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Development of a two-dimensional scale for evaluating technologies in high-tech companies: An empirical examination

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ABSTRACT

Based on a sample of 463 technology evaluations, this paper demonstrates empirically the conceptual split between "technological attractiveness" – which is outside of the control of the company and "technological competitiveness" – which is within the company's control. The 16 "technological attractiveness" criteria produced by the literature review gave a set of six different factors (62.5% of variance) depicting potential value. The 16 "technological competitiveness" criteria derived of the literature review were summarized with only four questions (58% of variance) depicting accumulated value. As such, this research shows that managers assess technologies on the basis of a limited set of criteria. These results have practical implications as they enable us to target technology audits to a more workable set of questions at the operational level.

Introduction

The R&D manager's job encompasses several issues. It is about finding the optimal balance of research versus development (and fundamental versus applied research), choosing between internal development and external acquisition, carrying out tasks autonomously versus cooperatively, communicating recommendations for action both vertically and horizontally within the organization, deciding which technologies should be commercialized, etc. (Badawy, 2010; Burgelman et al., 2008; Tidd and Bessant, 2009). But it also involves a business component. R&D managers face a collection of

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investment opportunities into different technology development projects. However, they cannot pursue all these projects. As R&D projects are a core element of corporate renewal, sustainability and competitiveness, the most sensitive issue where R&D decision makers exert their power are Go/Kill decisions (Shehabuddeen et al., 2006).

In the process of allocating resources (capital, people, physical facilities, equipment, etc.) across an array of significantly different technology programs, there is internal competition for limited resources (Badawy, 2007). A non-formalized approach to portfolio management puts the decision maker under strong pressures from various interest groups. It exacerbates bias due to personality as well as individual and emotional preferences. In order to formalize and systematize the evaluation process, models were designed in the past to help Chief Technology Officers (CTOs) tackle this major task. Seminal approaches to technology portfolio modeling should be attributed to A.D.L. (1981), Foster (1981) or Harris et al. (1981). Foster (1981) suggests drawing an R&D matrix combining 'prospects for increased productivity' and 'prospects for increased yield'. Harris et al. (1981) recommend building the technology portfolio by relying on 'technology importance' for competitive advantage and 'relative technology position' in comparison to competitors. The usefulness of these models is no longer questioned since research conducted by Cooper et al. (2000) shows that businesses implementing a systematic process for managing their project portfolios clearly outperform other businesses.

Many articles on technology portfolios have been published since the early 1980s and more recently (Chien, 2002; Say et al., 2003; Bitman and Sharif, 2008; Wang et al., 2008; Kester et al., 2009; Chiesa et al., 2009; Van Wyk, 2010). But, very little attention was paid to the set of indicators that practitioners should use for conducting their evaluation (Badawy, 1995). The objective of this paper is to fill this existing gap. The first section reviews existing models for technology assessment – weaknesses regarding the set of criteria used and associated measurements are emphasized. The second section suggests that criteria can be split into two distinct sets: controllable and non-controllable factors. Still in the second section, a set of 2×16 indicators is developed and propositions are made about the way these criteria can be categorized. Section three explains how propositions were tested with some 463 technology assessments collected in a sample of 50 high-tech companies. The fourth section is devoted to the presentation of research results and fifth section to discussion. The conclusion and research implications are presented in sixth section.

Literature review and theoretical background

Feeding the decision process

The starting point is to assess the existing situation. The R&D strategic decisions previously mentioned are fed by two kinds of inputs: evaluating alternative projects and identifying independencies and interrelationships among projects (Badawy, 1995). Different evaluation methods have been developed. Heidenberger and Stummer (1999) and Henriksen and Traynor (1999) have identified different approaches: financial cost-benefit measurement, scoring, mathematical programming, decision and game theory, simulation, artificial intelligence, heuristics, and cognitive methods. Mathematical programming, for example, solves the optimization problem thanks to a program operated with different constraints imposed on the model. Because of the level of complexity of particular techniques such as mathematical programming, managers might be discouraged from using them (Henriksen and Traynor, 1999). Poh et al. (2001) have compared different methods (based on weightings and ranking or on benefit-contribution) with an analytic hierarchy process (AHP); they have shown that the scoring method (i.e. a technique used for R&D project selection since the 1960s!) is the most favorable method for R&D project evaluation.

Evaluation of alternative projects is not enough. Several authors have stressed that most conventional models evaluate individual projects in isolation: they focus on individual opportunities. They do not capture interdependencies when projects are highly joined (i.e. where the success of A depends on the success of B) and interrelationships between projects such as mutual exclusion or overlap in resources utilization allowing some positive synergies (Stummer and Heidenberger, 2003; Tohumcu and Karasakal, 2010). Ouellet and Martel (1995) have proposed to measure synergies between projects at three levels: use of resources, technology and payoffs. Dickinson et al. (2001) have suggested drawing a (square) dependency matrix to capture interdependencies between projects.

Shortcomings of existing evaluation models

Limited use of existing models might be explained by the drawbacks of these methods. Though much has been written on evaluation models, several shortcomings have to be mentioned. The main criticism is that very little work has been done on criteria and measurement to be used for technology evaluation.

Many models are derived from financial analysis. They use financial metrics, such as discounted cash flows (DCF), internal rate of return (IRR), net present value (NPV), return on investment (ROI) or pay-back period (see e.g. Spradlin and Kutoloski, 1999 or Kirchhoff et al., 2001). More sophisticated versions incorporate probabilities and uncertainties into the financial calculation (Blau et al., 2004). The objective is to maximize the potential return per unit of risk (Carter and Edwards, 2001). The immediate limit of these approaches is that, by focusing on financial and/or economic returns, these metrics fail to deal with non-monetary criteria. Another serious weakness relates to the input used. Fixed costs, initial investment and variable costs can usually be approximated properly. But, estimating potential future cash (in-) flows over a very long planning horizon as well as probabilities to compute expected NPV might be speculative and oversimplified. A survey conducted by Cooper et al. (2000) highlighted a need for better information to feed the process of portfolio management. Despite financial measurements appear to be very clear-cut and elegant, the data they use are very often based on highly subjective judgments with wide variance (i.e. numbers pulled out of the air). Finally, financial approaches fail to distinguish between accumulated value and potential value. Accumulated value will be referred later as to be within the control of the company. On the contrary, potential value, which is not within company's control, has to be captured.

Some authors (see e.g. Yoon et al., 2002 or Kelley and Rice, 2002) suggest using patent statistics as a tool for decision making at the micro-level (i.e. to extend at the corporate level the indicators usually used at the level of the national technology capacity). Bibliometrics are used to identify potential research areas, to assess technological competitiveness and to set up priority in R&D investment (Levitas et al., 2006; Lee et al., 2009). Such techniques are very useful, but unfortunately very focused in their approach. Assessment of the technology portfolio cannot be restricted to a single indicator. This is obviously incomplete. Evaluation needs to rely on several criteria.

Most of the models rely on a narrow set of (3–6) criteria or pay a limited attention to the justification of the choice of criteria. Definition of anchored scales for assessment did not receive a lot of attention. The model developed by Ringuest et al. (1999) and later by Graves et al. (2000) only takes into account three variables: an estimate of the 'success probability' for each project and the 'financial return' whether the project is successful or unsuccessful. The scoring method developed by Henriksen and Traynor (1999) [for a federal research facility] relies on four criteria: relevance to the organization's strategy, scientific and/or technical risks, reasonableness considering the organization's budget and finally perceived return. Dickinson et al. (2001) use five variables: the 'NPV', the 'overall probability of success', the 'level of interdependence' (with other projects), the 'capability and process change' and the 'alignment with strategic objectives'. Linton et al. (2002) use very crude measures of 'intellectual property life cycle', 'stage of market life cycle', 'investment' and 'anticipated cash flows'. Stummer and Heidenberger (2003) use a limited set of six variables: cash flow, sales, patents, R&D funds, R&D staff and production capacity. Only a few authors have generated extensive lists. Ouellet and Martel (1995) use a wider list of 19 different criteria organized into 3 families (interdependencies, intrinsic value and risk). Balachandra and Friar (1997), thanks to an in-depth literature review in a related area (success in R&D projects and new product innovation), came up with a very extensive list of items but did not match these factors with proper measurements.

