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Dynamics of technological competencies

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Nr. 483

Dynamics of technological competencies

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Dynamics of technological competencies

Klaus Brockhoff

1. Introduction

Different forms in which companies integrate technological knowledge into their production and transform it into marketable products can evidently exist successfully alongside each other. Economic explanations for this observation must therefore be sought in which a general failure of competition and permanent survival by defending monopolistic niches are not relevant in the long run. We suggest that economically relevant explanations arise from characteristics of technological progress which can be used to explain the wide variety of observations that can be made as companies adjust to such external conditions. Nevertheless, the explanatory model that is developed here is only a partial model.

2. Cost theory as a basis of explanation

The economic effects of technological progress vary widely and occur on various levels. A theoretical review can only be given in very brief form.

On a first level, costs of knowledge generation within one organization can be considered. The competitive effects of these can be devalued by radically new knowledge. On a second level, transaction costs become relevant (Picot 1993, c. 4194-4204). These result from asymmetric information and their possible opportunistic exploitation, which each partner in a process that is based on the division of labor strives to preserve. This causes the transaction costs which are a result of "frictions" that arise from the coordination between the companies participating in the generation of an output of goods or services. The level of these frictions and therefore also the amount of the costs is determined by cultural influences or value systems which are not specific to the transaction, as well as by the form of the information and communications systems. Transaction-specific influences depend on the specificity, the variability or uncertainty, and the frequency of the transactions (Picot, 1993, c. 4198 f.). These factors of influence (Brockhoff, 1992, p.514-524) which can be affected not least by technological developments, are examined in more detail later.

In principle, it is assumed that transaction costs increase with increasing specificity, and that high specificity can less expensively be controlled through hierarchical coordination than through market-based exchanges. The transaction costs per transaction decrease with increased transaction frequency and thereby promote coordination via markets. Where specificity is low, increasing uncertainty will encourage coordination via markets, however, high specificity will incline more towards hierarchical coordination.

On a third level, we might observe opportunity costs. These arise, for instance, if binding relationships with particular partners inhibit more profitable relations with others. Within networks of companies, such as suppliers and users of jointly developed new technologies, such opportunity costs are of special importance.

What now needs to be clarified is: how does new technological knowledge affect these costs, and thereby favor different types of

organization for its use in new products? For this purpose we need first of all to refer to some specific characteristics of knowledge.

Knowledge can be used any number of times without being exhausted. This explains the interest in its dissemination from the point of view of every other potential user of the knowledge, because dissemination helps to reduce specificity. The specificity can be maintained through non-dissemination and thereby becomes a basis for the attainment of "rents".

Knowledge can be combined with other knowledge, thus creating new technologies that help to satisfy a wider range of needs. This reduces uncertainty about the exploitation of the original knowledge base. It leads to "architectural innovations": "Existing technologies are applied or combined to create novel products or services, or new applications. Competition is based on serving specific market niches and on close relations with customers"(Tidd, Bessant, Pavitt 1997, p.165). *Two examples will demonstrate this. The garden tool manufacturer Gardena views knowledge as a condition for a high level of innovativeness and combines it with high vertical integration to ensure delivery capability in the case of high seasonal fluctuations, or uncertainty of demand (FAZ Sept. 18, 1996, p. 26). Henkel developed its core competence in the adhesives industry from the packaging needs that were not adequately met by its suppliers in the 1920s (FAZ Jan. 9, 1998).*

Where there is cumulative technological progress, knowledge owners can achieve synergism from a technological point of view from the integration of new elements of knowledge. Whether these can be exploited in the market is a different question, which depends in particular on whether this market remains homogenous or will itself be heterogenized with the increase in offerings based on the new technologies. This can lead to excessively high costs if all needs are satisfied from a single source.

These characteristics of technological knowledge are important for the following considerations.

