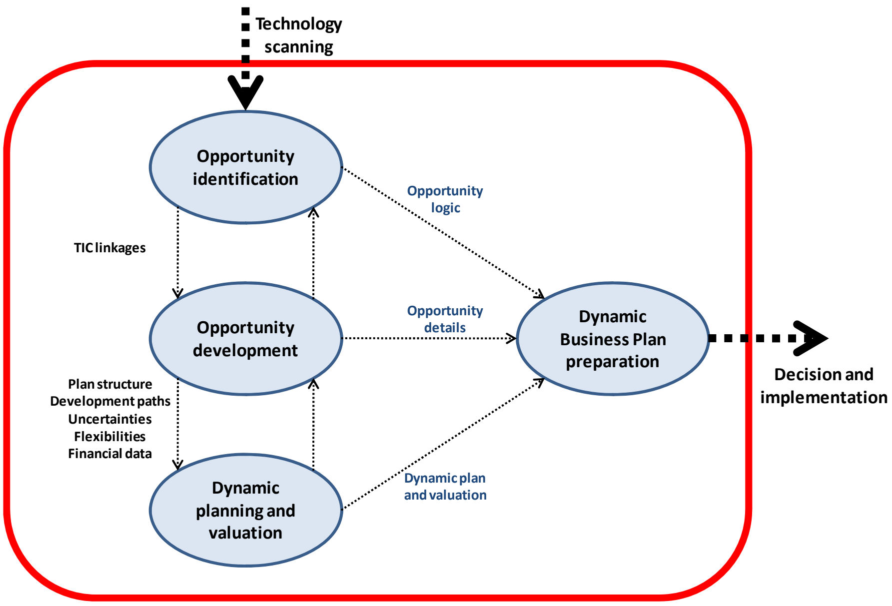
A final main contribution is an improved treatment of uncertainty. We propose a widening of the scope of previously proposed assessment methods, from valuation of opportunities to design of opportunities. This supports an improved search for value, through a broader identification of uncertainties and sources of flexibility, and their earlier consideration, starting from the stage of opportunity development.

3 The method

3.1 Overall description

The process of moving from a technology to the assessment of business opportunities presents a set of different challenges that require different approaches. We have identified four top-level challenges in this process, underlying its division in four phases (Figure 1):

Figure 1 Assessment method (see online version for colours)



1 Identification of technology based business opportunities

For this phase we have adopted the TIC linkage framework that builds upon the TPM concepts articulated by Markham and Kingon (2004). This framework links technical capabilities with customer needs through concepts of implementation, articulating the basic logic for a particular implementation and hence an opportunity, and is usually applied to create multiple concepts of implementation targeted at multiple forms of commercialisation, from a single technology. We propose an adaptation of the TIC linkage framework to identify synergies on which the parent corporation's business can build to grow its profits, since CVC investments usually have a combination of financial and strategic objectives (MacMillan et al., 2008; Chesbrough, 2002). During this phase:

1.1 The team performing the assessment will first specify current and potential, complete and partial, TIC linkages for each company on its own.

1.2 It will then look at combinations of these linkages to identify new or improved technologies or implementations, and develop the corresponding TIC linkages, as well as to identify opportunities for commercialisation and interactions between them (for example, affecting demand or adoption rate).

2 Development of the components of the opportunities

The TIC linkages of the evaluated company and the new TIC linkages articulate a set of business opportunities that must subsequently be developed with more detail. For this purpose we have created a tool that incorporates key ideas of DDP (McGrath and MacMillan, 1995) and the method for assessing uncertain projects through the scoring of a series of statements proposed by McGrath and MacMillan (2000). This tool lists important issues identified in the literature, grouped according to the typical structure of a business plan, for which the evaluation team must:

2.1 Assess the current and goal positions, and development paths between them.

2.2 Recognise uncertainties, express them as assumptions, and identify alternatives to address them.

2.3 Point out dependencies between issues.

This tool has an immediate use as a guide for the assessment team to go through the effort of gathering information, within their time and resource constraints, to convert as many assumptions to knowledge as possible, thus improving the assessment.

3 Dynamic planning and valuation of the opportunities

A plan for the exploitation of an opportunity specifies the work that will be carried out, the milestones and results that will be achieved, when they will be achieved, and the resources that will be required.

3.1 At the end of development, the team will have identified a structure for the technology-to-commercialisation plan, as well as development paths in specific issues, for the opportunities under scrutiny. The team will use this information to build a specific structure for the plan. In the previous phase the team will also have identified a set of critical uncertainties, and associated flexibilities, that should now be inserted in the structure of the plan, which as a result will take the shape of a decision tree (Faulkner, 1996).