Finally, the concept under study is not always clear. While many authors tend to focus on 'technology attractiveness', 'technology merit', or 'project value', many do not precisely define exactly what they are looking at. Most of the models mix internal and external criteria and controllable and non-controllable factors. For example, when Linton et al. (2002) suggest the existence of six broad categories – financial, strategic, quality, environment, market, technological – they do not consider that some of these categories cover internal (and controllable) and external (and non-controllable) issues.

In summary, existing models for technology assessment suffer from: (a) a somewhat unclear definition of what is being evaluated, (b) a restrictive set of criteria and (c) poor measurement scales to carry the assessment. This paper is an attempt to tackle these three drawbacks.

Development of propositions

Two distinctive sets of indicators: controllable and non-controllable

It has been stressed that some technology evaluation models rely on one single dimension (e.g. financial value). But, others use a two-dimensional framework.[1] These tools assume that every technology can be examined and scaled along two dimensions. However, these dimensions might vary from one model to another. I suggest that we can differentiate between controllable and non-controllable criteria. This pattern can be verified in many circumstances and it can be found in several domains.

Back to the very roots, this split can be related to the dichotomy of the Greek philosopher Epictetus: "Amongst things that exist, some depend on us and some do not". More recently, it can be found in the field of strategy with the Swot framework. The strengths and weaknesses of the company depend on its internal resources; the firm is free to adopt the behavior it wants regarding the internal resources that are supposed to be within its control (physical assets, distribution networks, technology portfolio, etc.). On the contrary, the opportunities and threats depend mostly on what is happening in the environment. As a matter of fact, the firm has little impact on external elements such as the actions of competitors, suppliers and regulators as well as the choices made by customers – these are mostly non-controllable factors.

Well known portfolio techniques used by strategists are also all based on a two-dimension framework differentiating controllable (c) and non-controllable (nc) criteria. The BCG matrix combines market growth (nc) and market share (c). The General Electric/McKinsey matrix refers to industry attractiveness (nc) and business strengths (c). The ADL matrix uses industry maturity (nc) and competitive position (c). These models are based on the same foundations: they differentiate between the sector attractiveness (potential value) and the SBU competitiveness (accumulated value) in its sector. The first dimension is mostly given and beyond firm's control while the second is supposed to be within the control of the firm.

Regarding technology assessment, several authors are implicitly in line with the dichotomy between controllable and non-controllable variables. Harris et al. (1981) refer to 'technology importance for competitive advantage', i.e. a dimension that can be traced back to factors such as the potential value added or the position in the life cycle which are mostly non-controllable, and to 'relative technology position' which describes clearly controllable factors (such as patent position or key talents). Sethi et al. (1985) plot a technology on two dimensions: its 'future importance' (in terms of market volume and life cycle) and the 'corporate strengths regarding the technology and relative to its competitors'. Capon and Glazer (1987) also suggested establishing technology portfolios along two dimensions. The first dimension is the 'time' – from technology inception to decline. It incorporates both technology and product life cycles by distinguishing pre and post market phases of technology exploitation. Second is the 'technology competitive position' of the firm. Brockhoff (1992) and later Ernst (1998) use two dimensions to draw patent applications: 'technology attractiveness' (as the growth rate of patent applications) and relative patent position for 'company's competitiveness'. Mikkola (2001) has suggested mapping a given technology along the 'benefit provided to customers' and the 'competitive advantage'; this allows portraying external vis-à-vis internal features.

In summary, there are things that are mainly within the firm's control, assets and competencies that depend on the firm's behavior and decisions; I will refer to these factors as "the company's technological competitiveness" (this is accumulated value). Criteria for assessing a firm's competitive position on a given technology express internal factors that are within the firm's control. So, on this

[1] Some other such as Balachandra and Friar (1997) and Balachandra (2001) rely on a three dimensions framework: the market (existing, new), the type of innovation (incremental, radical) and the technology (familiar, unfamiliar).

axis, the position of a given company could be very different from the position of another. There are also things that do not depend on the firm's actions, which are beyond its control: I will refer here to these elements as the "the attractiveness of the technology" (this is potential value). Criteria used for attractiveness (appeal or potential) of a given technology are important for value creation. These criteria refer mainly to external features that are idiosyncratic to the technology (Badawy, 2009). They are intrinsically related to the technology and are beyond the control of the firm. This means that technological attractiveness is identical for all companies competing in this technology.

Proposition 1. *Managers' assessment of a technology relies on a conceptual split between "technological attractiveness" (beyond the company's control) and "technological competitiveness" (within the firm's control).*

A conceptual model for technological attractiveness

The attractiveness of a technology appears as a function of various exogenous factors. As previously mentioned, these are factors depicting on situation faced by all the companies engaged in one given technological area. As shown in Table 1 a list of 16 indicators for depicting "technological attractiveness" was used from a previous study (Jolly, 2003).

It distinguishes between four families: market potential, competitive situation, technical potential and socio-political situation.

The market potential

This category should express the expected commercial reward that can be gained from a given technology. Market, demand and customers are key drivers when it comes to making decisions about technology. Many new products died because the emphasis was on technology excitement rather than appropriateness. Bond and Houston (2003) have stressed that it is essential to link technologies to the market – the main difficulty is that the market and technologies are likely to be highly uncertain. Market potential will be more or less easy to estimate depending on the degree of novelty. Existing markets are relatively easy to estimate. However, it is much more difficult to evaluate potential when the market is entirely new: there is much more uncertainty and many more unknowns about the

Table 1
Questionnaire used for evaluating technological attractiveness.

Environmental factors over which the company has a weak control		Weak attractiveness		High attractiveness
Market potential	Market volume opened by technology	low	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	high
	Span of applications opened by technology	narrow	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	wide
	Market sensitivity to technical factors	weak	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	strong
Competitive situation	Number of competitors	decreasing	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	increasing
	Competitors' level of involvement	unfavorable	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	favorable
	Competitive intensity	weak	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	strong
	Impact of technology on competitive issues	low	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	high
	Barriers to copy or imitation	low	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	high
	Dominant design	exist	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	non-exist
Technical potential	Position of the technology in its own life-cycle	stabilizing	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	emerging
	Potential for progress	low	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	high
	Performance gap *vis-à-vis* alternative technologies	narrow	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	wide
	Threat of substitution technologies	high	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	low
	Potential for unit-to-unit transfers	difficult	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	easy
Socio-political situation	Societal stakes	threatening	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	supportive
	Public support for development	spartan	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	generous

potential uses and the size of the market. Three criteria were developed to capture the market potential: the market volume opened by technology, the span of applications, and the market sensitivity to technical factors.

The higher the market volume opened by technology, the higher the market potential. This is true whether the technology is embodied into the product itself or into the production process. The market volume depends on the geographical coverage, the dynamism of demand, the time horizon, the benefits gained by consumers, their solvability, etc.

Relying on the resource-based framework (Prahalad, 1993), market potential is also a function of the span of applications that the technology opens. Technologies might differ in their ability to reach several markets, to fulfil different expectations, to be embodied in distinct applications, products, processes or services, and to target varied customer segments. Two extreme cases can be imagined: either the technology is confined to a single application, either it can be developed into several fields of applications (like the laser, the carbon fibber or the smart card). The wider the span of applications is, the higher the market potential. The interesting feature of technologies with a large span of applications is that risks can be spread over several segments. If one of these segments declines, it will not be a disaster. Other demand segments should compensate for the drop.

Finally, the higher the market sensitivity to technical factors, the higher the market potential. One extreme case is when technology-driven customers represent a limited segment, a narrow sub-section of the market. However, customers might not look for technical performance in itself. The other extreme is when technology allows satisfying needs and expectations of most of the market.