3. Developing a "knowledge spectrum"

3.1 Dissemination of knowledge

At one extreme, technological knowledge can be monopolized by one person or institution. Alternatively, it might be disseminated throughout a very large number of people or institutions. The owner of monopolized knowledge will rarely have an interest in its dissemination (network products could form an exception to this), however, s/he can hardly effectively resist it in the long-term. It is demonstrated that the monopolization of knowledge stimulates "technology races", whilst when knowledge is disseminated ("technical parity competition") other variables determine the competitive position of companies (Miller 1995, p. 511-524). This suggests instability of a position on an axis depicting dissemination of knowledge. The transition from monopolized to disseminated knowledge appears to be influenced by the type of technological progress, amongst other things. Empirical technological progress is more likely to enable monopolized knowledge, whilst cumulative technological progress makes wide dissemination easier through the use of the underlying theory. This character of the technological progress can change in the course of time as theories are developed to explain and forecast effects of new knowledge. *For example, two consecutive phases are described during the development of the radio in the history of technology: "the emergence of a pre-technical system, characterized by a high degree of empiricism and the concentration of innovators on solving operational problems arising from the incapacity of the dominant technical system to support further development of new services. When these tensions decreased, and when scientific knowledge was able to follow, and even precede technical evolution, the pre-technical system was able to generate by itself new services or products"*(Griset 1995, p.47).

3.2 Complexity of output

Knowledge can be employed in the form of very simple products or very complex products. The combinatorial properties of technological knowledge can support a development towards more complexity. The transition from one level of complexity to another is influenced by the latent or manifest demands of buyers on the one hand. On the other hand, technologically complex products, in particular, place high demands on learning within companies (Griset 1995). It is not certain that all competitors in an industry can meet these demands as they tend to increase costs of production. *Griset argues that the rise of electronics in the "radio industry" required the mastery of very complex technological systems with elements of hardware and software, which RCA mastered, however the "classical" companies within the industry such as Marconi, Telefunken, or CSF did not* (Griset 1995, p. 54 ff.).

Let us now examine complexity somewhat closer. The creation of complex means to satisfy needs is not one-dimensional. On the one hand, complexity can arise through the integration of more parts in one product (Henderson, Clark 1990, p. 9-30), on the other hand, however, it can also arise through the delivery of an increasing number of product functions, which can only occur as a result of a change in the range of performance of the same number of product components. These complexity dimensions are in principle independent of one another (Singh 1997, p. 6), so that they can appear in every possible combination. Similar ideas on complexity have been expressed many times. Sometimes, these ideas have been empirically substantiated (Henderson, Clark 1990, p. 9-30; Fujimoto 1993, p. 165 ff.).

The ability of generating synergism from combinatory use of knowledge could lead to a tendency of developing ever more complex products, unless this is balanced by a cost factor such as the learning mentioned above. This indicates another instability on the complexity spectrum.

3.3 Knowledge spectrum

Dissemination and complexity represent scales which span what we call a knowledge spectrum. Each scale can be divided into any desired level of fineness. Only four particularly prominent points on the scales are considered here. This makes it possible to keep the representation within manageable limits. The four positions shown by combining selected points on the two scales are dealt with in succession. These positions are illustrated in figure 1.