3.2 The financial assessment should then be developed on top of this decision tree, and an analysis method can be used to determine the optimal decision paths in the tree, according to the critical uncertainties that will be resolved with the progress on the plan, thus generating a *dynamic plan*.

4 Dynamic business plan preparation

We propose a business plan-like report as the final deliverable of the evaluation process, since business plans are effective tools for the characterisation and communication of business opportunities. Because there is no single optimal plan, but a set of multiple optimal paths dependent on the ways in which uncertainty is resolved, we suggest that this business plan be a *dynamic business plan*, in which the identification of critical uncertainties and relevant flexibilities, both *on* and *in* the project, is brought to the forefront of the analysis.

This method is facilitated by a suite of tools, briefly presented in Table 1, and described in further detail in the following subsections.

Table 1 Suite of tools

Stage	*Tool*	*Description*
Opportunity identification	TIC linkage	Basic logic for a particular implementation and opportunity, linking technical capabilities with customer needs through concepts of implementation.
	TIC linkage combination	Combining components of TIC linkages and subsequently developing new complete linkages to identify and articulate opportunities aligned with strategic objectives for CVC investment.
Opportunity development	Opportunity development tables	For relevant issues, a specification of the project's current and goal positions, development path, uncertainties and alternatives to reduce them.
Dynamic planning and valuation	Decision analysis	A decision tree models the project's plan structure, and the set of identified critical uncertainties and flexibilities. With a financial assessment on top of this tree, and an analysis method to determine optimal decision paths, a dynamic plan is generated.
Dynamic business plan preparation	Dynamic business plan	A dynamic business plan, in which the management of uncertainty and flexibility is brought to the forefront of the analysis, effectively characterises and communicates the business opportunity.

3.2 Opportunity identification

The assessment of CVC investment proposals will usually address primarily criteria of strategic fit. This requires knowledge of the technology and business directions in the parent company and the technology venture (MacMillan et al., 2008). The possible combinations of technology and business components from both sources must therefore be examined for the identification of business opportunities that may be created from those combinations.

3.2.1 Describing individual TIC linkages

We conceptualise the fundamental building block of high-tech business opportunities as TIC linkages (Figure 2) (Markham and Kingon, 2004).

The TIC linkages are created in a three step process:

1 Find technical advantages. The assessment team will start by identifying sources of technical advantage – higher performance, lower cost, or new, needed capabilities – that present significant improvements over alternative technologies, and uniqueness (difficulty to duplicate). The technical advantage is initially characterised in terms of *specifications* (measurable performance parameters) and then translated to

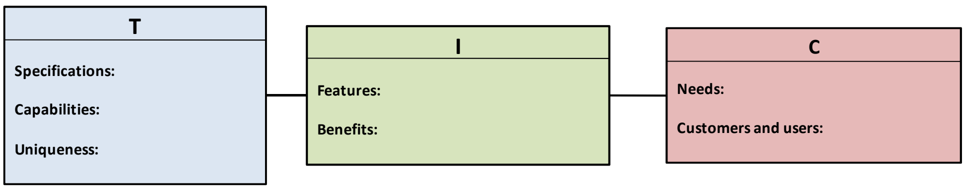
capabilities (what the specifications enable a specific implementation of the technology to do).

2 Identify opportunities for commercialisation. The team must then detect *needs* that the technical capabilities may address. This will provide the initial knowledge of the opportunities that is required to articulate an implementation and opportunity concept, in a way that offers plausible causality. Accordingly, these opportunities will not be the users, but the *circumstances* in which the users experience a *problem* (Christensen and Raynor, 2003).

3 Create the concept of implementation. This should align the technical capabilities with the opportunities: the technical capabilities enable *features*, which in turn will enable *benefits* to the customers by providing *solutions* for their problems.

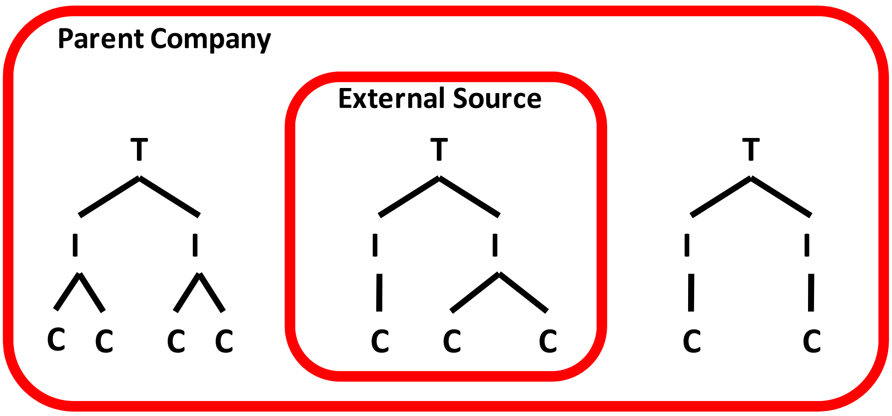
Because a single technology can be used to create many possible implementations for many forms of commercialisation, TIC linkages will usually be presented in the form of a tree.