The competitive situation

Competition is a strong driver of technological development. This is because technology has to find its way in a competitive world. Technology becomes attractive as soon as it enables firms to gain competitive advantage. This is why competition has to be scanned carefully. Managers must pay close attention to the level of competition in their business when they allocate resources to technology programs (Badawy, 2011). Six criteria were adopted for assessing the competitive situation: in-out competitive dynamic, level of involvement, competitive intensity, impact of technology on competitive issues, barriers to copy or imitation, and potential for the development of a dominant design.

The first criterion is the variation in the number of competitors (Klepper and Simons, 2000). When one new technology provokes the emergence of a new business, there is a high number of competitors entries into the business. This is due to low entry barriers. And, this is also because companies want to take the opportunity of developing their own technical standard – as there is rarely one single technical option when a business emerges. Because of these high degrees of freedom, many new competitors enter into the emerging business so to do their best to foster their standard. Consequently, when there is an increasing number of a competitor, this means that the business is attractive. On the other hand, when one dominant design has emerged, this reduces dramatically the chances for other companies to develop their standard. Consequently, the number of competitors is no more increasing – it is even reducing as many companies cannot adopt the dominant design or are not able to amortize their previous investments and prefer to leave the business. So, when the number of competitors decreases, the competitive situation is no more attractive – it is moving to a more and more structured market with a ‘‘happy fews’’.

The second criterion about the competitive situation is about the competitors' level of involvement. This criterion is derived from competitor analysis, as depicted by Porter (1980). Two extreme situations can be depicted. If no competitor is involved in the technology, this means that the technology is perceived as not attractive. On the opposite, if all competitors of a given industry are involved, this means that the technology is perceived to be attractive. Consequently, the more competition is involved, the more likely the technology is to be attractive.

The next related criterion is the competitive intensity. Attention paid by competitors to the technology gives an indication of its attractiveness. The average level of rivalry for technological development reflects the attractiveness: firms compete heavily when they assume some attractiveness – and they reduce their readiness to fight when they forecast reduced perspectives.

Also very important is the impact of technology on competitive issues (Khalil, 2000), that is to say the impact of technology on the value and/or cost of the offer in which it is incorporated, as perceived by the client/customer. The higher the impact, the more attractive the technology is. The actual dimensions on which firms are competing are not so important. Firms might be competing on cost, quality, speed of development, speed of delivery, performance, etc. What is important is the contribution of technology to the building of competitive edge.

Another aspect of the competitive situation is the status of barriers to copy or imitation. This concept is another point derived from industrial organization. It depicts the capacity of the technology to support a resource position barrier (to entry and to imitation). If barriers are low, the competitive situation is not attractive. Actually, investing in a technology would be useless if the company were not able to protect its technology against competition inclined to copy it. On the opposite, when barriers to copy are high, this makes the business safer and consequently more attractive.

Finally, relying on the fundamental work of Abernathy and Utterback (1978), and later of Utterback (1994), the absence or existence of a dominant design will impact on attractiveness. The dominant design (or de facto standard) is the standard that wins the allegiance of the marketplace. When an entirely new activity emerges, this gives space to multiple technical competing standards. When a dominant design does not exist, firms still have the chance to create it. This makes the technology field attractive. On the contrary, when the dominant design is established, the degree of freedom is reduced, survivors have to share the market and the technology is less attractive (Clymer and Asaba, 2008).

The technical potential

Five different criteria were used to evaluate the technical potential: the position of the technology in its life-cycle, the potential for progress, the gap with competitive technologies, the threat of substitution technologies, and the potential for unit-to-unit transfers.

These criteria rely on Foster's (1986) work on the technology life cycle and the threat of substitution technologies. The technology life cycle depicts the interest exhibited by one technology over time. It describes the evolution of the technology performance as a function of the cumulated investments realized by companies. When the technology is emerging, there is wide room for improvement, attractiveness is high. When the performance of the technology is stabilizing, attractiveness is low. This is why companies do not invest any more on drum brakes, cathode ray tube TVs, or mechanical watches. However, there is always a risk that substitute technologies will emerge. The threat is probably higher when the technology reaches its mature stage – as the dominant technology has exhibited diminishing marginal returns. To sum up, this means that the more mature the technology, the less attractive it is.

In the same vein, the concept of potential for progress has been studied by many authors (see e.g. Van Wyk et al., 1991). It can be defined as the difference between the level of performance reached at one given point of the development and the maximum that the technology is assumed to be able to deliver. The higher the reserve for progress, the higher the attractiveness. When the level of performance reached is close to the maximum, there are limited incentives to continue to invest in this technology.

A third technical criterion is the performance gap vis-à-vis alternative technologies. This refers to the role usually hypothesized for technology: it is a means of creating gaps vis-à-vis other existing competitive solutions. The wider the gap created, the higher the attractiveness of the technology. This gap is limited in the case of an incremental innovation and significant in the case of a radical innovation (Salomo et al., 2007). A "significant enough" gap must be created to overcome barriers (such as habits, system in place, etc.), otherwise, technological change might be difficult to implement.

The evaluation of the technical potential should also pay attention to the threat of substitution technologies. The probability of having new technologies emerging exists at every stage of the technology life cycle. Yet, the probability is possibly increasing when the technology reaches its maturity stage. Under this pattern, a high probability of threatening technologies makes the area not attractive while a low probability makes the domain highly attractive.

Finally, another technical criterion is the potential for unit-to-unit transfers. The dominant organizational relationships refer to vertical patterns (SBUs are under the hierarchy of the corporate level); whereas technology transfers usually occur at the horizontal level (between SBUs). Not all technologies exhibit the same level of transferability. Some are easy to transfer and others are not. This depends not on the company but on the intrinsic nature of the technology. This criterion might be underestimated because of the way R&D managers are evaluated. Most of the time, an R&D manager is controlled and remunerated according to what he does in his own field, i.e. inside his SBU. The impact of his action on other components of the organization and his contribution to other programs are very rarely taken into account by compensation policies and other tools for incentive.

The socio-political situation

Technological attractiveness is not only an issue with market, competitive and technical dimensions. Socio-political aspects might also have an impact on the development of one technological area. Two criteria were adopted: societal pressures on one hand, and public support on the other hand.

Evaluating technological attractiveness calls for an examination of the societal stakes that can arise because of the exploration of entirely new technical fields or that has already emerged after one technology was brought on the market. The point in question is the societal acceptability of the technology (Davis and Frederick, 1984). While some technologies are creating some fears (nuclear energy, or intrusive software, for example), some others are very welcomed by society at large (hybrid engines, recyclable products or systems, or any other green offering).

New technologies can be the source of negative externalities such as accidents in the workplace, air pollution, risk for consumers, impact on values, etc. These negative by-products might affect the well-being of very diverse stakeholders. Consequently, these stakeholders can in turn exert pressures on the companies that develop these technologies. The range of pressures is very large: it can start with simple claims and can rise to hard activism – including boycotts, sabotage, kidnapping, etc. To sum up, the higher the societal pressures, the less attractive the technology is. Companies should pay attention to these issues because societal pressures may impede business development (Freeman, 1984). Incentives can even totally disappear if some legislation emerge that will restrict or even ban the development of a certain technology. The current examples of the nuclear energy, the digital divide (between south and north), or genetically modified organisms (GMOs) in the pharmaceutical or seed industries illustrate this point. These examples show that societal pressures might be an issue for some industries but not for others.

On the other hand, the attractiveness of a technology also depends on public support for its development, i.e. the financial support obtainable from public sources (Hsu et al., 2009). Depending on the interest of public bodies (such as the European community) for some new technology areas, certain technologies are more "fashionable" than others. The higher the public financial support, the more attractive the development of the technology.

To sum up, this section has reviewed a set of 16 indicators of technological attractiveness that mainly come from the literature review. An interesting issue is whether or not managers in the real world deal with these criteria when they assess technologies and whether or not they cover the different categories examined. The following proposition will be tested:

Proposition 2. *In practice, managers assess 'technological attractiveness' on the basis of a fairly limited set of indicators encompassing market, competitive, technical and socio-political criteria.*

A conceptual model for technological competitiveness

It has been stressed previously that evaluating a company's position on one specific technology should rely mostly on endogenous criteria. As shown in Table 2; a list of 16 indicators for depicting "technological competitiveness" was taken from a previous research (Jolly, 2003); criteria were grouped into two families. Some relate to the technical capabilities of the company, i.e. to the technological resources within its control. Others relate to complementary resources which are also within its control.

