Towards a theory of the technology-based firm

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Abstract

The modern firm is a very viable economic institution, drawing strength from a competitive market economy, with embedded 'super-markets' for corporate control and 'sub-markets' for internal organization. The technology-based firm in addition draws strength from its co-evolution with modern science and technology (and vice versa), and thereby becomes increasingly important. However, received theories of the firm, of which there are many, have not particularly taken account of technology and technology-based firms, nor their management. This paper takes an empirical point of departure from recent findings regarding the positive relationship between technology diversification on the one hand and corporate growth and business diversification on the other. These findings are not readily explainable by received theories of the firm, which the paper reviews, and the findings are thus taken as an explanandum for a proposed approach to formulate a theory of the technology-based firm. The approach is compatible with various other theoretical approaches such as the resource-based, the transaction-cost and the evolutionary approach, but specifically takes the idiosyncrasies of technology i.e., technical competence as well as management into account. Through notably strong economies of scale, scope, speed and space associated with the combination of different technologies and resources, the technology-based firm is subjected to specific dynamics in its growth and diversification and shifts of businesses and resources. In particular, a technology-based firm tends to engage in technology diversification, thereby becoming multitechnological. As such the technology-based firm has incentives to economize on increasingly expensive new technologies by pursuing strategies of internationalization on both input and output markets, technology-related business diversification, external technology marketing and sourcing, R&D rationalization and technology-related partnering.

Keywords: Technology-based firm; Technology; Management; Diversification; R&D

1. Introduction: co-evolution of technology and the firm

In the history of institutions the modern business firm is a fairly recent innovation (emerging in 19th-century Europe), preceded by far by institutions like the church, the farm, the university (emerging in 12th-century Italy) and the bank (emerging in medieval Italy as well), and also by the modern nation-state. As an institutional species the modern business firm in market economies has developed a
remarkable viability and variety. In the 20th century larger and more diversified MNCs (multi-national corporations) and MPCs (multi product corporations) have emerged, typically internalizing some teaching, R&D, and banking functions and at the same time forging links with universities and banks, while the latter institutions at the same time increasingly adopt organizational features from business firms in advanced countries.

The viability of the firm as an institution partly stems from its recombinant property through the market for corporate control. The latter market is in fact a kind of ‘super-market’ since it works as a selection mechanism (‘selection mechanism’ in the sense of Nelson and Winter, 1977, 1982) of a higher order, speeding up both variety generation and selection. Secondly, the viability of a firm also stems from its ability to combine, cumulate, and recombine resources, as well as the ability to rapidly respond to business opportunities and threats, an ability fostered by competition, and the legal framework around a firm together with the signalling system of accounting. (This, however, may in turn produce monopolistic as well as myopic behaviour, both potential dis-functions of the firm as an economic institution).

A third basis for the viability of the firm stems from the development of governance structures and managerial capabilities. From a transaction-cost perspective the emergence of increasingly large-sized, diversified and internationalized corporations could be interpreted as a sign of increasingly lowered governance or management cost on an average, compared to market transaction costs. However, the modern firm has also increasingly learnt to utilize internal ‘sub-markets’ in order to reduce governance cost and/or raise innovativeness (e.g., through the M-form), as well as having learnt to link up with external partners in networks. Thus, the modern firm has developed into a quasi-integrated hybrid form of organization, still with a considerable source of central power, however, thereby distinguishing it from a mere network.

A fourth part of the viability of the firm stems from the long-run evolution of S&T, including the scientific ‘revolutions’ during the Renaissance (introducing, e.g., the method of systematic experimentation) and the Age of Enlightenment. The S&T evolution has continually generated business opportunities and consequential needs, while the basic human needs related to the fundamentally different biological evolution have remained much the same. An increasing range of business firms has then in one way or another (product- or process-wise) become reliant or based upon technology in exploiting business opportunities, thus giving rise to the technology-based firm (TBF) as a growing sub-species of the modern business firm.

As technology (engineering knowledge) has become an economic engine in technology-based firms, these have collectively also become an increasingly important and now major source of technology. Thereby firm-based technology has increased, absolutely as well as relatively. Thus, the increasing

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3 Despite the terms used here no biological analogies are intended. On the contrary, such analogies are often more misleading than helpful when applied to firms and technologies; see Penrose (1952) and Granstrand (1994a, Ch. 19). The (admittedly biology-inspired) terminology is used here as a language of general evolution, not necessarily confined to its application in biology (cf. von Bertalanfyy, 1968).

4 Humans have not, for example, developed three arms for cocktail parties, separate talking and eating body organs or entirely new senses with new forms of stimulation and entertainment.

5 There is no need to operationalize here through some cut-off point when a firm is technology-based and when it is not. However, it is important for the rest of the paper to spell out that the concept of technology is taken here in the narrow sense of natural science and engineering or technical knowledge, thereby sticking to an old tradition according to Cantwell (1994). More specifically I will equate technology with a body of knowledge of techniques that falls in areas containing in principle patentable knowledge, apart from the novelty and non-obviousness requirement of the patent system. Operationalization of technology in this way is immensely aided by the international patent system, which thus provides classification operations which in turn are important for codification (cf. with chemistry). In the same spirit, newness of technology could be defined as less than 20 years (= maximal patent lifetime) of occurrence and a unit of technological advance as the minimum invention level required for patentability. The patent system thus also offers an operationalization of novelty as well as of the size of a novelty in form of a simple metric norm. In general the patent system is underutilized as a way to operationalize technology. It is far from error-free but it is the best at hand, generally speaking.

importance of technology-based firms and firm-based technologies is a perfect example of virtuous co-evolution of an expansionary economic institution and S&T knowledge, at the same time independent of biological evolution in general. 8

Given the prevalence and increasing importance of this co-evolution of firms and technologies, it is natural to theorize about it as a phenomenon. This paper is an attempt to do so, and then with the primary focus on how technology-based firms can be characterized and how they form, grow and expand into many products, markets and technologies. Although heterogeneities in the firm may be important sources of potential economies to be reaped through management, the specific internal organization of technology-based firms is not the primary focus of this paper.

2. Received theory

2.1. General survey

Keeping in mind the ever-present difficulty of judging current times, one can venture to say that currently there is a surge of efforts among scholars to formulate new or improved theories of the firm, its nature, reasons for existence, behaviour (actual/optimal), differences and effects. This section cannot comprehensively review these efforts, nor put them in their historical context.9 A few common features of current theorizing will be pointed out, however, and then the role of technology and management in received theory will be briefly surveyed.

A first common feature of contemporary theorizing about the firm is that the firm is viewed as ‘something A of something B’, using two sets of terms for A and B. A-terms are then pool, set, bundle, nexus, cluster, portfolio, repository etc. and B-terms are resources, contracts, treaties, relations, capabilities, competences, activities, incentives, people, products and so on. In this way two fundamental properties of the firm are pointed out. First, the coherence in some sense 10 of the firm is expressed by the A-terms which is conceptually similar. Second, the heterogeneity of the firm is indirectly expressed by the range of conceptually different B-terms, the choice of which depends upon what is suggested to be considered as being of primary focal concern. 11 In passing one may note that no AB-combination strictly contradicts another and thus they may in principle be seen as complementary partial views.

A second fairly common feature is the emphasis on time-related properties of the firm (although there is considerable theorizing which is essentially static). Besides general time-oriented concepts such as dynamic, historic, evolutionary etc., commonly used terms refer to path-dependency, continuity etc. Here one can discern a dimension along which authors orient themselves, and that is from emphasis on continuity to emphasis on discontinuity in viewing the evolution of firms and their features. 12 However, although there is a great deal of writing about activities inducing discontinuities such as start-ups, mergers, acquisitions, spin-offs, restructuring, bankruptcies and the like, one is left with an impression that the currently prevailing emphasis is rather on continuity, stressing the firm’s resilience, adaptation, cumulation, long-run build-up of competitive advantage, sustainability and so on. 13 This espe-

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8 In some sense the Christian church as an institution on the one hand and S&T on the other hand would rather be an example of adversary co-evolution, at least in the Middle Ages.
9 That is to say, independence at large and so far. Biology and genetic engineering develop as a S&T field and biotech-based firms increase in numbers. New evolutionary patterns in nature may take root as a result, desirable or not. Incidentally, this may open up possibilities for new analogies between biology, firms and S&T.
10 This is a large research undertaking in itself, for which there is currently a need, although there are several good works of such a review type; see, e.g., Fransman (1994), and the whole journal issue of ‘Industrial and Corporate Change’, Vol. 3, No. 3, 1994, for a review of current theorizing, related to the concept of dynamic capabilities.
11 The very concept of coherence of the firm has been elaborated by Dosi et al., (1992). Thus, a firm is like a coherent but ‘white elephant’, with pluralistic explanations, not necessarily contradictory.
12 A similar continuity–discontinuity dimension exists among views on evolution of technologies.
cially pertains to views on large firms. Thus, one may be led to believe that continuity and large size of the firm are associated, but one may as well be led to believe in a general increase of continuity in industrial society. 14

The continuity view of the firm implies the existence of inertia and various speed limits in the processes of evolutionary (rather than revolutionary) change of the firm, speed limits beyond which there are no time/cost trade-offs (e.g., regarding learning or mobility of resources). That is, beyond some point time cannot be bought, and thus time is an independent analytical concept, irreducible to money and other economic resources.