Figure 2 TIC linkage (see online version for colours)



TIC linkages can be used to describe both the external source and the parent company's currently explored and potential opportunities (Figure 3 presents a situation with two technology sources in the parent company, and one external source).

Figure 3 Individual TIC linkages (see online version for colours)



3.2.2 Combining technologies, implementation and commercialisation

Combining components of these linkages and subsequently developing new complete linkages provides a way to identify and articulate opportunities aligned with the previously outlined strategic objectives, by making use of the parent company's specific knowledge and capabilities.

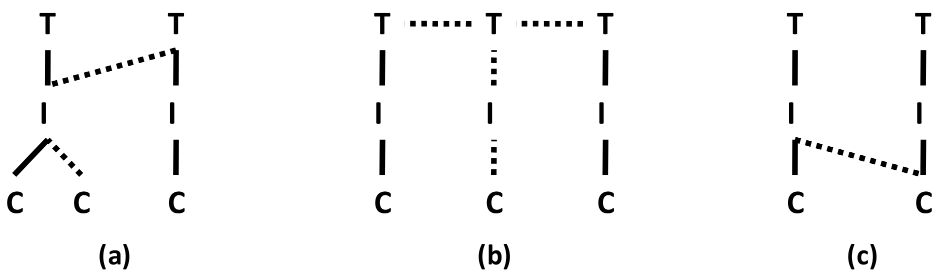
The following is a list of examples of combinations, one for each of the three strategic objectives of CVC:

1 Leverage or upgrade existing competences through resource combinations and transfers – combining an external technology and a current use to provide an implementation with an enhanced customer value proposition that may enable addressing a new segment (Figure 4a).

2 Reserve the right to operate in new technologies and forms of use – exploring new opportunities for commercialisation from a new technical capability arising from the combination of technologies (Figure 4b).

3 Develop a business value system of third-party implementers and complementors – providing a new implementation to a common need (current or new), driving up the demand of an existing implementation (Figure 4c).

Figure 4 Combinations of TIC linkages



The meaning of the combinations arises in each specific case from the integration of the TIC linkages logic with the strategic linkage logic. Although grasping the full meaning of the combinations may require some elaboration, the basic construct arising from that integration will always provide at least a logic template to be filled from the assessment team's expert knowledge.

We have looked at a representative set of cases for each of these objectives and experimented with modelling the synergies with combinations of TIC linkages. In this exercise, we came across four types of combinations: T-T (creating a new technology), T-I (enhancing an implementation), I-I (enhancing or creating a new implementation) and I-C (linking a new implementation with an existing commercialisation opportunity).

3.3 Opportunity development

Each TIC linkage of the evaluated company or new TIC linkage is a building block for an implementation and business concept that must now be developed in more detail.

The tool created to facilitate this work lists a number of strategic issues that must not be overlooked, identified in relevant literature (MacMillan et al., 1987; McGrath and MacMillan, 2000; Kakati, 2003; Van Mieghem, 2008), and grouped according to areas that are usually considered in a business plan (Table 2).

Table 2 Classes of issues for opportunity development

Technology	Operations
Implementation	Sales and marketing
Commercialisation opportunity	Team and management
Regulation and competition	Funding and financials

The design of the tool is also based on the key principles of the DDP method (McGrath and MacMillan, 1995): specification of business goals, characterisation of uncertainties, and planning to reduce uncertainties.

3.3.1 Initial analysis

For each issue, the team must specify:

1 The current position of the project – How does the project currently look?

2 The goal position for the project – How does the project have to look to deserve funding?

3 The development path for the project – How can the project be developed from its current position to the goal position?

For each of the previous points, the team should then:

1 Identify uncertainties in the assessment, i.e., assumptions, and express them as probability distributions of outcomes.

2 Determine how critical the reduction of the identified uncertainties is.

3 Identify alternatives to reduce the uncertainties and the corresponding cost.

4 Verify whether the uncertainties depend on other issues in the project.

Figure 5 shows the structure of the tables that support this analysis.