The value of technological resources

The evaluation of technological resources should take into account several aspects: tangible assets, intangible assets, and human resources. Nine different criteria were developed.

Table 2
Questionnaire used for evaluating technological competitiveness.

Internal factors over which the company can exert a strong control		Weak position		Strong position
Technological resources	Origin of the assets	external	□□□□□□□□□□	internal
	Relatedness to the core business	unrelated	□□□□□□□□□□	related
	Experience accumulated in the field	no experience	□□□□□□□□□□	world-class player
	Registered patents	none	□□□□□□□□□□	many
	Value of laboratories and equipment	low	□□□□□□□□□□	high
	Fundamental research team competencies	low	□□□□□□□□□□	high
	Applied research team competencies	low	□□□□□□□□□□	high
	Development team competencies	low	□□□□□□□□□□	high
	Diffusion in the enterprise	undiffused	□□□□□□□□□□	diffused
Complementary resources	Capability to keep up with fundamental S&T knowledge	none	□□□□□□□□□□	strong links
	Financing capacity	low	□□□□□□□□□□	high
	Quality of relationships between R&D & Production	weak	□□□□□□□□□□	strong
	Quality of relationships between R&D & Marketing	weak	□□□□□□□□□□	strong
	Capacity to protect against imitation	low	□□□□□□□□□□	high
	Market reaction to the company's design	unfavorable	□□□□□□□□□□	favorable
	Timetable relative to competition	behind	□□□□□□□□□□	ahead

The origin of the assets criteria expresses a possible dependency on external suppliers. Two extreme cases are distinguished. Either the firm is dependant vis-à-vis external suppliers (another company, a university, a public research center, etc.) or it is totally independent because the technology was developed entirely in-house. When a company relies totally on an external technology supplier, this creates dependency – but even worse, this does not allow creating some differentiation (especially if the technology is licensed to competitors by the licensor).

The relatedness to the company's core business is the distance, the alignment, or the potential contribution of the technology to the firm's core competencies. This has been stressed by authors such as Coombs (1996) – relying again on the resource-based framework (Hamel and Prahalad, 1990; Prahalad, 1993). The hypothesis is that the closer the alignment between one technology and one core competence, the higher the competitiveness should be, because of the expected synergistic effects. A program which is not in line with the existing technological platform would prevent the company from performing well. This argument coincides with the current trend of resource-based theory, which is to refocus on core competencies rather than expand in several unrelated directions (Leten et al., 2007; Hussinger, 2010). Technological resources also include the firm's accumulated experience and familiarity in one given technological field. Two extreme cases can be distinguished. Either the company is familiar with the area, has already invested a lot, and have devoted enough resources in the past to be a leader of the field; or, the firm has been almost totally absent of the technological field.

Another aspect encompasses the patents owned by the firm, as analyzed by Teece (1986) and Ernst (1998). The wider the patent portfolio, the higher the protection, and the stronger the firm is supposed to be. An assessment relative to competition will give a better image – if most of the competitors tend to value patenting (this will not be true if firms prefer to keep secret rather than to patent).

The value of its laboratories and equipment, the expertise of R&D staff are criteria that have been stressed by authors such as Roussel et al. (1991). Development is known to be more expensive than either 'applied research' or 'fundamental research' (OECD, 2005). As such, the competencies of development teams are crucial for the success of the program.

Finally, the diffusion of technological knowledge in the company stems from the strong emphasis given over the last ten or fifteen years on the value of lateral transfer, sharing knowledge within the group, horizontal development, learning and knowledge management, etc. (Rogers, 2001).

The value of complementary resources

Almost as important as technological resources are complementary resources. These include the links established by the firm with the scientific community in order to keep up with the latest fundamental knowledge in sciences and techniques (S&T). CTOs in companies are much more used to applied research and development than to fundamental research. To fill this gap, they need to build bridges with providers of fundamental research (Decter et al., 2007; Link et al., 2008; Annapoornima et al., 2010). The stronger these bridges are, the stronger the position of the company will be. The capacity of the company to finance the development of technology is another criterion. R&D managers are not morons. They are fully aware of financial issues. They know that they will have to convince their Chief Financial Officer that a given technological program should be capable of attracting financing – either internally or externally. Fighting to attract budgets is a major issue. R&D–Marketing and R&D–Production interfaces are another category of complementary resources (De Luca et al., 2010). R&D no longer lives in an ivory tower. R&D laboratories must not behave as independent units. CTOs have to recognize the importance of interfaces between functions. Interfaces between R&D and Marketing as well as between R&D and Production are intangible assets that need to be developed. Technological competitiveness depends on the strength of the link between R&D and Marketing (Griffin and Hauser, 1996). The two functions should establish channels of communication so as to fluidify the transfer of knowledge between them – especially knowledge about consumer behavior on one side, and functionalities offered by the technology on the other. Strong interfaces facilitate implementation whereas weak interfaces handicap business success. In the same vein, CTO's responsibilities encompass the transfer of the knowledge they develop to the forward stages of the value chain.

Managers should pay special attention to the quality of the bridges between R&D and Production. The capacity to protect against imitation is important as any effort to build a technological competitive advantage might be ruined if the technology in question is not protected (Allarakhia and Walsh, 2011). The impact of the design developed by the company on the market refers to the associated probability of the transformation of the company's design into a dominant one. The company's design might be marginalized or close to being transformed into a dominant design. R&D managers are not disconnected from the reality of demand. They understand that their technical choices have to be accepted by the market. The closer the company is to establishing a dominant design, the stronger its position. The timetable relative to competition exemplifies the importance of time in current competitive battles. It is well-known that being late in a technological race creates a competitive disadvantage. How to reduce time to develop, time to industrialize, time to market are very common challenges. Based on a similar rationale as Proposition 2, the following Proposition 3 was inferred from previous developments:

Proposition 3. *In practice, managers assess the competitiveness of one given technology on the basis of few indicators depicting technological resources and complementary resources.*

Methods

Variables and measures

As shown on the right part of Tables 1 and 2, semantic differential scales were developed for each indicator introduced in the previous part. They were co-constructed in the process of an executive seminar. Measurement was made on a ten point scale. When a negative relationship was hypothesized, the scale was reversed to assure consistency among questions. The advantage of subjective ratings is to explicitly recognize the experience and value of the professional judgments made by managers. These knowledgeable persons are able to aggregate different constructs into one single score, to incorporate some factual data and intuitive perceptions in their analysis. Models incorporating qualitative judgments tend to be more acceptable to managers. Relying on such ratings partially compensates for data unavailability.

Data collection and sample

The questionnaire was administered in 63 different companies. This is a convenience sample resulting from contacts with the industry. All companies chosen had at least 100 employees. Almost all companies targeted belong to high-tech industries, i.e. they dedicate more than 4% of their turnover to R&D. In each company, the same approach and the same tool was used: a group of experienced managers was asked to assess the technologies within their control using the set of 32 different criteria for evaluation (as presented above). Interviewees ranged from scientists to sales managers. In the best cases, this resulted in a group of three to five managers who were asked to rate a set of three to four different technologies.

In each company, data collection was organized in two phases in order to control respondents' subjectivity. Each manager participating in the study was first asked to complete the questionnaire alone. Then, answers from all the respondents were shared at a common meeting. Discrepancies were tracked for each technology assessment and people far from the group's average were asked to explain their departure. In the second phase, after the discussion had taken place, each participant was allowed to modify his rating. This resulted in more convergent assessments. Data used afterwards for analysis are those resulting from this Delphi type process.