The third common feature of theories of the firm is the notion of existence of a firm’s interior in some sense, as opposed to its exterior (or its environment). The notion of an interior and an exterior follows from a notion of a boundary of a firm but does not require such a notion. That is, a concept of a boundary of a firm is sufficient but not necessary in order to have a concept of an interior of a firm. 15 Although perhaps overly abstract, this nevertheless has implications for transaction cost theorizing.

Authors tend to orient themselves along the interior–exterior dimension as well. Authors emphasizing the role of the exterior environment often have difficulties to explain why firms facing similar environments differ. 16 Also a reverse statement is true. The resource-based theories of the firm, which now attract a great deal of effort, 17 may be tempted to emphasize the interior, although resources do not necessarily have to be seen as entirely belonging to the interior. 18 In particular, the existence of resources in some kind of interior is taken as given, which makes resource-based theories similar to neoclassical theory of the firm in their difficulty of explaining how the firm once came into existence and started to develop its resources in the first place.

Emphasis along the interior–exterior dimension also tends to reflect on the emphasis given in strategy formulations for firms. A strategy may emphasize economizing upon resources on the one hand, their ‘push’ and ‘stretch’, economies of scale and scope, costs etc. and on the other hand economizing upon external opportunities, ‘market pull’ etc. Of course, both views are possible and advisable to reconcile in an iterative, interactive process of strategy formulation (see Section 4).

Business transactions constitute a particular form of interactions between the interior of the firm and its exterior, giving rise to costs and benefits. Transaction cost theory traditionally uses the firm and the market as two distinct types of organizing an economy, which enables one to look at transaction costs for one type relative to the other as an opportunity cost, subsuming any relative benefits. The permissible range of boundaries of the firm in an optimal economic organization could then in principle be found by equalizing the transaction costs for the two polar types. 19

A particularly important resource, attracting much attention in contemporary theorizing, is competence or capabilities. The process of competence-building or learning could be seen partly (but only partly) as resulting from interaction between the interior and exterior. 20 The notion of core competence, advocated by Hamel and Prahalad (1994) and Prahalad and Hamel (1990), is closely linked not only to the notion of an interior of the firm, but to the notion of some central part of this interior. 21 In passing one

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14 The old vs. the young Schumpeter is the classic example of this, of course.
15 Cf. corresponding notions in topology or in fuzzy set theory. Cf. also the notion of a set of boundary-spanning activities.
16 Since separate different firms belong to each other’s exterior, however, their exteriors differ in principle.
18 Examples of this would be resources shared with external partners or external relations seen as resources. New information technologies offer increasing possibilities for firms to develop resource-sharing relations rather than narrow exchange relations with the environment, giving rise to notions such as ‘the network firm’ or ‘the virtual corporation’ or ‘the imaginary organization’.
19 To the extent that the modern firm has developed into a quasi-integrated hybrid of the pure polar types of organizations, i.e., markets vs. hierarchies, as mentioned in Section 1, one can question the empirical validity of this dichotomy. This in turn does not invalidate the transaction cost concept, but it severely complicates its use as an opportunity cost concept.
20 Cf. the notion of learning by interacting in Lundvall (1992).
21 The term ‘core’ is etymologically related to the Latin word for heart. ‘Core competence’ may be defined somewhat ambiguously but is used mostly in the sense of something central (not only distinctive) in the interior of a firm.
may also note that centrality notions of this sort also tend to be associated with notions about continuity and stability, and may even invite static thinking. 22

A particularly important competence in turn is managerial (or organizational) competence (or capability). 23 Managerial competence is necessary to mobilize, combine and exploit other resources in response to business opportunities. Viewed as a resource it differs fundamentally from all other resources since it is the only resource that is truly necessary for a firm, functionally as well as legally. 24

2.2. Diversification of firms

An important feature in the evolution of firms is diversification, that is, in a general (and a bit ambiguous) sense the firm’s process as well as state of expansion into a wider variety of activities. Diversification along various dimensions is characteristic of firms, as both specimens and species. Typically the concept of diversification among scholars refers to product diversification, but it is sometimes also used to refer to market diversification, of which internationalization would then be a special case. Internationalization and the MNC have received a great deal of attention, 25 product diversification and the MPC less so, at least until fairly recently. 26 This is surprising since the MPC has long been the rule rather than the exception, and more so than the MNC in fact. 27 Nevertheless, neo-classical theory of the multiproduct, multifactor firm appeared before any specific theory of the MNCs. However, it was not really until the 1980s that other types of economic MPC-theorizing emerged, after the introduction of a formal concept of economies of scope by Pantzar and Willig in the mid-1970s, the revived interest in transaction cost theory triggered by Williamson (1975) and the general aftermath of the diversification failure wave of the 1970s. 28

Both MNCs and MPCs are reconcilable with most received theories, be they transaction cost-based, resource-based or evolutionary. 29 Such current theories offer some general explanations and predictions regarding MNCs and MPCs. The challenge ahead is to make them more specific and precise.

2.3. Technology and management in theories of the firm

The distinction between technology and management is fundamental for our purposes here. (For an overview of definitions of these concepts, see Granstrand, 1982). Technology and management as two separate concepts have implicitly or explicitly featured in theories of the firm since long ago; see Table 1 for an overview. However, differences in technology and management in and among firms over time (including technical and managerial innovations and learning, and a skewed distribution of levels of technology and management among firms at any point in time) have not featured in theory-making until fairly recent attempts. Thus one may

22 Cf. the notion that there is a certain industry the firm operates in and should define for strategic purposes, with Levitt (1960) as a classic proponent. Similarly, notions of a fundamental corporate identity or timeless vision invites rigidity in the long run (cf. the well-known C&C concept in the Japanese NEC).

23 Again several distinctions are possible (managerial, organizational, economic, entrepreneurial etc.) but not of primary importance at this stage, except to say that neither technology (= technical competence) nor managerial competence should be subsumed one under the other, if catch-all concepts are to be avoided (cf. Eliasson, 1994a).

24 Self-organizing entities devoid of any central management are conceivable (just as there are seemingly self-organizing communities of social insects like an ant colony or a bee-hive), for example a small cooperative or a network organization, but some kind of hierarchy with some kind of management is still likely to develop beyond a certain scale for various reasons.


26 Penrose (1959) is a classic pioneering work on the subject. For good literature reviews, see Ramanujam and Varadarajan (1989) and Montgomery (1994).

27 A possible reason behind the relative preoccupation with MNCs may be their closer links to policy issues, at least in market economies. (For a planned economy of the old Soviet type, the MPCs in form of so-called MNTKs were probably receiving more attention than the MNCs).

28 A good example of such theorizing is Teece (1982). A classic empirical work on MPCs is Rumelt (1974), just as Hymer (1976) was for MNCs.

29 Exceptions would be the OLI-paradigm of Dunning for MNCs, a paradigm which does not (easily) lend itself to incorporating MPCs, and neo-classical theory of MPCs, a theory which does not naturally extend to MNCs.
Table 1
Typical representations of technology and management in theories of the firm^a^.