Figure 5 Structure of the opportunity development tool

Issue	Assessment		Uncertainty	Addressing Uncertainty			
				How	Value	Cost	Dependencies
	Current						
	Goal						
	Develop						
	Current						
	Goal						
	Develop						

3.3.2 Analysis development

Once the initial analysis is complete, the team should:

1 Address the uncertainties that can be reduced within the time and resources available for the assessment. Most of this will be achieved with information gathering from researchers, industry experts, potential customers, suppliers, or partners, and other relevant information sources.

2 Address the remaining uncertainties. Some may be actively reduced with learning activities outside the time and resource constraints of the assessment, while others will be too costly or impossible to reduce, and will just naturally disappear with time and the evolution of the project. The team must identify inherent flexibility or appropriate flexibility investments to address these types of uncertainties.

The information regarding value, cost and dependencies of addressing uncertainties will be useful to prioritise these efforts.

As soon as information gathering is completed, the team will be faced with a set of certain and uncertain assessments about the current and the goal positions for the project, and the development path between both positions. The global assessment of the opportunity will be related to the ability of the project to successfully execute an overall dynamic plan to go from its current position to the desired position. If at any point, there is no such plan that is feasible or if the expected result of the best plan is a loss, the project should be cancelled.

3.4 Dynamic planning and valuation

Addressing uncertainty requires considering alternative potential development routes and building the appropriate capabilities to enable managerial flexibility to pursue upside routes and limit losses in downside routes.

At the end of development, the team will have identified a structure for the technology-to-commercialisation plan, as well as development paths in specific issues, for the opportunities under scrutiny. The opportunity plan is the tool that brings together the critical uncertainties, flexibility investment alternatives, and flexibility enabled responses to uncertainty. This *dynamic plan* should be the core of a business plan. It will be different from a *static plan* conceived to perform well in the 'most likely' scenario (lower/higher initial costs, or lower/higher maximal/minimal performance), but it will be better suited to the certainty of uncertain conditions, by being able to perform well in more than one 'most likely' scenario.

3.4.1 Decision tree construction

The decision tree construction process can be thought of as an iterative process that successively incorporates the most important uncertainty nodes and associated decisions. The tree rapidly expands with the number of uncertainties and decisions that are incorporated, and its analysis and interpretation become increasingly difficult. Hence, for practical purposes, parsimony is advisable, especially in the case where decision trees are used to guide general management decisions.

To develop the decision tree, the assessment team should:

1 Build the sequence of stages for the venture. Architecting such a sequence requires careful and logical consideration: the limits of the stages should include the times when managers are expected to make decisions on how to continue activities. An example of such a sequence is: research and development, prototype development, implementation of the technology and beginning of commercialisation.

2 Incorporate investments in flexibility. Considering each investment at a time, the alternatives (including no investment) should be introduced as decision nodes, at the relevant point in the sequence. This turns a linkage between two stages into a decision node with different activity paths.

3 Incorporate uncertainties. The critical uncertainties identified in opportunity development should be introduced one at a time. In this case, a linkage between two stages becomes an uncertainty node with several different outcomes (usually a discrete set, although a continuous set can be defined).

4 Incorporate managerial flexibility. In order to consider the use of flexibility, decision nodes are placed after the corresponding uncertainty node. The decision node should reflect a decision management can make that will minimise the loss in performance associated with unfavourable outcomes, and improve performance by taking advantage of situations where the outcome is favourable.

3.4.2 Planning and valuation

Once the entire decision tree is completed, the assessment team will:

1 Develop standard financial analysis for each unique project path in the decision tree. This is a process that is greatly simplified and automated with the current level of integration between DTA and spreadsheet software, provided by packages such as TreeAge or Crystal Ball.

2 Use its favoured financial performance criteria to guide choices at the decision nodes. Completing the set of choices in the decision tree creates a *dynamic plan* for the venture, which reflects management's ability to dynamically pursue alternative paths, reacting to new information as it becomes available.

   A dynamic plan is composed of a set of alternative sequences of conditional uncertainties and decisions, and is therefore characterised by a probability distribution of financial outcomes. In general, the team should at this stage choose the set of decisions that yield a preferred probability distribution.

   As an example, if the team is focusing on optimising the expected NPV, DTA can be used to determine the optimal decisions at each decision node and, as a result, the optimal paths to pursue. For this situation, DTA will require analysing the tree from leaves to root, computing expected NPVs at each uncertainty node, and choosing the option with the highest expected NPV at each decision node.

3 Perform *what-if* or sensitivity analysis, using the decision tree as a platform to investigate the impact of alternative decisions, or the robustness of the decisions to assumptions in the team's assessments.