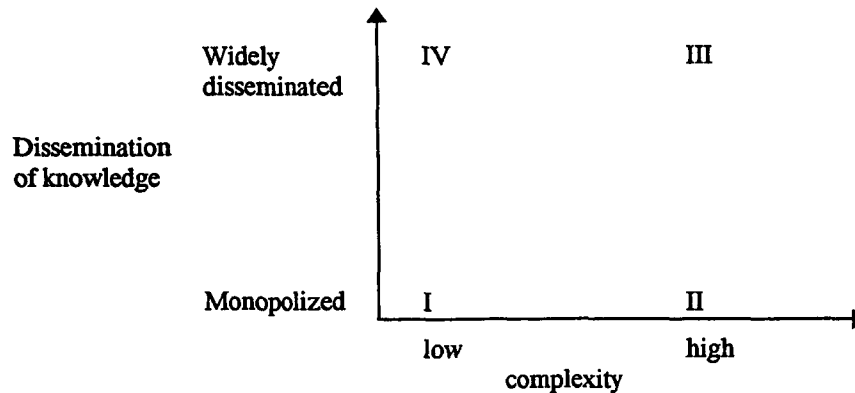


Figure 1: The knowledge spectrum

Often, only one of the quadrants of this diagram is dealt with. This creates the impression that only this position secures corporate competitiveness. The theory that such particular positions represent absorbing states, towards which all successful companies must develop carries this idea further. In one article it is said: "Industry will gravitate toward the concept of core competencies, or strategic technologies, to focus its efforts" (Bridenbaugh 1996, p. 162). This seems to imply that when this state is reached no further changes will follow. Such theories overlook the dependence of successful management on adjustments to economic or technological constraints, which in turn may be subject to radical change. It is therefore not justifiable to recommend particular positions to all companies, as has recently occurred when concentration on core competencies or R&D cooperation as its consequence or the use of system suppliers have been suggested as particularly successful strategies.

4. Four quadrants in the knowledge spectrum

4.1 Monopolized knowledge in non-complex products (I)

At the extreme, one individual can create or possess new knowledge which can be exploited economically, even if it is in the form of a product which is not complex initially. This product can be a radical innovation. The owner of the new knowledge simultaneously creates information asymmetries vis-a-vis other people. *The Benz motor car, for which petrol had to be bought at the pharmacy and which was driven on traditional dirt roads, the crystal receiver with the headphones for listening to radio transmissions or the first Apple PCs are examples of this.* At this stage, the products do not require complementary products for their performance. They appear as "stand alone products". The specificity is high, as is the uncertainty of their future success, and only a few transactions are expected at first. Production takes place by hierarchical coordination.

The technological progress which makes such products possible can be "radical", in that it enables considerable increases in performance compared to traditional products. This makes the new products potentially desirable by customers. However, this technological progress can also be "disruptive": an innovation which opens up previously undeveloped market segments, and enables value added there, even if a majority of customers detects underperformance with respect to characteristics presently held in high esteem (Christensen 1997, p. 15 ff.). Established market players can easily overlook this kind of technological progress, because it only appeals to a small customer group, possibly allows only for lower margins at first and does not (yet) meet the expectations of the mainstream customers. Should the mayor suppliers recognize this type of technological progress, they might choose to push ahead the further development of the old technology because by doing so they can protect their sunk cost from the pending devaluation of the technological potentials tied up in it. The "sailing ship effect" describes this response. It is bound to fail when the performance potential of the new technology is significantly higher than that of the old technology.

The hierarchical coordination in the first quadrant of the knowledge spectrum does not remain stable. There are various reasons for this. Firstly, the integration of knowledge in a product does, as assumed here, lead to a "feasible" solution, but there may be superior technologies which can fulfill the same purposes. In case of a more or less simultaneous perception of needs, in particular, this can trigger demand pull technical progress, which is characterized by the fact that the same outputs can be achieved by very different factor inputs. As a rule, different factor inputs cause different costs; the most cost-effective combination of factors will be superior, all other things being equal. This is indicated by a multitude of parallel inventions documented in the history of technology (Lamb, Eaton 1984, p. 47 ff.) as well as the attempts to secure specificity through comprehensive fencing of important patents by their applicants (Spero 1990, pp. 58-67). Both of these are indications of the technical races referred to above. The existing specificity can, therefore, get lost. *An interesting indication of this problem occurs in the computing industry: "When Apple had been the only game in town, the engineering team could design a machine to please themselves. But competition, and the need for larger sales volumes, raised the stakes and restricted design freedom"* (Penzias 1989, p. 185).

Secondly, a monopolistic technological position cannot necessarily justify economic specificity, if it is in a firm's best interest to give it up. The technological knowledge is made generally accessible in order to gain an economically more advantageous position through the initiation of complementary products (e.g., software for a particular hardware), the coverage of markets which cannot be easily accessed by the firm itself (e.g., through licensing), to secure future participation in a cumulative technological advance, or to obtain network effects.