<table>
<thead>
<tr>
<th>Theory (central authors)</th>
<th>Focal concern</th>
<th>Basic categories/factors</th>
<th>Representation/role of technology factor</th>
<th>Representation/role of management factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neo-classical (NCT)</td>
<td>Optimal factor input and product output decisions in short/long-run profit maximization</td>
<td>Factor inputs; Product outputs; Production function; Profit, prices, costs</td>
<td>Production function Factor input</td>
<td>Flawless, costless profit maximizer</td>
</tr>
<tr>
<td>Mathematical programming (MP)</td>
<td>Optimal activity level decisions for maximizing output or profit under resource constraints</td>
<td>Resource inputs; Product outputs; Activity levels; Profit, prices, costs</td>
<td>Resource consumption coefficients Factor input</td>
<td>Flawless, costless profit maximizer</td>
</tr>
<tr>
<td>Transaction cost (Coase, Williamson) (TCT)</td>
<td>Existence and boundaries of firms in a market economy</td>
<td>Transaction cost as a function of uncertainty, bounded rationality, opportunism, information asymmetry, asset specificity</td>
<td>Process technology-oriented Reducible to transaction costs</td>
<td>Embedded in transaction costs</td>
</tr>
<tr>
<td>Principal agent (PAT)</td>
<td>Relation between resource owners (principals) and resource managers (agents)</td>
<td>Contractual design for the organization facing asymmetries of information and incentives among owners and managers of resources (properties)</td>
<td>Implicit as just any source of asymmetries</td>
<td>Explicit maximizers of different, interdependent utility functions, incurring a management cost to owners</td>
</tr>
<tr>
<td>Evolutionary (Nelson, Winter) (ET)</td>
<td>Evolution of the firm</td>
<td>Selection mechanisms, variety generation, routines, dynamic processes etc.</td>
<td>Innovative and imitative R&amp;D as randomizer and variety generator</td>
<td>Embedded partly in routines, partly in entrepreneurial activities</td>
</tr>
<tr>
<td>Resource-based (RBT)</td>
<td>Competitive success and evolution of firms</td>
<td>Resources (e.g., competences)</td>
<td>As a particular competence</td>
<td>As a particular competence</td>
</tr>
<tr>
<td>OLI (Dunning)</td>
<td>MNC existence and behaviour</td>
<td>Advantages of MNCs stemming from ownership, location and internalization</td>
<td>Embedded in ownership</td>
<td>Embedded in internalization</td>
</tr>
</tbody>
</table>

^a^The table is not complete. Various variants and extensions of the theories are ignored here, and only a sample of illustrative concepts is given.
claim that although there has been a co-evolution of technology and firms, there has been no corresponding co-evolution of technology and theories of the firm. In all fairness, one must admit that technology has penetrated the firm more in practice than in theory. \[10\]

The technology factor is increasingly attended to in economic theorizing, however, but the management factor much less so. While its role in practice is pervasive, its role in theory is evasive. Part of the difficulty stems from the lack of good representations and operationalizations of managerial competence. While no one doubts the presence of technological evolution, many doubt whether there has been any evolution of management, although arguments for the latter evolution could be made and cases of managerial innovations apart from mere fads could be demonstrated. \[31\]

The consequences of assuming a managerial evolution in general, and differential managerial learning among firms specifically, are vast, however. \[32\] The problem is how to represent management theoretically and for the latter evolution could be demonstrated. \[31\]

The consequences of assuming a managerial evolution in general, and differential managerial learning among firms specifically, are vast, however. \[32\] The problem is how to represent management theoretically and rational and how to relax assumptions in received theory without letting the management factor be a catch-all concept.

Finally, in brief terms of the categories in Table 1, the theoretical approach in this paper has as its focal concern the technology-based firm, its formation, existence, growth and diversification. Basic factors are especially resources and their characteristics, notably technology and management, management cost and economic characteristics of resource-related processes (economies of scale, scope, speed and space), static as well as dynamic. Technology is represented as a body of knowledge, together with physical characteristics of its embodiments. As a resource, technology has certain idiosyncrasies, giving rise to specific and strong economies. Similarly management is a body of knowledge, together with behavioural characteristics of its embodiments. As a resource, management is viewed as a specific meta-resource. As a set of ‘behavioural algorithms’ (including routines as well as random elements), management is costly and imperfect but has a property of self-improvement.

3. Empirical findings and analysis

3.1. The key role of technology diversification in corporate economics

This section summarizes the empirical findings of a research project on the economics and management of large, technology-based firms in Europe, Japan, and the US, carried out in 1987–1994 by the author and his colleagues. \[34\] The project consisted of sev-
eral sub-studies, altogether covering by interviews, questionnaires and published data a sizable sample of the world’s largest technology-based corporations. 35

Major empirical findings of the project were as follows.
1. Technology diversification at firm level, i.e., the firm’s expansion of its technology base into a wider range of technologies, was an increasing and prevailing phenomenon in all three major industrialized regions, Europe, Japan and US. This finding has also been corroborated by Patel and Pavitt (1994). The prevalence of technology diversification as a phenomenon in technology-based firms prompted the notion of a multi-technology corporation (MTC) as, roughly expressed, a firm having diversified into several technologies (i.e., technical competence areas).

2. Technology diversification was a fundamental causal variable behind corporate growth. This was also true when controlled for product diversification and acquisitions. 36

3. Technology diversification was also leading to growth of R&D expenditures, in turn leading to both increased demand for and increased supply of technology for external sourcing.

4. Technology diversification and product diversification were strongly interlinked, often in a pull-push pattern in economically successful firms, leading to hybrid MPC/MTCs.

5. The high-growth corporations followed a sequential diversification strategy, starting with technology diversification, followed by product and/or market diversification. This result was independent of region and industry.

6. Japanese companies had on an average the most developed managerial capability for concerted technology, product and market diversification.

These findings were not readily explainable in terms of received theories of the firm, as reviewed in Section 2. Without going into detail about the pros and cons in using received theories to describe, explain and predict the behaviour of technology-based firms, one can note that technology diversification, being a central feature in the empirical findings, does not feature at all in received theories. Moreover, most theories do not explicate the dynamics and the heterogeneity of technology, and many restrict their focus to process technology (see, e.g., Milgrom and Roberts, 1990, for an otherwise novel approach).

3.2. Theoretical analysis of technology diversification at firm level

At a given point in time an MPC/MTC (by definition) comprises several products (or businesses) and technologies, comprising the product base and the technology base respectively for the corporation. These bases are linked to each other, e.g., as in Table 2 (built on an actual case). The more technology-product couplings, the more synergies there may be. Here one could note, for example, the following.

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35 The main interview and questionnaire study covered 14 Japanese large corporations (Hitachi, NEC, Toshiba, Canon, Toyota etc.), 20 European (Ericsson, Volvo, Siemens, Philips etc.) and 16 US (IBM, GE, AT&T, GM, TI etc.) representing, e.g., 38% of total US industrial R&D in 1988. Analysis of published data, as reported in Oskarsson (1993), covered 57 large OECD corporations. Additional case studies of companies and product areas have been conducted as well.

36 This finding has later been confirmed also by Gambardella and Torrisi (1997) for 32 of the largest European and US electronics firms.

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<table>
<thead>
<tr>
<th>Technology</th>
<th>Product business</th>
<th>P1</th>
<th>P2</th>
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<td>Electronic hardware</td>
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<td>Electronic packaging</td>
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<td>Computer communication</td>
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<td>Image processing</td>
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<td>Systems technology</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
a) The technology base of product \( P_1 \) is highly technologically diversified, while for \( P_2 \) it is not.

b) Electronic hardware is a generic technology, while hydro-acoustics has a narrow applicability in the product base of the corporation.

How has an MPC/MTC developed such a coupled technology-product structure? Generally speaking, it may of course result from radical restructuring done for various reasons, but here we will focus on a second route with more organic evolution. \(^{37}\) For a given product, new customer requirements and technological opportunities create a need for making transitions in the technology base of a product, which leads the company to develop or acquire new technologies through product-related technology diversification. Once acquired, these technologies may then give the company an incentive to engage in technology-related product diversification through economies of scale and scope (see further below). This type of ‘first pull then push’ interplay between technology diversification and product diversification, simply speaking, results from ‘market pull’, followed by internal ‘technology push’ (or ‘resource push’).

Fig. 1 illustrates this stepwise corporate evolution in principle over time (with time points \( t_1 \) to \( t_6 \) and an arrow denoting entry into a TP-combination and \( \dagger \) denoting exit from a TP-combination). The combined technology/product base thus shifts over time, just as the customer base may do in accordance. Product invention-based companies in electrical and mechanical engineering then often display a kind of ‘rooted’ diversification, sticking to the original product business area, while diversifying into others. A kind of ‘floating diversification’ on the other hand is common for a raw material-based company or a chemical company over long periods of time, in the sense that the company diversifies away (i.e., exits) from its original product business area. For this type of companies, physical by-products in extraction and processing also play an important role in the diversification process.

Technology diversification as an empirical phenomenon has only recently attracted an interest among researchers, and then primarily outside the economic tradition, with pioneering works by Pavitt (1988), Pavitt et al. (1989) and Kodama (1986a,b). \(^{38}\) The apparently key role played by this variable in the economics of technology at corporate level, as described above, is a new finding for which any explanation at this stage must be tentative.

Regarding causes and consequences of technology diversification, tentative modeling is presented in Granstrand and Sjölander (1992b) and Granstrand et al. (1992a), which emphasizes progress in S&T together with differentiation of both S&T fields and market needs. This view is closely related to the view that an expanding set of opportunities, technological as well as business opportunities, is a major factor in a number of phenomena. The notion of opportunity has attracted a great deal of scholarly interest since long ago. Schumpeter (1976) discards the notion of a set of investment opportunities vanishing over time with reference to ever-changing capital-consuming technology. Penrose (1959) treats technology and industrial R&D as one (out of several) important sources of new opportunities for product diversification in general. Scherer (1980) identified technological opportunity as the most important factor behind differences in innovativeness between different industries. Jaffe (1989), in trying to quantify technological opportunities, argued that R&D and technology must be looked upon as con-

\(^{37}\) This route has been typical for diversification in Japanese corporations.