3.5 Dynamic business plan preparation

The results of the previous phases should now be combined in an assessment report that will support a decision on the investment and an eventual move towards its implementation. We propose a business plan format for this report, with the content originating from the following inputs:

1 An opportunity section can be built from the core logic described by the TIC linkages.

2 For the sections on specific areas, the information gathered in the opportunity development phase, already grouped accordingly, will enable an appropriate characterisation of where the venture currently stands, where it wants to be, the path to get there, and uncertainties and alternatives to address them.

3 A dynamic plan for the venture is available from the planning phase, with an overview of the most important investments in flexibility, the key uncertainties and the corresponding flexibility enabled decisions.

4 The financial performance indicators can be presented with the dynamic plan, and the underlying standard financial projections included as appendix.

4 Case example

This section demonstrates the application of the method with a fictitious illustrative case of an energy company considering an investment in the development of a new highly efficient concentrated solar power (CSP) design.

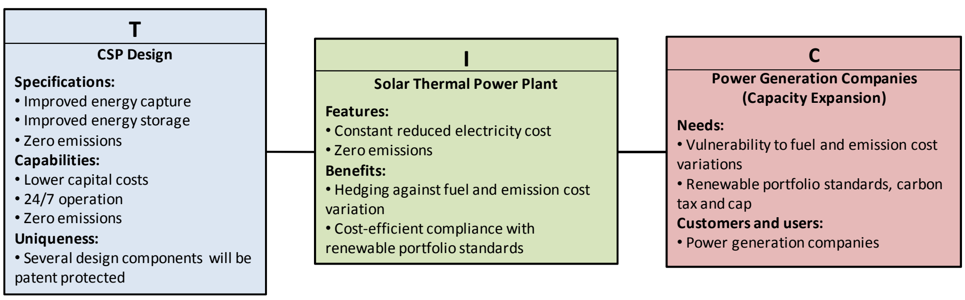
4.1 Opportunity identification

Vulnerability to fuel and emission cost variations and compulsory renewable portfolio standards are critical concerns for electricity supply companies. Integrating highly efficient CSP plants in a power generation portfolio would enable these companies to hedge against cost variations and to comply with renewable portfolio standards in a cost-efficient way.

A proposal for such a new CSP design is under consideration here. If successful, it would reduce the cost of electricity by 40%, relative to current CSP designs. With the current costs at 16 USc/kWh (GEF, 2005), this design could bring the cost down to less than 10 USc/kWh, a cost range where it becomes competitive with natural gas power plants.

Figure 6 shows the TIC linkage for this business opportunity associated with the new technology.

Figure 6 TIC linkage for the technology under consideration (see online version for colours)



The energy company has a business unit with world-class expertise and experience in designing and constructing complete turnkey combined cycle power plants. These are provided to power generation companies, which face two important challenges: market liberalisation requires them to be more cost-competitive, and increased social awareness of environmental impacts raises blocking risk when those impacts are unacceptable. Natural gas combined cycle (NGCC) power plants have both lower costs and higher social acceptability than power plants using other fossil fuels (Fontini and Paloscia, 2007).

The TIC linkage for this business opportunity in the parent corporation is displayed in Figure 7.

Figure 7 TIC linkage for parent corporation (see online version for colours)

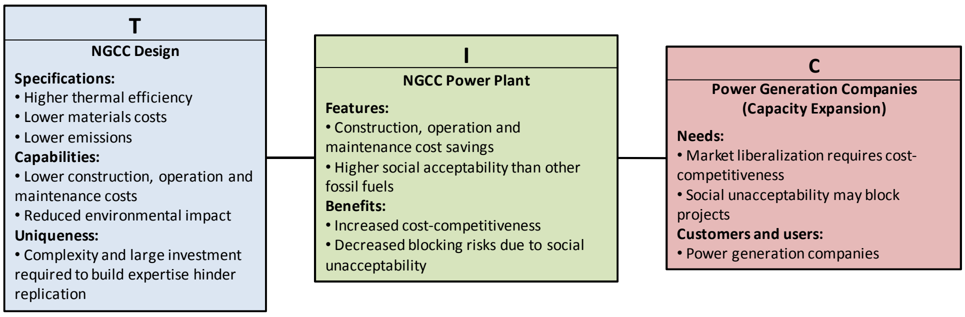
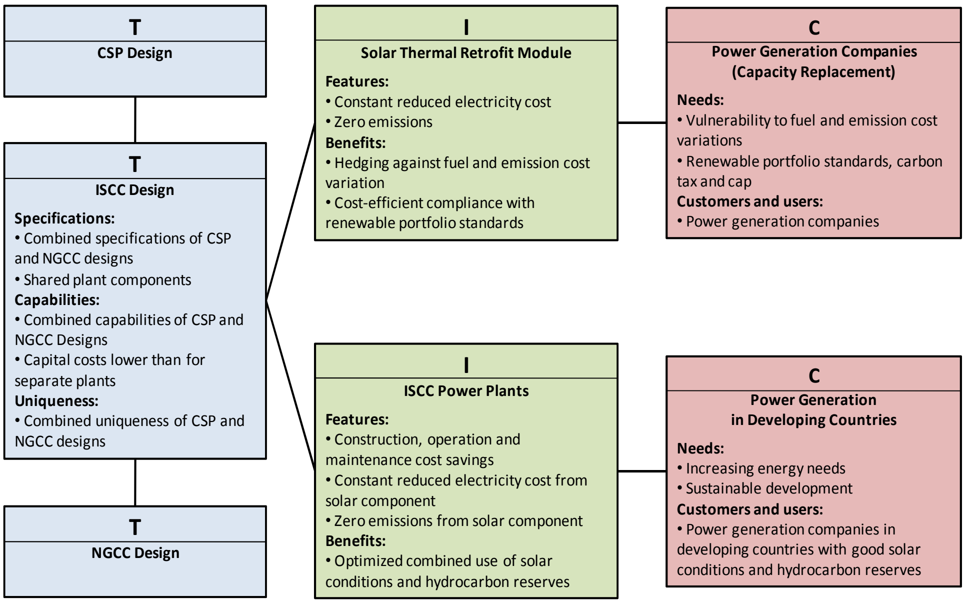