Data from some companies were discarded from the final sample because they were not collected with the expected level of care or because of globally limited variations in company's respondents' answers (i.e. generating insufficient information, for example, a manager giving ratings exclusively concentrated over a small range, such as 6–8 whatever the indicator or the technology) or also because they exhibited insufficient reliability. After elimination of these doubtful cases, the final sample comprised 50 companies. The final sample was split as follows: specialized chemicals (4), pharmaceuticals (6), biotechnologies (2), semiconductor (2), electronic products (4), telecommunication equipment (8), software (9), automotive suppliers (3), medical technologies (1), equipment/service for the industry (8), and defense and space (3). Most of these companies are from European countries (mostly from United Kingdom and France).

Statistical analyses

Data for the 50 companies give a matrix of 463 observations on 32 variables. The test of propositions is based on correlation analysis, Cronbach alpha coefficients and factorial analysis. Correlations between the 32 variables allow to see the whole picture and test the existence of some obvious patterns (Proposition 1). Cronbach alpha coefficients allow to test the reliability of the categories developed (Propositions 2 and 3).

Three principal component factor analyses were also performed. The reason for using these analyses was to test whether the composition of the factors produced by the analysis was in line with research propositions or not. The first analysis was made on the whole set of criteria (32). The size of the sample (463 observations) complies with the usually required minimum ten-to-ten ratio for factor analysis (Hair et al., 1998: 99). If Proposition 1 is true, then factors should exhibit a homogeneous composition either with "technological attractiveness" variables or with "technological competitiveness" variables. If Proposition 1 is false, the factors should mix the two families of criteria on an equal basis. Based on the same rationale, a second analysis was performed on the sub-group of hypothesized exogenous variables (16) and a third on the sub-group of hypothesized endogenous variables (16). The Kaiser–Meyer–Olkin (KMO) test was used to express the quality of the analysis. A Varimax rotation was performed for each analysis in order to spread variation more evenly over the components produced.

Results

Test of Proposition 1 on the whole set of indicators

Do the data reproduce the conceptual split between attractiveness and competitiveness? Two different analyses were conducted to test this proposition: correlation and factorial analysis.

Correlations analysis: Tables 3a–3c give the overall pattern of correlations between the 32 variables. For presentation, it was split into three: Table 3a: correlations between attractiveness variables, Table 3b: correlations between competitiveness variables, and Table 3c: correlations between attractiveness and competitiveness variables. More positive correlations can be observed inside the group of attractiveness variables and inside the group of competitiveness variables than between these two sets of variables. This shows the homogeneity in the group of ''technological attractiveness'' indicators and the group of ''technological competitiveness'' indicators – with a special emphasis on the second group.

Factorial analysis: A first factorial analysis was conducted on the entire set of 32 variables mixing the 16 hypothesized ''technological attractiveness'' variables and the 16 hypothesized ''technological competitiveness'' variables. The KMO test is at .754. This level is correct. Regarding the quality of representation of the initial variables, nine reach an extraction level higher than .70, thirteen variables were between .60 and .70 and the remaining ten variables show an extraction level below .60. As such, quality of representation is acceptable.

Based on the principal component method, the factorial analysis produces ten factors with eigenvalues >1. Results are presented in Table 4. These ten factors represent 64% of variance. The minimum loading criteria for interpreting factors, after a Varimax rotation, is .500 (except a few exceptions that will be reported). With this rule, all the ten selected factors (except # 2) either bundle ''technological attractiveness variables or bundle technological competitiveness'' variables.

Factor # 1 (11.7% of variance) bundles four variables with high loadings: ''fundamental research team competencies'' (.807); ''applied research team competencies'' (.762); ''development team competencies'' (.761); ''capability to keep up with fundamental scientific and technical knowledge'' (.716). All these variables relate to endogenous indicators. All exogenous variables exhibit very low loadings with this factor. Factor # 2 (7.2% of variance) is composed of four criteria: ''barriers to copy or imitation'' (.675); ''capacity to protect against imitation'' (.674); ''registered patents'' (.579); and, ''quality of relationships between R&D and production'' (.510). A fifth criterion received a weaker loading: ''value of laboratories and equipment'' (.454). These criteria relate to ''technological competitiveness'' except the first one which relates to exogenous features.

All other exogenous variables show low to very low loadings. Factor # 3 (6.9% of variance) is made exclusively with endogenous criteria: ''market reaction to the company's design'' (.795); ''quality of relationships between R&D and marketing'' (.626); and, ''timetable relative to competition'' (.542) – and, with a weaker loading: ''diffusion in the enterprise'' (.415) and ''origin of the assets'' (.398). Again, all exogenous variables show low loadings. Factor # 4 (6.7% of variance) is made with four ''technological attractiveness'' variables: ''market sensitivity to technical factors'' (.674); ''span of applications opened by technology'' (.608); ''market volume opened by technology'' (.579); ''impact of technology on competitive issues'' (.501); and, to a weaker extent, ''performance gap/alternative technologies'' (.400). The correlation analysis already allowed to identify this set of variables as positively and significantly interrelated.

All endogenous variables show very low loadings. Factor # 5 (6.2% of variance) combines ''competitors' level of involvement'' (.898); and ''competitive intensity'' (.899). This is not surprising as these two variables were previously identified as having a high correlation level. Factor # 6 bundles two attractiveness variables: ''potential for progress'' (.790); ''position of the technology in its life-cycle'' (.730). Factor # 7 combines two competitiveness variables: ''relatedness to the core business'' (.789); and, ''experience accumulated in the field'' (.495). Finally, factors # 8–10 homogeneously depict attractiveness dimensions.

In summary, all the competitiveness variables are spread on factors 1, 2, 3 and 7. All the attractiveness variables – except one – are spread on factors 4, 5, 6, 8, 9 and 10. This means that Proposition 1 is accepted: there exist two distinct families of indicators for conducting a technology portfolio audit. The profiles of the ten factors produced by the analysis confirm empirically the hypothesized split between the concept of ''technological attractiveness'' and the concept of ''technological competitiveness''.

Table 3a
Correlations between attractiveness variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Market volume opened by technology	1															
2. Span of applications	.427**	1														
3. Market sensitivity to technical factors	.278**	.243**	1													
4. Number of competitors	−.036	−.157**	.174**	1												
5. Competitors' level of involvment	−.123*	.043	−.091	.028	1											
6. Competitive intensity	−.070	.059	−.111*	.005	.741**	1										
7. Impact of techno on competitive issues	.248**	.229**	.393**	.064	.027	.047	1									
8. Barriers to copy or imitation	.024	.060	.223**	.084	.008	.041	.290**	1								
9. Dominant design	.004	−.090	.023	.085	−.038	−.018	−.003	−.050	1							
10. Position of the techno in its life-cycle	.208**	.268**	.371**	−.019	−.080	−.013	.323**	.190**	.012	1						
11. Potential for progress	.293**	.320**	.301**	.014	−.072	.026	.313**	.175**	.018	.582**	1					
12. Performance gap/alternative technos	.150**	.243**	.215**	−.006	.079	.118*	.214**	.101*	.037	.231**	.302**	1				
13. Threat of substitution technologies	.161**	.185**	.110*	.036	.094	.060	.066	.088	−.055	.128*	.145**	.211**	1			
14. Potential for unit-to-unit transfers	.161**	.148**	−.025	−.146**	.117*	.142**	.011	−.115*	.125*	−.002	−.040	.021	.130*	1		
15. Societal stakes	.148**	.219**	.209**	−.078	−.082	−.054	.151**	.145**	−.032	.285**	.199**	.067	.110*	−.005	1	
16. Public support for development	.115*	.049	.076	.070	−.056	−.017	.067	.113*	−.050	.172**	.064	−.066	.131*	.109*	.320**	1
Mean	6.70	6.29	6.58	5.45	5.27	5.08	6.81	5.81	5.44	6.25	6.79	6.31	5.68	6.09	6.38	4.49
Standard deviation	1.867	2.096	2.058	2.003	2.304	2.245	1.869	2.162	2.442	2.100	1.991	1.823	2.042	2.118	2.095	2.649
Minimum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Maximum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Number of correlations at .05	2		2		1	1		3	1	1			3	1		
Number of correlations at .01	9	9	7	1	1	1	5	3		4	3	1			1	

** Correlation is significant at .01 level (bilateral).
* Correlation is significant at .05 level (bilateral).

Table 3b
Correlations between competitiveness variables.