\(^{38}\) Incidentally no reference is made to it in surveys by Ramanujam and Varadarajan (1989) and Montgomery (1994). The connection between R&D and product diversification has been dealt with in literature, however, with Nelson (1959) as a pioneering theoretical work, later verified by Link and Long (1981).
sisting of a number of distinct technological areas. This view is consistent with the frame of reference in Granstrand and Sjölander (1990) which introduced the notion of a multitechnology corporation, acquiring and exploiting a variety of technologies. In fact, it may be argued that technological opportunities are generated in a fundamentally important and inexhaustible way through the combination and recombination of various technologies, new as well as old. Of course, far from all combinations are technically and/or economically feasible, but the technological opportunity set might still grow rapidly and even progressively, due to the exponential growth of the number of combinatorial possibilities in principle. Such a process of combinations and recombinations could be considered to lie at the heart of the invention and innovation processes, in which technologists, managers, and markets filter out technically and economically infeasible combinations.

Theoretically, in the process of taking advantage of technological opportunities, technology diversification at the corporate level may lead to increased sales in four different and complementary ways. Firstly, there are static economies of scale to the extent that the same, or close to the same, technologies could be used in several different products with minor adaptation costs. Because exploiting knowledge in various applications is characterized by relatively smaller variable costs per additional application in relation to the fixed cost of acquiring the knowledge, the static economies of scale are significant when a technology has a wide applicability to many different product areas in a corporation. This is the case for generic technologies by definition. Secondly, knowledge is not consumed or worn out when applied, but it is typically improved through learning processes when applied several times, which allows for dynamic economies of scale. Thirdly, different technologies have a potential to cross-fertilize other technologies, yielding new inventions, new functionalities and increased product and/or process performances when combined, regardless of whether the technologies in question have a wide applicability to many product areas or not. This cross-fertilization then yields what could be called true economies of scope, which are not the kind of economies of scope that arise from shared inputs, and are special cases of economies of scale. This third type of economy, potentially associated with technology diversification, depends on specific technologies which could be combined or integrated, and also vary over time, depending upon the intra-technology advancements. Fourthly, combining technologies mostly requires some technology transfer, and (under certain conditions) intra-firm technology transfer is faster and more effective than inter-firm, giving rise to speed and timing advantages in an MTC, advantages that will be labelled economies of speed here.

According to the empirical findings above, technology diversification leads not only to sales growth but also to growth of R&D expenditures. Tentatively, this is because when a larger number of technologies is involved, a larger amount of coordination and integration work is needed, apart from the cost of acquiring each new technology, as difficulties arise in connection with conducting multidisciplinary R&D. These difficulties are widely reported and typically involve conflicts between professional subcultures in science and technology, NIH-effects and other innovation barriers (see Granstrand, 1982). Thus, in order to reap net benefits from technology diversification leading to growth of both sales and R&D expenditures, the integrative capabilities of both technologists and managers become decisive.

Finally, it should be noted that the causal relationship between R&D costs and sales has been widely observed, although with no recognition of the importance of technology diversification. In brief, successful R&D with a time lag tends to lead to sales growth on an average. In some corporations there is also a tendency to let annual R&D budgeting decisions be influenced by a certain fraction of past

\[ N \]

**If** \( N \) **is the number of important technologies, some of which have mutual relations giving rise to combination costs, the R&D costs at product level could specifically be hypothesized to depend quadratically on** \( N \), **that is, R&D costs** \( \text{R&D costs} = a + bN + cN^2 \). **If some of the possible interdependence relations among the** \( N \) **technologies are assumed to contribute roughly equally to R&D costs, then these would hypothetically grow exponentially, i.e., R&D costs** \( \text{R&D costs} = a + \exp(bN) \), **as a result of technology diversification. The often observed progressive rise in R&D costs in a product area over time, or over successive product generations, could thus be explained, at least partially, by technology diversification, with the shape of progressive growth being somewhere in between quadratic and exponential growth.**
years’ sales, which sets up a causal relationship between past sales and future R&D costs. Thus, there is an observed tendency for R&D costs and sales income to mutually reinforce each other over time but with different time lags and different strengths in the causal couplings. Moreover, comparisons of R&D intensities among competitors, which are commonly made in some industries when making R&D budgets, may yield industry-wide similarities in R&D intensity. However, such practices may have to be reconsidered when taking the consequences of technology diversification and technology-related product diversification into account.

4. Elements of proposed theory

The purpose of this section is to put the empirical findings and their tentative theoretical explanations in Section 3 into a more general theoretical framework for the technology-based firm, and thereby draw as well on received theory as briefly recapitulated in Section 2.

This can only be a first step towards a theory of the technology-based firm. As such it departs primarily from resource-based theory but also from evolutionary theory and systems theory in general aspects.

4.1. The environment-resource-management view of the firm in general

An outline of the proposed theory of the technology-based firm is as follows. A business firm in general is viewed as a legally identified, dynamic human system, consisting of a set of heterogeneous resources in an institutional setting (defining, e.g., property rights). The firm has an interior and an exterior (or environment) subjected to management and business ideas with a dynamic goal (or incentive) structure having commonalities for coordinating purposeful action. The interior interacts with the exterior in various ways, in particular through business transactions (economic exchange) on a market, taken as a network of meetings between buyers and sellers. The business transactions are essentially exchanges of resources between the firm and its environment, typically production factors and products (in a wide sense, including any services) for money. A business is defined here as a set of business transactions, which is coherent in some sense in terms of resources, products and markets.

As the system evolves, resources are transformed as a result of interior operations or activities as well as of interaction with the exterior. In particular, resources are acquired and exploited through both interior operations and business transactions. To the extent that resources are acquired and exploited by the firm through business transactions, one can speak of them as inputs and outputs of the firm respectively. However, resources could also be classified as inputs and outputs of a resource transformation process (production process in a wide sense) inside the firm, not necessarily directly linked to business transactions with the exterior.

The environment must be explicitly recognized since it provides business opportunities without which the firm will atrophy. At the same time a firm faces environmental challenges or threats and may go bankrupt or disappear through merging or acquisition or liquidation. This normally results from interaction with the environment, which thereby provides not only opportunities but also threats. The opportunities and threats in the environment are changing, partly influenced by the firm, partly beyond its influence. The influence depends on the firm’s management and (other) resources, which in turn are influenced by the environment and its past, current and anticipated interaction with the firm. The major strategic task for management is to position the firm in the stream of opportunities and threats, having a suitable resource structure that can also be transformed over time to meet new opportunities and threats. 40

In a TBF, then, all of the elements in the general view of the firm have technology-oriented components. Thus, technologies constitute a vital part of the firm’s resources. A substantial part of the firm’s interactions with the environment are influenced by internal and external technical and technological

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40 This formulation does not imply that opportunities are fully exogenous to the firm. For example, a firm that comes up with an innovation may create entirely new opportunities, some of which also spill over to other firms.
changes, opportunities as well as threats, and the corresponding part of the environment is technology-oriented and constitutes the firm’s technological neighbourhood. Moreover, technology management is a vital part of management and technology-oriented ideas and goals are a vital part of the firm’s business ideas and goal structure, although typically more or less aligned to economic goals.

So far there is not much new about this view of the firm in general as a system, which is dynamic, self-organizing, resource-transforming, interacting, human, purposeful etc. Nor is it yet clear that the TBF is a particularly interesting special case for theorizing, although empirical evidence points in that direction. It is when the structure of the resource set and its associated processes of acquisition and exploitation are specified that something new and useful can hopefully be achieved. Next this specification will be made, or at least forwarded a bit.