Figure 8 Combinations of TIC linkages (see online version for colours)



The combination of the CSP and NGCC designs results in a new integrated solar combined cycle (ISCC) design, with the technical advantages of the original designs and an additional advantage of reduced capital costs relative to separate plants, due to shared plant components.

Based on this design, solar thermal retrofit modules can be provided for integration with existing fossil fuel plants, in areas with available land and good insolation. These modules can be supplied for the same customers identified for the solar thermal power plant, to replace fossil fuel capacity with solar thermal capacity.

ISCC power plants can also naturally be provided. Their features match the needs of power generation companies in developing countries with favourable solar conditions and rich hydrocarbon reserves, which require a sustainable development of their electricity supply to meet increasing demand.

Figure 8 presents the combination of the two technologies and the TIC linkages developed from the resulting technology.

4.2 Opportunity development

As an example, let us consider the development of the ISCC design and a specific issue in the technology area – stage of technology development (Table 3):

- For the current position:
  - A research project for the creation of a new design has been proposed. Preliminary computational models have been developed to confirm the possibility of achieving the levels of performance of the proposed design.
  - The assessment team has complete knowledge about the current stage of development of the technology.
- For the goal position:
  - The research phase of the project will be completed with a proof of concept unit. This proof of concept unit will have to prove that the design is able to provide electricity with a cost at least 40% lower than current designs.
  - The assessment team has complete knowledge about the goal position on this issue of the technology development.
- For the development path:
  - In the first phase of research, each of the design's components will be developed separately. The second phase will address the integration of these components. In the third phase, a proof of concept system will be created and tested.
  - With current information on the project, the team's assumption is that the total duration of R&D can take between two and six years. The best research team available to work on this project has already been assembled and it is not likely that its expansion will result in an ability to shorten the duration of the project.
  - The team will try to improve its assessment of this issue by gathering data from industry analysts and looking at previous R&D projects. This is an important issue to get more data on, requiring an effort well within the capacity of the assessment team, and without dependencies on other issues.

Table 3 Initial analysis of stage of technology development

Issue		*Assessment*	*Uncertainty*	*Addressing uncertainty*			
				How	*Value*	*Cost*	*Dependencies*
Stage of technology development	Current	A research project for the creation of a new design has been proposed. Preliminary computational models have been developed to confirm the possibility of achieving the levels of performance of the proposed design.	None				
	Goal	The research phase of the project will be completed with a proof of concept unit. This proof of concept unit will have to prove that the design is able to provide electricity with a cost at least 40% lower than current designs.	None				
	Develop	In the first phase of research, each of the design's components will be developed separately. The second phase will address the integration of these components. In the third phase, a proof of concept system will be created and tested.	The total duration of R&D can take between two and six years.	The estimates of total duration can be improved by gathering data from industry analysts and looking at previous R&D projects.	High	Low	None

Table 4 Final analysis of stage of technology development

Issue		*Assessment*	*Uncertainty*	*Addressing uncertainty*			
				How	*Value*	*Cost*	*Dependencies*
Stage of technology development	Develop	In the first phase of research, each of the design's components will be developed separately. The second phase will address the integration of these components. In the third phase, a proof of concept system will be created and tested.	The total duration of R&D can take between three and five years: • 0.4 3 years; • 0.2 4 years; • 0.2 5 years; • 0.2 failure.	Project review point at year 3: • if unlikely to succeed, cancel. • if complete, continue. • if extra funding required – continue or abandon, depending on effort to completion.	High	Low	None