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
17. Origin of the assets	1															
18. Relatedness to the core business	.207**	1														
19. Experience accumulated in the field	.213**	.330**	1													
20. Registered patents	.186**	.165**	.216**	1												
21. Value of laboratories and equipment	.267**	.241**	.287**	.355**	1											
22. Fund. research team competencies	.315**	.133**	.261**	.122*	.337**	1										
23. Applied research team competencies	.270**	.221**	.357**	.182**	.478**	.643**	1									
24. Development team competencies	.372**	.201**	.296**	.031	.387**	.570**	.593**	1								
25. Diffusion in the enterprise	.357**	.234**	.349**	.150**	.352**	.279**	.257**	.271**	1							
26. Capability to keep up with S&T know.	.381**	.166**	.194**	.165**	.316**	.606**	.475**	.493**	.314**	1						
27. Financing capacity	.209**	.250**	.251**	.180**	.322**	.254**	.353**	.364**	.190**	.351**	1					
28. Quality of relationships R&D and Production	.184**	.170**	.272**	.356**	.358**	.205**	.305**	.322**	.157**	.260**	.379**	1				
29. Quality of relationships R&D and Marketing	.203**	.004	.062	.140**	.208**	.285**	.294**	.283**	.255**	.212**	.232**	.384**	1			
30. Capacity to protect against imitation	.067	−.060	.027	.361**	.269**	.227**	.224**	.285**	.050	.316**	.275**	.436**	.251**	1		
31. Market reaction to the comp's design	.243**	.037	.244**	.267**	.272**	.211**	.282**	.170**	.319**	.248**	.244**	.352**	.444**	.248**	1	
32. Timetable relative to competition	.354**	.171**	.277**	.270**	.290**	.287**	.310**	.370**	.222**	.336**	.317**	.298**	.272**	.202**	.465**	1
Mean	7.20	7.64	7.14	5.25	6.26	5.92	6.80	7.02	6.01	6.76	6.89	6.90	6.82	5.91	6.81	6.39
Standard deviation	2.260	1.937	2.046	2.859	2.143	2.533	1.972	1.764	2.036	1.804	1.914	1.858	1.933	2.238	1.784	1.874
Minimum	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1
Maximum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Number of correlations at .05				1												
Number of correlations at .01	14	11	11	10	11	10	9	8	7	6	5	4	3	2	1	

** Correlation is significant at .01 level (bilateral).
* Correlation is significant at .05 level (bilateral).

Table 3c
Correlations between attractiveness and competitiveness variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17. Origin of the assets	.054	.082	−.037	.074	.026	.003	.002	.054	.019	.004	.125*	.099	−.027	−.038	−.018	−.060
18. Relatedness to the core business	.138**	−.124*	.071	.063	.107*	.017	.152**	−.091	.026	−.034	−.035	.011	.000	.153**	−.119*	.033
19. Experience accumulated in the field	.070	−.021	.080	.076	.024	−.019	−.009	−.043	−.014	−.176**	−.150**	.043	−.056	.015	−.147**	−.243**
20. Registered patents	.046	−.107*	.052	−.017	.004	−.048	.098	.328**	.133*	.036	.079	.027	−.046	−.175**	−.148**	−.141**
21. Value of laboratories and equipment	.044	.006	.223**	.060	.062	.038	.092	.219**	.079	.023	.110*	.184**	.043	−.020	−.067	−.124*
22. Fund. research team competencies	.138**	.229**	.071	−.059	.031	.000	−.120*	.041	−.100	−.002	.195**	.272**	.168**	−.007	.074	−.076
23. Applied research team competencies	.074	.061	.061	−.029	.123*	.083	−.031	.071	−.009	−.004	.107*	.275**	.047	−.014	.003	−.096
24. Development team competencies	.098	.105*	.115*	.054	.122*	.030	−.027	.071	.006	.046	.083	.197**	.109*	.113*	−.025	.007
25. Diffusion in the enterprise	.213**	.171**	.088	.141**	.002	−.042	.053	−.010	.060	.017	.015	.062	−.062	.101*	.000	−.016
26. Capability to keep up with S&T know.	.122*	.213**	.099	−.064	−.028	−.029	−.105*	.076	.030	.060	.234**	.190**	.056	.064	.036	−.005
27. Financing capacity	.083	.048	.143**	−.085	.095	.109*	.063	.033	.026	.007	.042	.071	−.042	.095	−.071	−.139**
28. Quality of relationships R&D and Production	.049	.074	.215**	−.026	.092	.107*	.062	.244**	.070	−.019	.062	.101	−.009	.063	.040	.036
29. Quality of relationships R&D and Marketing	.122*	.115*	.046	.090	−.088	−.040	−.084	.116*	−.060	.015	.030	.140**	−.048	−.052	.027	.119*
30. Capacity to protect against imitation	.073	.077	.263**	.003	.048	.052	.061	.528**	.017	.121*	.168**	.128*	.043	.014	.174**	.080
31. Market reaction to the company's design	.125*	.081	.187**	−.031	−.140**	−.091	.059	.095	.117*	−.075	.073	.186**	−.055	−.078	.002	−.019
32. Timetable relative to competition	.137**	.138**	.060	−.105*	.140**	.160**	.068	.115*	.133*	.073	.179**	.203**	−.017	−.070	.035	−.011
Number of correlations at .05	3	4	1	1	3	2	2	1	3	1	2	1	1	2	1	2
Number of correlations at .01	4	4	5	1	2	1	1	4		1	5	8	1	2	3	3

** Correlation is significant at .01 level (bilateral).
* Correlation is significant at .05 level (bilateral).

Table 4
Factorial analysis on the whole set of criteria (after rotation).

Factors	1	2	3	4	5	6	7	8	9	10
% of the total variance explained	11.7	7.2	6.9	6.7	6.2	6.0	5.9	5.4	4.3	3.9
Market volume opened by technology	.082	−.159	.199	.579	−.142	.146	.228	.169	.064	−.156
Span of applications	.211	−.077	.156	.608	.081	.265	−.168	.160	−.048	−.196
Market sensitivity to technical factors	.006	.348	−.035	.674	−.157	.113	.074	.028	.052	.191
Number of competitors	.004	.096	.014	−.011	.083	−.020	.066	.065	.032	.896
Competitors' level of involvment	.079	.034	−.068	.001	.898	−.027	.072	.003	.022	.045
Competitive intensity	.032	.002	.016	−.041	.899	.002	−.030	.077	.081	.027
Impact of tech on competitive issues	−.248	.199	−.030	.501	.128	.357	.362	.012	−.109	.055
Barriers to copy or imitation	.001	.675	.014	.065	.038	.183	−.082	.214	−.197	.123
Dominant design	−.182	.140	.141	−.149	.051	.084	−.012	−.153	.787	.134
Position of the techno in its life-cycle	−.014	.153	−.134	.210	−.026	.730	−.033	.192	.045	−.018
Potential for progress	.129	.061	.071	.197	−.011	.790	−.104	.079	.012	−.011
Performance gap/alternative tech.	.272	−.061	.227	.400	.228	.304	−.220	−.189	.019	.143
Threat of substitution technologies	.129	−.061	−.046	.351	.261	.031	−.088	.356	−.022	.187
Potential for unit-to-unit transfers	.203	−.208	−.136	.225	.090	−.041	.120	.260	.691	−.102
Societal stakes	.062	.112	.003	.234	−.058	.228	.003	.570	−.072	−.057
Public support for development	−.074	.094	.082	−.009	.089	.038	.016	.833	.074	.095
Origin of the assets	.346	−.108	.398	−.261	−.030	.263	.393	−.006	−.116	.065
Relatedness to the core business	.144	−.020	−.033	.003	.035	−.109	.789	.045	.078	.004
Experience accumulated in the field	.314	.160	.162	.180	−.012	−.210	.495	−.336	−.050	.100
Registered patents	.023	.579	.326	−.163	−.014	.139	.233	−.162	.016	−.008
Value of laboratories and equipment	.404	.454	.158	.106	.064	−.102	.277	−.143	.059	.137
Fund. research team competencies	.807	−.005	.161	.066	.024	.055	−.045	.092	−.142	.043
Applied research team competencies	.762	.150	.119	.055	.106	−.059	.142	−.134	−.071	−.004
Development team competencies	.761	.106	.016	.068	.055	.034	.163	−.024	.040	.026
Diffusion in the enterprise	.305	−.035	.415	.156	−.058	.053	.401	.086	.118	.281
Capability to keep up with S&T know.	.716	.097	.226	−.014	−.029	.181	.048	.127	.109	−.057
Financing capacity	.444	.278	.130	.076	.108	−.069	.302	−.078	.239	−.202
Quality of relationships R&D and Production	.300	.510	.323	.141	.077	−.207	.078	.054	.207	−.118
Quality of relationships R&D and Marketing	.336	.164	.626	.078	−.068	−.126	−.153	.216	−.002	.068
Capacity to protect against imitation	.351	.674	.097	.036	−.036	.122	−.160	.191	.090	.017
Market reaction to the comp's design	.116	.211	.795	.155	−.086	−.069	.038	−.063	.025	.003
Timetable relative to competition	.268	.227	.542	−.036	.309	.212	.216	−.028	.014	−.226

Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization.
Rotation converged in 12 iterations.

Test of Proposition 2 on technological attractiveness indicators

Cronbach Alpha coefficients were computed for each hypothesized category. This gives: .602 for the three market indicators ($n = 462$); .428 for the six competition indicators ($n = 447$); .533 for the five technical factors ($n = 459$); and, .499 for the two socio-political factors ($n = 446$). As such, these results give partial credit only to the first category.

A factorial analysis was conducted on the set of 16 attractiveness criteria using the principal component method. The extraction table exhibits four initial variables at more than .700, eight in the range [.5; .7] and four in the range [.4; .5]. The KMO test is at .700. This means an acceptable level of quality since this is an attempt to create an entirely new scale. Figures are given here after the Varimax rotation.

Table 5 gives the results of the factor analysis. The analysis displays six factors with eigenvalues >1. These six factors explain 62.5% of variance. These results give credence to Proposition 2.

Interpretation of factors was conducted with figures higher than .500 – except for "barriers to copy and imitation", "performance gap/alternative technologies", "impact of technology on competitive issues", and "threat of substitution technologies". Factor # 1 explains 13.5% of variance. It is close to factor # 6 produced with the analysis of the 32 variables. It comprises two variables with high loadings: "potential for progress" (.795); and "position of the technology in its own life-cycle" (.787).

Table 5
Factorial analysis on attractiveness criteria (after rotation).

Factors	1	2	3	4	5	6
Percentage of the total variance explained	13.48%	11.93%	11.61%	9.59%	8.67%	7.21%
Market volume opened by technology	.172	−.198	.738	.031	.009	.038
Span of applications	.347	.100	.669	.051	−.070	−.169
Market sensitivity to technical factors	.352	−.216	.389	.050	.500	.001
Number of competitors	−.130	.099	−.050	.040	.795	.165
Competitors' level of involvment	−.024	.910	.026	−.008	.055	−.022
Competitive intensity	.056	.913	−.022	.064	−.010	.058
Impact of technology on competitive issues	.445	.032	.280	.039	.393	−.066
Barriers to copy or imitation	.262	.031	−.128	.358	.421	−.247
Dominant design	.129	−.016	−.143	−.053	.152	.867
Position of the techno in its life-cycle	.787	−.035	.045	.271	−.012	.038
Potential for progress	.795	−.016	.161	.080	−.006	.035
Performance gap/alternative technos	.439	.203	.353	−.177	.129	.060
Threat of substitution technologies	−.041	.204	.457	.356	.199	−.047
Potential for unit-to-unit transfers	−.177	.202	.465	.254	−.278	.506
Societal stakes	.320	−.087	.124	.639	−.020	−.067
Public support for development	.002	.082	.045	.824	.089	.084

Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization.
Rotation converged in 11 iterations.

These belong to the technical indicators category. Two other variables with lower loadings can also be attached to this factor: "impact of technology on competitive issues" (.445); and, "performance gap vis-à-vis alternative technologies" (.439). Factor # 2 explains 11.9% of variance. It is the same as factor # 5 of the first factorial analysis. It articulates only two variables with very high loadings: "competitors' level of involvement" (.910) and "competitive intensity" (.913). This refers without ambiguity to the competition category. Factor # 3 explains 11.6% of variance. It is a combination of two variables with high loadings: "market volume opened by technology" (.738); and, "span of applications opened by technology" (.669). These two belong to the market indicators category. A third one with a lower loading can also be attributed to this factor; this is: "threat of substitution technologies" (.457).

Factor # 4 explains 9.6% of variance (it is similar to factor # 8 produced by the factorial analysis conducted on whole set of variables). It combines only two variables: "public support for development" (.824) and "societal stakes" (639). This is clearly the socio-political category. Factor # 5 explains 8.7% of variance. It comprises one single variable with a high loading, i.e. the "number of competitors" (.795). Two other variables with weaker loadings "market sensitivity to technical factors" (.500) and "barriers to copy and imitation" (.421) do not allow to clearly distinguishing one specific category. Finally, factor # 6 explains 7.2% of variance. It is loaded with the two remaining variables: "dominant design" (.867) and the "potential for unit-to-unit transfers" (.506). These two criteria are not directly related from a conceptual point of view.

In summary, market variables are well captured by factor # 3. Competition variables spread over factors # 2 and 5. Technical variables are well summarized by factor # 1. And, factor 4 bundles the two variables in the "socio-political" category. These profiles give partial credence to Proposition 2. The hypothesized partition is not entirely reproduced empirically by these data. As a consequence, Proposition 2 is partially supported by these data.

Test of Proposition 3 on technological competitiveness indicators

Cronbach Alpha coefficients were computed for the two hypothesized category. This gives: .780 for the nine technological resources ($n = 447$); and .781 for the seven complementary resources ($n = 431$). As such, these results give honest credit only to these two categories.

A factorial analysis was conducted on the set of 16 competitiveness variables using the principal component method. The quality of representation is less than with the set of attractiveness variables.

Table 6
Factorial analysis on competitiveness criteria (after rotation).

Factors	1	2	3	4
Percentage of the total variance explained	18.51%	14.60%	13.51%	11.44%
Origin of the assets	.276	−.096	.553	.322
Relatedness to the core business	.082	.055	.023	.775
Experience accumulated in the field	.185	.203	.190	.663
Registered patents	−.116	.686	.216	.244
Value of laboratories and equipment	.289	.521	.157	.383
Fundamental research team competencies	.795	.085	.213	.034
Applied research team competencies	.722	.232	.125	.259
Development team competencies	.781	.133	.114	.193
Diffusion in the enterprise	.208	.021	.588	.357
Capability to keep up with S&T knowledge	.696	.184	.301	.039
Financing capacity	.381	.421	.124	.335
Quality of relationships R&D and Production	.242	.683	.188	.117
Quality of relationships R&D and Marketing	.280	.317	.577	−.248
Capacity to protect against imitation	.345	.683	.063	−.192
Market reaction to the company's design	.033	.352	.751	−.010
Timetable relative to competition	.229	.306	.535	.151

Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser normalization.
Rotation converged in 6 iterations.

Thirteen variables are in the range [.5; .7] and three are less than .5. The KMO test is at .865. This last point means that the analysis demonstrates a good level of accuracy.

Table 6 gives factor analysis results. A four factor solution emerges with eigenvalues >1. These four factors explain 58% of variance. These results give credit to Proposition 3. However, as too many variables (14/16) were loaded on the first factor in the initial computation, a Varimax rotation was conducted. Interpretation of factors was conducted with figures higher than .500 – except for only one variable" financing capacity "(which also exhibits a low extraction level).