4.2. The resources of a firm

4.2.1. General resource structure

The resource set is considered as the firm’s capital (or capitalized assets), and is decomposable into physical, financial and immaterial (or intangible or intellectual) capital (IC). Immaterial capital plays a key role, and encompasses both disembodied IC (including business ideas) and embodied IC, the latter in the form of relational capital and competences (or capabilities) possessed by humans. Disembodied IC is partly protectable by intellectual property rights (IPRs), including trade secret protection (whether weak or strong) of business ideas. Table 3 gives an overview of the resource categories used here, which in fact is one way (out of several)

to present a structure of asset categories on a balance-sheet.44

IPRs constitute an important part of IC.45 The IPRs are both registered and unregistered. The company know-how in the form of trade secrets is an important part of unregistered IPRs. This know-how is partly disembodied human competence. The embodied human competence is part of the company’s IC, controlled through employment contracts. Thus, it has to be looked upon as leased human capital or IC rather than human capital owned by the company.46

The capital structure (resource structure) differs across companies and sectors and may then be used for constructing taxonomies of, e.g., companies, e.g., classifying them into raw material-based, IC-intensive, knowledge-based, technology-based etc. The capital structure of a company also is reflected in its culture and management style (and vice versa, of course). Thus, organizational features and management skills are differentiated across sectors (forestry, banking, pharmaceuticals etc.), and management as an asset acquires a certain specificity to other assets, as well as to the local environment. Such adaptations

44. This does not mean that there is nothing disputable about such a view.
45. At this level of analysis, concepts such as resource, capital, and asset could be used interchangeably.
46. Several terms are usable and distinctions could be introduced but, at this level of analysis, terms such as competences, capabilities, abilities, skills, knowledge and so on can be used (roughly) interchangeably. Also the terms immaterial, intangible and intellectual could be used interchangeably in this connection although some would argue that intellectual capital has a more narrow connotation, than immaterial capital.
Table 3: Resource categories of a firm

<table>
<thead>
<tr>
<th>Material (tangible)</th>
<th>Financial capital</th>
<th>Intellectual property rights (Disembodied IC)</th>
<th>Good-will and power in internal/external relations (relational capital)</th>
<th>Human capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical capital</td>
<td></td>
<td></td>
<td></td>
<td>(embodied)</td>
</tr>
<tr>
<td>Natural resources</td>
<td>Liquid capital</td>
<td>Patents</td>
<td>Employees</td>
<td>Managerial</td>
</tr>
<tr>
<td>Raw materials</td>
<td>Bonds</td>
<td>Databases</td>
<td>Customers</td>
<td></td>
</tr>
<tr>
<td>Machinery</td>
<td>Shares</td>
<td>Know-how</td>
<td>Suppliers</td>
<td></td>
</tr>
<tr>
<td>Work in progress</td>
<td>Securities etc.</td>
<td>Licenses</td>
<td>Competitors</td>
<td></td>
</tr>
<tr>
<td>Inventories etc.</td>
<td></td>
<td>Brand names</td>
<td>Universities</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Designs</td>
<td>Investors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software</td>
<td>Interest</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Copyrights</td>
<td>organizations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concessions etc.</td>
<td>Societies etc.</td>
<td></td>
</tr>
</tbody>
</table>

Note: Exactly what IC should encompass is debatable but it should definitely include IPRs as well as human competence (or capital or capability) and good-will. For simplicity, IC will here be taken to comprise all immaterial or intangible resources or assets, admittedly with some conceptual borderline problems.

4.2.2. Acquisition and exploitation of resources

The processes by which resources are acquired and exploited (including processes for generation, combination, transformation, regeneration and recombination of resources) vary widely across companies and sectors, of course, and give rise to variations in economic performance, in turn affecting further acquisition of resources. Resources by themselves then have different intrinsic economic properties that make their acquisition and exploitation processes different from each other, just as their transformations could be characterized in economic terms in various ways. We will distinguish between four general types of process related economies involved: static and dynamic economies of scale (in the ordinary sense of declining average cost), scope (in a broad sense of synergies), speed (advantages of absolute and relative pace of a process) and space (advantages of location).

4.2.3. Management as a meta-resource

It is not sufficient to view the firm simply as a set of resources without any reference to the way in which this set came into existence and then evolved. In order to get a business firm started operationally (not only legally), there must be some business opportunity in the environment and a business idea in some person’s mind of how to exploit this opportunity. The business idea, which may be treated as a piece of IC (e.g., a patent or a trade secret) and the person as an entrepreneur (manager) constitute the initial necessary resources.

Managerial competence is also part of the firm’s IC and is a decisive resource for reaping different types of economies for the firm’s formation, sustained existence and development. Management 47

Note: No essential distinction is made at this level of the analysis between management, entrepreneurship, leadership, administration etc. Neither is a distinction made here between ownership and management. Ownership can rather be viewed as management at a specific managerial level, when need arises to make this admittedly important distinction (as in PAT).
acquires, combines and exploits resources in response to business opportunities in the firm’s exterior, thereby performing a control function (in a wide sense) in the system. In that sense, management could be viewed as a meta-resource. As such, managerial competence is a unique resource that is not substitutable in its entirety. The use of this resource takes time and is associated with a cost, which we can call management cost. Such a concept of management cost can then be used as an alternative to a transaction cost concept when only two governance structures are used, i.e., markets and hierarchies, and it can be used as a complementary analytical concept in a general case. What makes management so special as a resource is that it is a resource which is of unique decisiveness for any firm, and that it is a resource which has to be ‘self-sourcing’ and ‘self-allocating’ in some sense. That is, management has to decide by itself (owners apart) how much effort to allocate to different tasks. This decision in turn requires some effort, and thus a theoretically difficult recursive problem of mental economy arises, usually resolved in practice by attending to time limits and a dominating need for corrective action rather than calculation.

However, management cannot be viewed as a meta-resource, incurring a management cost, solely in a traditional rational economic perspective. Various behavioural characteristics at individual and organizational level have also to be considered, just as done in TCT (with bounded rationality and opportunism). To illustrate, a behavioural characteristic among entrepreneurs of importance for transaction cost considerations in general is what we can call their ‘entrepreneurial hubris’ giving them a bias towards overvaluing their IC, i.e., their business idea and managerial competence. This means that they tend to perceive a market failure even if there is none regarding the firm’s initial capital value. This behavioural bias (‘economies of hope’) tends to keep the firm together, as well as tending within limits of course, to develop the firm, giving it more ‘animal spirits’ and ‘sweat equity’ in the pursuit of entrepreneurial goals and acts of will. That is, this type of expectation bias among entrepreneurs, which in that sense is to be regarded as a managerial deficiency (or ‘management failure’, to allude to the market failure concept), increases corporate coherence and sustainability. (Again within limits. Often there is too much of entrepreneurial hubris, then risking disaster and dissolution of the firm). Additional influence from any market failure, e.g., regarding market valuation of knowledge or complementarities, only serves to reinforce corporate coherence. The latter is thus explainable (at least partly) by reference to market failure or management failure (in the above sense) or both, each factor being in itself a favourable condition in principle for coherence, provided it is suitably biased.

Managerial competence is moreover to be regarded as a bounded, difficult to codify, non-protectable by patents, dynamically evolving, heterogeneous resource, especially in a large corporation, with many sub-competences pertaining to different managerial areas, tasks and functions (marketing management, financial management etc.). Technology management, then, is of particular concern in a TBF.

4.2.4. Knowledge properties in general

Since knowledge (competence, capability) plays a key role as an IC resource, its intrinsic economic properties need to be recognized. This is often done and there are various ways to characterize these properties, the characterization below being just one. However, it is important to make a fairly complete characterization of properties of economic relevance in order to limit discussion of epistemological issues.

Thus, knowledge (competence) embodied in humans (1) consumes much time and effort to acquire it, especially at individual level; (2) consumes little time and effort to use it, once acquired; (3) improves and cumulates through use without deterioration (knowledge is limitlessly reusable or inexhaustible without wear, implying non-rivalry in consumption, and possibly with negative depreciation), but may deteriorate without use, creating a need for mainte-

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48 The occurrence of managerial evolution, innovations and learning serves to lower this cost, just as new technologies may do, e.g., new information and communication technologies; see Section 2 above.

49 There are other dimensions of entrepreneurial characteristics as well, of importance for the formation and existence of a firm, such as need for achievement, need for autonomy and need for power.
nance; (4) is irreversibly transferable to others, if it is suitably codified and adapted to the recipients' knowledge, while still being kept by the knowledge-holder (and possibly even improved through 'learning by teaching'). Thus knowledge is cheaply cloned or reproducible if codified; (5) is impossible to be dispossessed of, for an individual, and difficult to dispose of, i.e., to unlearn or scrap. Machines are scrappable, but knowledge is not, thereby inducing irreversibility of its advances; (6) often has strong complementarities with other knowledge parts; (7) is easily rendered obsolete by new knowledge parts, appearing over time; (8) is possible for an individual to keep in (almost) perfect secrecy control; (9) is impossible to distribute quite equally among agents; (10) is generally more expensive to generate than to regenerate or imitate e.g., knowing that something is possible, or exists, cheapens the search for it) and the generation of knowledge is uncertain and filled with surprises.

Thus, compared to physical resources (capital), knowledge resources have some fundamentally different properties, like being inexhaustible, irreversibly produced and transferred, due to a dispossession impossibility, and reusable and reproducible at no or low cost. Economic and legal concepts and 'laws' for physical resources thereby could be expected to apply in some respects fundamentally different from knowledge resources.

Acquisition and exploitation of knowledge are thus characterized by a large fixed initial investment cost with a small variable cost in application. The variable cost may even be negative sometimes, because of learning by using the knowledge. The 'technical' lifetime of knowledge is infinite and, through learning by using, its depreciation is negative as long as it is not rendered obsolete by other knowledge.