The opportunity development analysis has identified the need to gather information on the duration of the project. The team accordingly engaged in contacts with industry analysts and gathered historic data from comparable R&D projects and reviewed their analysis of the development path (Table 4):

- The team's assumption is now that the complete duration of this phase can take between three to five years.
- To deal with this uncertainty, only the first three years of the project will be initially funded, and a review point will be created at the end of year 3:
  - If the project is found to be unlikely to succeed, it will be cancelled.
  - If it is complete, it will proceed.
  - If it is found likely to succeed but requires more funding, the investors have the option to continue or abandon, according to the reviewed effort to completion and the impact of a delayed entry into commercialisation.

As a second example, we may consider the team's current assessment that developing countries provide the most promising opportunities for commercialisation (Table 5). There is however great uncertainty about this assessment, mostly related to uncertainty in macro-economic and regulatory conditions. To address this uncertainty, the team may consider two options for the scope of the initial R&D phase:

- Developing a modular ISCC design, consisting of a solar thermal retrofit module with a very flexible interface, enabling a combination as efficient as possible with a wide variety of legacy or new fossil fuel power plants, including NGCC plants. This design would be more appropriate for the replacement of capacity, but it could also be taken to developing countries, by fitting NGCC power plants with solar thermal modules, although at the cost of a reduction in the efficiency of the overall system. This reduced efficiency would likely reduce the potential for commercialisation, but would allow the venture to begin commercialisation earlier and reap the benefits of learning curve and economies of scale effects. The investment in the design of a more efficient ISCC design could be carried out gradually as part of specific ISCC power plant projects.
- Developing an integrated ISCC design, with both solar thermal and natural gas parts specifically designed to optimise the efficiency of the overall power plant. This design would be more appropriate for developing countries. For the capacity replacement, some additional development work would be required to release a retrofit module capable of addressing it. This would delay commercialisation, with the consequent negative impact on revenues.

A dependency arises between this issue and the previous one, due to the fact that both contribute to the magnitude of time to commercialisation.

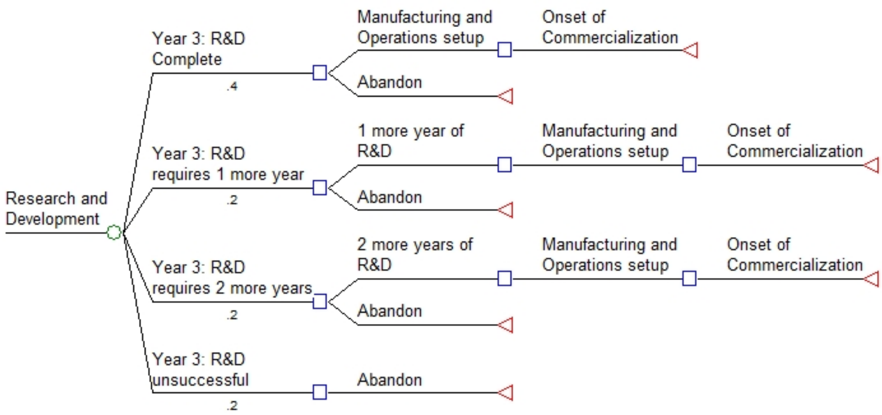
Table 5 Final analysis of initial opportunity

Issue		*Assessment*	*Uncertainty*	*Addressing uncertainty*			
				How	*Value*	*Cost*	*Dependencies*
Initial opportunity	Current	Developing countries appears to be the most attractive opportunity.	• 0.25 the opportunities are equally attractive; • 0.25 capacity replacement is more attractive; • 0.50 developing countries is more attractive.	Choose between modular and integrated design, depending on the tradeoff between benefits from being an earlier mover or presenting a higher technical advantage.	High	High	Length of technology development has critical impact on time to commercialisation.
	Goal	Enter the most promising of the two opportunities at the end of R&D and demonstration.	None				
	Develop	To be specified at the planning phase.					

4.3 Dynamic planning and valuation

An overall simplified sequence of stages for this opportunity is the following: research and development, manufacturing and operations setup, and onset of commercialisation. Considering the first critical uncertainty, on the success, time and funding required for the R&D phase, the previous sequence branches on a first uncertainty node. With a review point introduced in year 3, the management has now the flexibility to continue or abandon the project for each of the possible outcomes (Figure 9).