Factor # 1 explains 18.5% of variance. It is similar to factor # 1 obtained from the factorial analysis conducted on the whole set of variables. This factor captures all the three variables describing team competencies and bundles a fourth variable which also depends on R&D people. These variables were previously highlighted in the correlation section: the "fundamental research team competencies" (.795); the "development team competencies" (.781); the "applied research team competencies" (.722); and, the "capability to keep up with fundamental scientific and technical knowledge" (.696). As such, it mixes the two hypothesized categories. Factor # 2 explains 14.6% of variance. It exhibits some strong similarities with factor # 2 obtained from the factorial analysis conducted on the whole set of variables. It is a combination of five variables: "registered patents" (.686); "capacity to protect against imitation" (.683); "quality of relationships between R&D and production" (.683); "value of laboratories and equipment" (.521); and, to a lesser extent, "financing capacity" (.421). Again, there is a mix of technological and complementary resources. Factor # 3 explains 13.5% of variance. It is similar to factor # 3 obtained from the first factorial analysis. It puts together five variables: "market reaction to the company's design" (.751); "diffusion in the enterprise" (.588); "quality of relationships between R&D and marketing" (.577); "origin of the assets" (.553); and, "timetable relative to competition" (.535). As four variables (out of five) belong to the complementary resources category, this factor is much more in line with the expected categorization. Factor # 4 explains 11.4% of variance. It is the same as factor # 7 produced with the first analysis. It bundles the two remaining variables: "relatedness to the core business" (.775); and, "experience accumulated in the field" (.663). This clearly relates to technological resources.

These four factors do not reproduce exactly the original split made with "technological resources" on one side and "complementary resources" on the other side. Factor # 4 is the only pure one. Factors # 1 and 3 partially validate the proposal and factor # 2 is clearly not in line with the assumption made.

Discussion

Factorial analysis on the whole set of variables

The empirical evidence of a split between attractiveness and competitiveness shows the unreliability of models of technology assessment based on a single dimension. Audit of the technology portfolio cannot be done on a single dimension, nor can it mix conceptually different constructs. The point is important as companies can only modify their competitive position by their own actions. They cannot change the intrinsic attractiveness of a given technology. The significant correlations observed and the underlying structures that emerged with ten different factors give some incentives for carrying out different factor analysis.

Reducing the set of technological attractiveness variables

This section is an attempt to interpret the factors produced by the analysis. I suggest labeling this first factor: "technical potential". The two variables of factor # 2 express related concepts that can be summarized under one single label: "aggressiveness among competitors". The three variables of factor # 3 express the "market opportunities" offered by the technology. The two variables of factor # 4 deal with the interrelation of technology and society. They can be summed up under the already suggested title: "socio-political issues". The wording of the main variable contributing to factor # 5 can be reproduced identically: "number of competitors". Finally, I suggest putting the emphasis on the first variable of factor # 6 which expresses the "competitive fluidity".

The interesting part of this analysis is that six questions can be used instead of the 16 initial variables. A simplified version of the audit of technological attractiveness can be summarized as follow: (1) How high is the technical potential of the technology? 2) What is the level of aggressiveness among competitors? (3) What are the market opportunities opened by the technology? (4) How is the technology regarded by society? (5) What is the trend in the number of competitors? (6) How is the competitive fluidity?

Reducing the set of technological competitiveness variables

This section is an attempt to interpret factors produced by the analysis of competitiveness variables. Factor # 1 is an unambiguous expression of the strength of the whole research team. It can be summarized under the simple label: "R&D team competencies". Regarding factor # 2, I suggest wrapping up these four criteria in the following wording: "assets and practices supporting the R&D team". Factor # 3 combines two variables expressing the value of the company's technical choices and three other variables depicting the organizational choices made by the company. It expresses the "value of the company's technical and organizational choices". And, finally factor # 4 can be summarized as follow: "familiarity of the company with the targeted technical area".

The interesting part of this analysis is that only four questions can be used instead of the 16 initial variables. A simplified version of the audit of technological competitiveness can be summarized as follow: (1) What is the level of R&D team competencies? (2) What is the value of the assets and practices supporting the R&D team? (3) How valuable are the company's technical and organizational choices? (4) How familiar is the company with the targeted technology?

Conclusions and future research

Summary of results

This research demonstrates empirically the existence of a split between two sets of technology assessment criteria. Correlation and factorial analyses make a clear distinction between technological competitiveness criteria (accumulated value) and technological attractiveness criteria (potential value). The first set of indicators refers to those which are within the company's control and the second to indicators that are beyond the company's control; these results are in line with Griffiths and Webster (2010). Consequently, any auditing method based on one single dimension cannot be considered as valid (the combination of attractiveness and competitiveness is not meaningful). The research partially demonstrates the existence of a split between market, competition, and technical criteria. However, it does not reproduce exactly the hypothesized sub categories regarding technology versus complementary resources; this does not mean that these categories do not exist conceptually, but that they have not been empirically verified.

Limitations and further research

First, the percentage of variance reproduced by the three factor analyses is relatively low (64%, 62.5%, 58%). Second, some variables such as "threat of substitution technologies" or "financing capacity" are not well represented. Third, firm diversity in terms of sector, size, nationality or culture was not analyzed in this research. Thus, generalizability is limited; the set of factors resulting from the analysis correspond to this sample.

As suggested by Chiesa et al. (2008), future studies should analyze the effect of the business sector, the company's size, national origin or company culture. The nature of the business sector might have an impact. For example, the quality of the relationships between R&D and marketing will probably be more significant in the automotive industry than in bio-tech. It can be also argued that the role of socio-political factors vary along different business sectors depending on the level of potential negative externalities. Similarly, it can be argued that the country where the audit is taking place might modify the results. A technology audit in an emerging country is based on different underlying rationales than in one in an industrialized country (Jolly, 2008). Such investigations on control variables would provide a test of the existence of a general model versus more sector, nation or culture dependant perspectives. Longitudinal analysis might also allow test factor stability and generate some trends about possible changes in the set of criteria over time.

The interest for managers

This research has very practical implications for managers who design and conduct technology portfolio audits. First, the set of 32 indicators produced by the literature review can help them to

Table 7
A more efficient set of ten indicators for evaluating technologies.

Environmental factors over which the company has a weak control	Weak attractiveness	↔	High attractiveness
Technical potential	low	↔	high
Aggressiveness amongst competitors	weak	↔	strong
Market opportunities	narrow	↔	wide
Socio-political issues	negative	↔	positive
Number of competitors	decreasing	↔	increasing
Competitive fluidity	rigid	↔	fluid

Internal factors over which the company can exert a strong control	Weak competitiveness	↔	High competitiveness
R&D team competencies / competition	low	↔	high
Assets and practices supporting the R&D team	weak	↔	strong
Value of the company's technical and organizational choices	poor	↔	favorable
Familiarity with the targeted area	unrelated	↔	related

reflect on the assessment criteria that they are currently using; it is an opportunity to review their own practices. Second, the demonstrated distinction between attractiveness and competitiveness should urge managers to consider with suspicion any auditing method which is based on a single dimension, i.e. mixing external and internal criteria or mixing potential value with accumulated value criteria. Regarding criteria beyond the firm's control, the only possible strategy, if the attractiveness is low, would be to quit the domain and to target an area considered to be more attractive. Regarding criteria within its control, there are precisely the indicators that can serve as a benchmark to evaluate managers' performance. Finally, instead of using a long, costly and time consuming list of 32 criteria to carry out an audit, a technology assessment of an acceptable quality can be carried out using a reduced set of ten criteria as shown by Table 7. These questions were presented in previous sections (*Reducing the set of technological attractiveness variables* and *Reducing the set of technological competitiveness variables*). Six questions are sufficient to assess technology attractiveness and only four questions are necessary for the internal audit. A shortened list of criteria is useful because it is easier to mobilize people. It also facilitates the implementation of the audit process. It reduces the difficulty of data collection and computing. Consequently, this saves both time and money.

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