Thus knowledge has strong economies of scale, both static and dynamic, and has increasing returns in use as long as it is not obsolete, thereby creating a risk of lock-in (i.e., the competence trap). Because of the scope of complementarities among its parts, knowledge also often has strong economies of scope. Moreover it is not time-consuming to use, once acquired, and it is highly mobile if codified (although there may be multiple, incompatible codes). The codification (or disembodiment) process may be time- and effort-consuming, however, and the less knowledge is codified (into one language), the more time and effort are needed to transfer it among humans.50 Science and R & D are important in order to improve the codification process, but are by no means the only ways to do so.

Codification is important not only for facilitating transfer of knowledge per se, but also to enable its cumulation. Cumulation takes place within an individual and a group (through use of memories), among humans (through transfer) and between human generations, and results in a common pool or stock of knowledge.51 This pool may partly be publicly available, and some knowledge may adopt a 'public good' characteristic.52

All in all, knowledge has properties that give it a great economic potential as a resource, even uniquely great in some respects. However, there are also properties that strongly limit exploiting this economic potential. As is well known, knowledge is difficult to value, price and sell. This is partly because knowledge is highly differentiated, which makes it difficult to match demand with a competitive supply, and partly because knowledge may easily be stolen with little chance of IPR enforcement (cf. Arrow's information paradox, Arrow, 1974). New ideas and knowledge, which may be difficult to codify and specify partially without risking full disclosure, are especially vulnerable to theft and inadvertent diffusion. New ideas and knowledge can be kept perfectly secret by an individual for cost-free eternity, (torture aside) but then benefits from learning by using the new knowledge and complementarities from combining it with the knowledge of others are lost.

Thus, the intrinsic properties of knowledge create an economic potential, at the same time as these knowledge properties create limits to knowledge exploitation, not least to exploitation through market

50 Throughout the text here, both time and effort are emphasized. This is because there are very limited possibilities to make trade-offs between time and efforts (or costs). That is, in learning and teaching you can buy time through increased efforts only up to a point, due to speed limits.

51 The terms 'pool or stock of knowledge' are deceptive since they are often used together with the term 'flow' which indicates a physical transfer rather than diffusion or cloning of knowledge.

52 This does not mean it is a free good in the sense that it is costless to acquire and use (see Nelson, 1992).
exchange mechanisms. This gives a natural rationale for having some kind of system in an economy which stimulates knowledge exploitation without too many negative side-effects and costs for ‘running’ it. In fact, if a system could be designed that stimulates not only knowledge exploitation but also its acquisition, the system would be doubly effective. This is indeed what the IPR system is intended to accomplish regarding technical knowledge.

4.2.5. Special properties of technology

Technology is a special kind of knowledge and as such has, in addition to the general knowledge properties above, special properties, not all of them shared by other types of knowledge. These properties include the following.

1) An artifact link, i.e., technology is linked to artifacts (materials, products) or systems of artifacts and to the processes by which they are produced. These artifacts and their production processes are possible to characterize by physical design and performance parameters, which typically evolve over time as their underlying technologies develop. A certain technology may, moreover, be linked to many artifacts, i.e., having a wide applicability or being multi-purpose, just as a certain artifact may be linked to many specific technologies, i.e., being multitechnological.

2) A science link, i.e., technology is linked to natural sciences and their methodology.

3) A relatively high degree of codifiability in general, partly stemming from the links to artifacts and the links to natural sciences, through the use of formulae in a formal language (mathematical, chemical, computational etc.), drawings, models, patent documents, textbooks, and a scientifically oriented language. Also the artifacts serve as codifiers of parts of technical knowledge, the embodied technology. However, in certain areas (e.g., new and/or less science-based) there is an important tacit knowledge component as well. The tacit component is not static, since codification is a dynamic process, linked to R&D and scientification of technologies. On the other hand, R&D uncovers new technologies with, sometimes, a low degree of codification initially. High codifiability facilitates the specification and transfer of technical knowledge as well as its accumulation.

4) A ‘practical purpose’ link, i.e., technical knowledge is generated largely with an intention to have something working in practice or have some technical performance level achieved.

5) Links to globally oriented common systems for its operationalization (specification) and assessment, especially the patent system and the educational system but also systems for standardization, testing, regulation, classification etc.

An implication of these idiosyncrasies of technical knowledge is that it is easier to have a system for registering technical knowledge, due to its higher codifiability and its artifact link. The patent system is such a system and it also stimulates the codification of technology. At the same time, as its main purpose, it stimulates technology generation, diffusion (cloning) and technology cumulation. The patent system thus reinforces some of the knowledge properties of technology, giving rise to economies of scale, scope and mobility (speed and space) of technology, although at the possible cost of some R&D and output market distortion plus the cost of administering the patent system. Thus we have still another special property of technology, namely that it is possible to protect by patent rights.

The heterogeneity of technology must be emphasized, although this property is not unique to technology as a body of knowledge. Technology being heterogeneous means that different technologies and types of technologies may be identified (not without difficulties) and combined, and that their economic properties typically differ. These properties of a specific technology, or combination of technologies, pertain to its genericness or degree of applicability, customer utility impact and production cost impact, mediated through the corresponding technical performance parameters, cost of acquisition, complementarities, substitution effects, potential for advance-

53 Sometimes, however, complementarities are not gained since technology exploitation may also be hindered rather than fostered by a fragmentation of IPRs among agents that raise transaction costs even to the point of hindering exchange through market transactions. One example of this is the digital audio tape (DAT) technology; another may occur in what is now termed multimedia, in which case numerous interests in media, telecom and computing industries converge and conflict.
ment, excludability or protectability (e.g., through patents) and state and rate of diffusion on the market.

Needless to say, technologies are dynamically evolving. Technological changes that give rise to innovations at a closer look typically then involve some new combination of partly old technologies. An empirically important phenomenon is the increasing technology diversification at business level, giving rise to multitechnology products and processes, in turn giving rise to multitechnology corporations as typical TBFs. At the same time, fundamental breakthroughs in S&T give rise to generic or multipurpose technologies. Altogether, these two phenomena create more and more technology/business couplings with associated economies of scale and scope, possible to reap by active and innovative management.

Finally, it is important to distinguish technology from management. Both technology and management are knowledge resources and as such bounded, heterogeneous and dynamically evolving and, via their embodiments, both affect transformations of other resources. However, management primarily has links to human resources, behavioural characteristics and social sciences. Compared to technology, managerial knowledge is less codifiable, more localized and non-protectable by patents.

4.3. Diversification

4.3.1. Types of diversification

A firm can be viewed as composed of one set of businesses (or product/market combinations), constituting its business base, and one set of resources, constituting its resource base, and a many-to-many correspondence between resources and businesses (with a standard production function as a very special case), subjected to environmental changes and management and organizational behaviour. A firm may engage in two fundamental types of diversification—business diversification (with product, service and market diversification as special cases) and resource diversification (with, e.g., technology diversification as a special case). Resource and busi-

Fig. 2. Shifts in the resource and business base over time.

ness diversification corresponds to input and output diversification, from the point of view of the firm as a whole. Note that ‘business diversification’ here typically refers to business on the firm’s output markets, while diversification on the firm’s input markets is subsumed under resource diversification. This is an essential distinction in the argument below, saying that the interaction between these two diversification processes is one important source of dynamics in the evolution of the firm.

Each business of the firm has in turn a resource base, and each type of resource may be exploited in several businesses. These links can be summarized in a resource/business matrix (see below), analogous to the product/market matrix commonly used in describing diversification. 55

As the firm evolves over time, its resource base and business base may shift, with some resources R₁, businesses B₁, and mutual BR-couplings scrapped (or substituted), some kept (conserved) and some added. See Figs. 2 and 3 for two graphic representations of this phenomenon.

Strictly speaking, the concept of diversification refers to the ‘adding part’ of these shifts. As a basis for a typology we can then distinguish between the processes of substitution or exit, conservation, and diversification or entry, pertaining to both businesses and resources. Any change in the business base as

54 Such a firm could be labeled multi-business, multi-resource and corresponds to the multiproduct, multifactor firm in neoclassical theory.

55 In fact, a key contribution by Wernerfelt (1984) was to emphasize the resource perspective in strategy-making, which previously had commonly focused only on product/market diversification (with internationalization as a special case).
The rate at which the resource and business base shifts over time is in principle possible to measure by using a distance measure between two sets, possibly overlapping, be they sets of resources or businesses. An innovation typically leads to changes in the resource and/or business base, and to the extent that resources and businesses are kept, compared to those that are scrapped and added due to the innovation, the change is gradual rather than radical. Tushman and Anderson (1986) make the distinction between competence-destroying (i.e., scrapping) and competence-enhancing (i.e., adding) technological innovations. Many if not most technological innovations shift the competence base (including the technology base) without inducing disjointness, and with an enhancement (diversification) bias, i.e., with more adding than scrapping of competences (see Granstrand, 1994a, Ch. 7). In addition, several technologies in the technology base are usually retained or conserved.