Figure 9 Decision tree after inclusion of R&D uncertainty and flexibility (see online version for colours)



The second critical uncertainty is related to the initial commercialisation. The options available to face this uncertainty depend on the scope of the R&D stage. As an example, if a decision is made to focus on the integrated design, the choices will be the following (Figure 10):

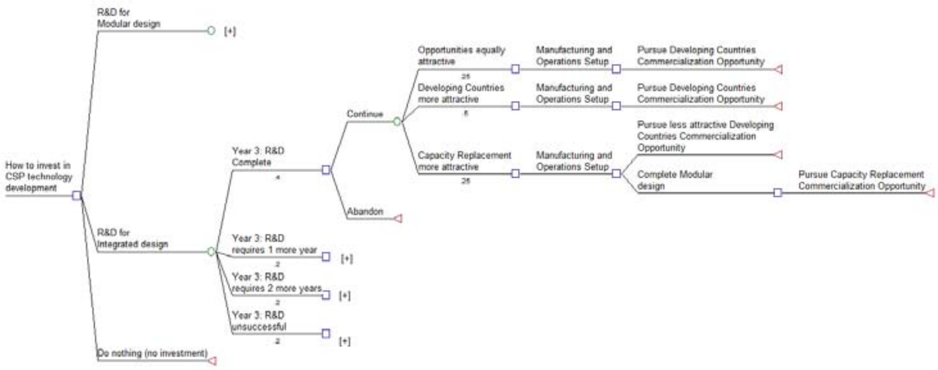
- If both opportunities are equally attractive, the developing countries market is selected. The same happens if this turns out to be the most attractive market.
- If the capacity expansion opportunity is the most attractive, it is possible to start with the less attractive opportunity anyway, or to work on the design of a retrofit module and work on capacity replacement opportunities when it is complete.

In the most likely scenario, R&D is completed in three years and the initial opportunities are in developing countries. When planning for this scenario, the team would decide to focus R&D on the integrated design, and if thinking of responses to uncertainties, it might contemplate reactions to delays in the R&D phase, and the work on the retrofit module in case the capacity replacement opportunities turned out to be more attractive.

Working with the complete decision tree, the option to focus R&D on the modular design turns out to be more attractive. This is mainly due to a set of effects that planning for a most likely scenario is unable to capture: the expected benefits of being able to take advantage of any opportunities immediately with the modular design outweigh the loss of possibilities resulting from the performance differential in the developing countries;

additionally, the R&D phase delays on the time to commercialisation intensify the benefits of being able to go begin commercialisation immediately with the modular design.

Figure 10 Decision tree after inclusion of critical uncertainties and flexibility (see online version for colours)



5 Conclusions

This paper proposes and describes an innovative, integrated method for evaluating and developing technologically based start-ups. It extends previous practice in three ways:

- It is oriented to corporate investors, who may be primarily interested in using new technology to maintain strategic advantages. In contrast to venture capitalists, corporate investors are mainly concerned with developing technological synergies rather than rapid profits by selling all or part of the start-up. The process thus calls for special efforts to define any synergies that a new technology may contribute to the corporate sponsor.
- It focuses on a TIC chain, which recognises that corporate investors may not be concerned with a ‘product’ in the conventional sense of something that can be sold, but may implement the new technology as part of their production process. Similarly, corporate investors may never bring their developments to ‘market’ but may commercialise the technology by improving their operations. In short, we broaden the ‘product’ and ‘market’ concepts used in the literature to those of ‘implementation’ and ‘commercialisation’.
- It leads to the preparation of a ‘dynamic business plan’ that explicitly embodies a strategy of how the investors will develop, modify or close their start-ups according to how technological and competitive circumstances evolve. This approach contrasts with traditional business plans that focus on some most likely scenario, and do not consider how a wider view of the possibilities would impel a more flexible development of the start-up, one that is more likely to take full advantage of its possibilities.

The proposed innovative process is supported by a suite of tools that enable its implementation in practice.

This approach has been developed with the adaptation and integration of a set of state-of-the-art tools and concepts, from practice and from literature, for which no significant limitations to technical or business domain of application are known, so we believe that its applicability is generalised.

Although individual components of the approach have been extensive and thoroughly applied in practice, the full approach has so far been applied only to the example presented in this paper, and to a more elaborate case in Mikati (2009). We expect that a systematic, comprehensive and professional application of the approach will help us fine tune it and possibly uncover further aspects that may be systematised with extensions to the current platform. One of the areas where we expect to be able to improve the approach is the use of the pool of knowledge created in opportunity development in the dynamic planning and valuation step.

A future research line worthy of attention is the separate identification and articulation of ambiguity, uncertainty and complexity challenges, and the adaptation or incorporation of new tools and conceptual frameworks to improve the way in which these challenges are addressed individually and as a whole.

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