Thus, to the extent that technology conservation and diversification dominate over technology substitution, the resulting change becomes more gradual than radical, which is in line with the cumulation and continuity view of the firm (see Section 2).

Generally speaking, then, the size and rate of change in the resource and business base implied by any diversification move provide a basis for distinguishing between, on the one hand, continuous/incremental/related etc. diversification and, on the other hand, discontinuous/radical/unrelated resource and/or business diversification. This latter type is also referred to as conglomerate diversification. As is well known, most studies show the poor economic performance of such diversification, although it could be argued that perfect capital markets (e.g.,) should lead to neither economies nor diseconomies. However, conglomerate or unrelated diversification is in practice related to some extent through the use of common managerial resources. Management failure in the form of managerial or entrepreneurial hubris mentioned earlier then easily comes into play, as does the principal agent problem arising from management seeking job security in corporate diversification.

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56 Cantwell and Piscitello (1996) argue that, for the largest European and US firms, technological diversification and internationalization of technological activity have historically occurred sequentially, while a new contemporary complementarity between them has been emerging since the 1980s.
its environment. There are other sources of dynamism as well, fairly well recognized. One is management (in a broad sense, including entrepreneurial acts in the organization as a whole) to the extent that it is not entirely adaptive to environmental changes. Another is endogenous innovations, rather than adaptations. However, two additional sources of dynamism need to be recognized as well.

The first is the increasing returns that accrue in the resource acquisition and exploitation processes per se, in particular learning (in a broad sense, including learning in recurrent contracting, leading to reduced transaction costs). The second source is the interaction between resource and business base shifts, diversification in particular. As resources are acquired to support a specific business, some of these resources may have multiple uses with properties that improve the economic prospects of going into a new business, e.g., through the provision of economies of scale and scope. This in turn may require that new resources are acquired as well.

Moreover, resources already acquired for a business that is later scrapped may be difficult to scrap or dispose of in a market in the short term, leading to possibly sunk fixed costs, in turn creating an incentive to use surplus resources for business diversification. A resource may also be lost or scrapped for other reasons (e.g., loss of key people or concessions), leading to scrapping a business, thereby possibly releasing other resources with alternative uses and so on. These dynamics in scrapping/keeping/adding businesses and resources with alternative uses are in reality influenced by the firm’s interaction with its environment, of course, but it is important to note that external dynamics is a sufficient (at least in the long run) but not a necessary condition for internal dynamics. That is, a firm could in principle go on scrapping (substituting) and adding (diversifying) even in a static (let alone stable) environment. 61

The internal diversification dynamics is driven by the economic properties of resources and their transformation, notably of four types considered here: economies of scale, scope, speed and space. These economies derive from the physical or intrinsic properties of resources, in conjunction with the many-to-many transformation or production (in a wide sense) correspondence between resources and businesses. Different diversification patterns then put different requirements on management in reaping the relevant economies involved. Too much of simultaneous resource and business diversification, as in conglomerate diversification, may then overtax management as well as other resources. Commonly observed sequences of corporate evolution like internationalization (market diversification) followed by resource diversification, spurring subsequent product diversification, can then be explained by dynamically changing mixes of economies of scale, scope, speed and space. Concurrent diversification, e.g., more or less simultaneous internationalization and product diversification, may then be achieved through complementarities, giving rise to economies of scope; resource sharing, giving rise to economies of scale; managerial learning, removing certain diseconomies of scale; a premium on time to certain markets; plus locational economies (economies of space). Knowledge resources in general and technology in particular then have properties, many of which are unique, that provide a strong form of dynamics to the firm and its diversification process.

4.3.3. Technology-related diversification

Section 3 above described how technology diversification had been empirically found to be the primary variable leading to growth of the technology-based firm, while at the same time leading to growth in the firm’s R&D expenditures. The sales growth induced by technology diversification can be hypo-

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61 This case has been well recognized in literature. Penrose (1959) is definitely a pioneering work, followed by Teece (1982) and Chandler (1990) and others. Normally, reference is made to resource slack, indivisibility and under-utilization.

61 One example being diversification induced by life (or long) time employment, e.g., in Japan.
esized to result from four sources: static as well as dynamic economies of scale in applying technologies across products and markets, i.e., across businesses; economies of scope (in a broad sense) in combining different technologies; and economies of speed in acquisition and transfer of technologies in the firm. High sales growth was particularly associated with a sequential diversification strategy, with technology diversification followed by technology-related business diversification. The growth of R&D expenditures resulting from technology diversification was hypothesized to derive from the cost of new technologies plus the cost of overcoming difficulties in combining various technologies, i.e., a kind of diseconomies of scope (but not congestion). Increasingly expensive R&D needed to support existing businesses then gives an incentive for technology-related business diversification to economize upon the (quasi-fixed) R&D investments, be it through product diversification or market diversification or both. The relative failure of MPCs vs. MNCs observed in literature could then be hypothesized to result from a higher degree of technology-relatedness (implying scale, scope as well as speed economies) in MNCs, everything else equal. In addition, internationalization may provide locational economies or economies of 'space' in relation to R&D. Since diverse S&T activities tend to agglomerate in various regions of the world (Cantwell, 1989, 1994) an MTC gains further locational advantages by locating R&D and technology-sourcing activities in such 'multitechnology regions'.

Skeptics of business diversification, of whom there are many, might object that technology diversification does not necessarily have to lead to technology-related business diversification. The need for technology diversification is largely generated by forces exogenous to the firm. As empirical studies have shown, many firms also grow through technology diversification without engaging in business diversification. However, as R&D expenditures grow through technology diversification, a need arises to recover them through expanding their business base. Many firms have in the past responded to this by market diversification, especially internationalization, thereby becoming MNCs. Internationalization of TBFs has usually concerned the firm’s output markets, but increasingly internationalization of R&D also takes place.

An alternative, sometimes complementary and sometimes not, depending on limited managerial capabilities, is to engage in technology-related product diversification and spread R&D costs over several product areas. Compared to internationalization, however, this puts other and seemingly larger demands on management.

Another general response to rising R&D costs in TBFs is the development of markets for technology with increasing division of R&D labour among TBFs. Rising R&D costs, in conjunction with generiness of new technologies, increase both supply and demand for them on a technology market. Empirical studies have also shown an increase in external sourcing of new technologies in TBFs. More general rationalization of R&D work is also possible, e.g., through cost-reducing innovations in the R&D process itself (e.g., in software development).

Still another possibility for mitigating the rise in R&D costs so common to TBFs is to engage in technology-related partnering, either pure R&D partnering or technology-related business partnering. In fact the growth of partnering among TBFs of all sizes is to a considerable extent motivated by rising R&D costs, influenced by technology diversification. Again technology-related partnering puts special demands on management, general management as well as technology management, but in this case it is management linked to several firms, which requires a quite different type of quasi-integrated governance structure.

Thus, some predictions for TBFs, based on rising R&D costs through partly exogenously driven technology diversification, are that they will respond in one or more of five ways: internationalization, technology-related business diversification, external technology sourcing as well as technology marketing, rationalization of R&D, and technology-related partnering.

In summary, the economic properties of technology as a resource create, through technology diversification and technology-related business diversification, an economic potential for the firm. Other physi-

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62 This corresponds to the L factor in Dunning’s OLI-paradigm.
cal and intellectual resources may also provide an economic potential in similar ways, of course, but it is argued here that technology has some unique and particularly strong properties in these respects, including the associated tendencies toward costly (and risky) R&D. That physical capital and intellectual capital have some fundamentally differing economic properties is clear, but how then does technology differ from other IC resources? Don’t other competences or knowledge resources provide economies of scale and scope much as technology does? Yes, they do, but as described in Section 4.2 above, technology has some unique properties which lead to a particularly strong economic potential. For example, it is possible to embody (‘productify’) technology in artifacts to decrease transactional hazards, and more so than in the case of pure knowledge-based services. The possibilities to codify can be argued to be larger on an average for technology than for other competences, which improves the prospects of cumulation and transfer, which in turn improves the prospects of reaping economies of scale, scope, speed and space.

S&T discoveries and inventions (e.g., radio waves, photocconductivity, the laser) have a feature of indivisibility, in the sense that the magnitude with which they are made (acquired) is far from fully determined by the need for them in a particular situation of resource utilization. This property they share with discoveries in other knowledge areas in general (cf. the discovery of the American continent by explorers and exploiters). Mother Nature simply has a way of revealing herself in chunks, not always proportional to the effort of her explorer. However, the patent system is unique to technology (not science) and technical inventions, and gives by design a unique economic potential to technical advances beyond a certain technical (as opposed to economic) size or level of invention. The indivisibilities induced by the patent system yield possible slack and economies of scale, but this may be a minor consideration compared to the role of the patent system in providing potential economies, e.g., of speed, for the patent holder relative to competitors, through the ordinary temporary, restricted monopoly protection associated with patent rights.\textsuperscript{64,65}

The role of patents in firms (and economic development in general) is an issue which could be elaborated at great length. Most authors do not regard the role of patents as very important, however. E.g., Chandler (1990) attributes a secondary role to them in firm formation historically. On the other hand, there are not many studies with this focus. At the same time a ‘pro-patent’ era has emerged in the 1980s as IC has become generally more important. And insofar as IPRs as a whole are concerned with trademarks, trade secrets etc., their historical role has been larger than commonly recognized.

4.3.4. The management factor

Thus, omitting further elaborations here, we may infer that technology has properties which create strong economic potentials. Some of these properties are shared with other resources, in particular with other competences, while some properties are unique. Some properties are intrinsic in the nature of technology, some are man-made. The IPR system in particular is part of the institutional setting that by design endows technology with unique economic properties, although it is debatable how strongly they are.

However, the general economic potential of technology is not realized automatically, nor are its returns automatically appropriated, not even partly by a firm which has invested in acquiring it. In order to accomplish that, management (in a broad sense,

\textsuperscript{64} If the indivisibilities are small they could be taken to ‘convexify’. The number of patents related to a product is often large and also increases empirically. At the same time, it may be claimed that the genericness of many patents increases.

\textsuperscript{65} The timing properties induced by the patent system are notable. First, there is a ‘winner takes all’ race to get a patent granted; second, (single) patent protection expires fully after a fixed time interval.
including organizational capabilities) is a necessary but not sufficient competence. This is not the proper place to elaborate upon how it can be achieved, more than to indicate a few challenges to current managerial thinking, based on the empirical findings and the theoretical analysis above. First, a specialization strategy of ‘sticking to the knitting’ could be severely criticized on the above grounds, for one thing (see Granstrand et al., 1992a). Second, in order to reap technological economies of scale, scope, speed and space, technology transfer and integration are of decisive importance in acquiring and exploiting technology, often with in-house R&D as a dominant mode of acquisition. This opposes the current approach (at least in the West) that favours one-sided decentralization of R&D and technology management. Moreover, down-sizing middle technology management in that connection may jeopardize critical integrative functions for reaping the economic benefits of technology diversification.

Hence, the management factor must explicitly enter into a theory of the technology-based firm and its diversification processes as a variable intermediate between technological and economic changes at firm level. Management is then not only to be represented by its embodiment in humans, expressing itself in managerial performance (of which the yardsticks are much poorer than for technical performance), but also to be represented by a knowledge area, subjected to evolution through learning, cumulation and innovations just as for technological evolution. At the same time, managerial knowledge and practices co-evolve with new technologies (e.g., new computer and communication technologies) with an interplay between technological and managerial innovations. Management serves as an explanatory factor together with the technology factor not only behind the formation, sustained existence and diversification of the technology-based firm, but also behind differences in economic performance of firms (exogenous factors apart), and in an even wider perspective as a partial explanation of the strength in the co-evolution of S&T and the firm as an institution. Unfortunately for many economic theories, management has somewhat paradoxically been a big, dark box, perhaps even bigger than the black box of technology. Fortunately for economic research, much exciting work thereby remains to be done.

5. Summary and conclusions

As an economic institution the firm has developed a strong form of co-evolution with S&T, with increasing importance of TBFs as well as firm-based technologies. Empirical studies have shown that the MTC is the rule rather than the exception among technology-based firms, and that technology diversification is a primary variable leading to growth of the firm as well as to growth of its R&D expenditures, often leading subsequently also to technology-related product diversification.

Received theory of the firm has (with some exceptions) not particularly addressed technology-based firms and their management. This paper has proposed an approach for theorizing about such firms by focusing on technology as part of the firm’s intellectual capital and general resources, interacting with an environment, under active and innovative management. The firm’s resources, including management as a special part, can be acquired and exploited in various ways. Technology then has intrinsic and partly unique properties leading to particularly strong economic potentials through any or all of four basic types of economies involved—scale (static and dynamic), scope (in a broad sense), speed (and timing) and space (location and mobility). The IPR system is one but only one source of these unique properties, and serves to strengthen the economies associated with technology.

The approach for theorizing is first to characterize a firm in general and a TBF in particular, next to give descriptions and explanations of why TBFs form, grow and diversify in various ways, and finally to offer some predictions.

A firm in general is taken to be a human system characterized by its dynamic and heterogeneous resources, its environment, with an institutional setting, its internal and external interactions, including transactions, its business ideas, its goal structure and its management. Resources are being purposely acquired, transformed, and exploited under management as an active and even innovative control function, giving rise to a mix of the four basic types of economies, those of scale, scope, speed and space. Management could partly be seen also as a resource for the firm, but then as a uniquely decisive meta-resource with very special features. For the formation
of a firm, management and a viable business idea are necessary. For the sustained existence of the firm, the net management cost must also be perceived to be lower on average than net market transaction costs.

A technology-based firm is then a firm for which each of these firm-characterizing elements contains or is influenced by technology and technical artifacts in a vital way in some sense. Technology is characterized by both its 'soft' and 'hard' sides, being a dynamic body of knowledge, strongly linked to changing technical artifacts (typically products), with physically measurable technical attributes, impacting in uncertain and innovative ways user and producer utilities and goals, as well as the firm’s business interactions and competitive situations. Technology could partly be seen as a resource, but only partly since it enters into both the input and output characterizations of a firm, and influences competition on both input and output markets. As a knowledge resource, being part of the firm’s intellectual capital, technology shares the general characteristics of knowledge, but in addition displays unique features, such as being protectable by patents. These unique features give technology particularly strong economies of scale, scope, speed and space, which however need active and innovative management to be reaped within a TBF, putting emphasis on the qualities of its technology management.

Empirical studies have also shown the importance of technology diversification for the growth of a TBF, which then typically evolves into a MTC. However, technology diversification also leads to growth of R&D expenditures, which induces the TBF under competition to engage in one or more of five strategies: internationalization, technology-related business diversification, external technology sourcing and marketing, R&D rationalization, and finally technology-related partnering with others, including other TBFs. The latter leads to the creation of quasi-integrated systems or families of firms, in order to reap technology-related economies of scale, scope, speed and space.

In relation to received theories of the firm, the theoretical approach offered here has similarities and differences. Various perspectives and basic categories are similar to the ones in received theory, not only resource-based theory and evolutionary theory, but also transaction cost theory and neo-classical theory. The main difference is the emphasis and explication of technology and its idiosyncrasies as well as the emphasis on management, including technology management.

The central role of technology diversification in the evolution of a technology-based firm, then becoming multitechnological, is moreover a new perspective with strategic implications for management. The strong potential economies of scale, scope, speed and space associated with combining heterogeneous technologies and their characteristics, the realization of which depends upon the qualities of management, are thus central explanatory categories. In particular, the relative superiority of probably less than perfect technology management over conducting transactions on imperfect technology-related markets is decisive.

Finally, in line with the emphasis on technology, it must be remembered that technology as well as firms are such pervasive and complex phenomena that there are long, probably never-ending, paths to take in further theorizing about their co-evolution. To mention one direction for further research: as firm-based technologies increasingly develop, theorizing about their evolution is also called for. After all, Mother Nature has ‘managed’ to reveal herself in strange ways, be it to firms or other institutions.

**List of abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>C&amp;C</td>
<td>Computer and communications</td>
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<tr>
<td>ET</td>
<td>Evolutionary theory</td>
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<td>IC</td>
<td>Immaterial or Intellectual capital</td>
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<td>IPR</td>
<td>Intellectual property right</td>
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<tr>
<td>MNC</td>
<td>Multinational corporations</td>
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<td>MP</td>
<td>Mathematical programming</td>
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<td>MPC</td>
<td>Multiproduct corporation</td>
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<tr>
<td>MTC</td>
<td>Multitechnology corporation</td>
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<tr>
<td>NCT</td>
<td>Neo-classical theory</td>
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<tr>
<td>NIH</td>
<td>‘Not invented here’</td>
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<td>OLI</td>
<td>Ownership–Location–Internalization</td>
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<tr>
<td>PAT</td>
<td>Principal agent theory</td>
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<tr>
<td>R&amp;D</td>
<td>Research and development</td>
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<tr>
<td>RBT</td>
<td>Resource-based theory</td>
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<tr>
<td>S&amp;T</td>
<td>Science and technology</td>
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<tr>
<td>TBF</td>
<td>Technology-based firm</td>
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<tr>
<td>TCT</td>
<td>Transaction cost theory</td>
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