Thirdly, a legally protected unique technological position with specificity cannot usually be maintained in the long run, because the period of legal protection is limited. Specificity can be lost through the appearance of imitators who are attracted by the rents created by that specificity. *The rise of generics manufacturers on the ethical pharmaceutical markets is a good example of this.*

Even when the period of protection is not limited, technological progress and the differentiation of demand can mean that the monopoly must be surrendered. *In telecommunications, it has been ob-*

served that technological progress "...enables a wide variety of outputs and therefore leads to a diversification of the markets which can no longer be managed by a state administration. Here, therefore, a causality is formulated which posits technological development as an action component, and the economic opening of the market as its consequence" (Witte 1997, p. 8). This "causality" is also supported empirically (Witte 1997, p. 13). The monopoly cannot prevent the appearance of technologically related outputs, which in the subsequent period develop into technological alternatives to the core output. This suggests that market heterogeneity makes the exploitation of technological synergies by one market player seem uneconomic.

Fourthly, radically new knowledge, in particular, makes its owner into an interesting acquisition target or into a highly esteemed cooperation partner. If this occurs, however, knowledge is transferred to others. Acquisition of the whole firm is more expensive than the acquisition only of the desired technology or cooperation for two reasons: firstly, a higher degree of control is obtained, in particular over the owners of the knowledge, and this has to be paid for; secondly, it is not always possible to avoid the acquisition of assets that cannot be used optimally by the acquirer along with the acquired firm.

In the case of cooperations, the hard-to-come-by knowledge can be so well protected that its owner can put a visible and economically valuable stamp on the cooperation. *The reference to the label "Intel inside" on many PCs produced by different manufacturers documents this. But it is not an entirely new phenomenon. Around 1920, L'Hohlwein cigarettes were sold. The designer of the boxes, Ludwig Hohlwein, granted a license to the manufacturer, the Menes cigarette factory in Wiesbaden, to use his name as a trademark (exhibition catalog Altona Museum 1996).*

Thus, the first position in the knowledge spectrum is not stable. A firm which takes this position may either leave it for self-interest or will find itself confronted by attacks on its position from others.

4.2 Monopolized knowledge in complex products (II)

Knowledge can be "combined" with other knowledge without being exhausted. This creates new opportunities for the satisfaction of needs. These combinations increase the complexity of the product which is to satisfy the wants of potential buyers. The possibility that the demands of the customer may be exceeded and that undesirably complex products could be created as a result will only be mentioned in passing here. It is a result of incomplete information. This "overengineering" is a first indication of the instability of the economic position adopted.

There are many examples describing the second position in the knowledge spectrum discussed here. We are told that: "for years, Eastman Kodak was the only company that did all three: cameras, film, and developing" (Design Management Institute 1993, p. 5), thus offering a very complex product. In another case "plain old telephone services (pots)" became over time "progressively combined forms of communication..., which include speech, text, data, stills, and eventually also moving pictures" (Witte 1997, p. 8). Initially these opportunities were bundled by a monopoly, however, they then broke the bounds of this market regime with their increasing breadth and complexity. Another case: The Meissen china manufacture even today is proud of excavating its own clay, developing and mixing its own colors etc. All of these are made into complex works of art.

The treatment of knowledge that leads to complex products is an important part of the training of engineers and scientists. Pavitt points out that research is carried out "precisely to train technological problem-solvers to integrate knowledge from a variety of disciplines in the development and use of complex systems" (Pavitt 1993, p. 133). Kesselring wrote a "theory of design (composition)", which was intended to support the creative activities of an engineer in the interaction of invention, design, and formation with regard to economic, ethical and other goals (Kesselring 1954). The principle of variants, that is, the search for similar solutions to meet a need which is formulated as a task, and the principle of generation, that is, searching for existing and re-combinable assemblies or the development of new assemblies and components, are nowadays taught as elements of technical problem-solving (Eversheim 1996, pp. 7-20

ff.). *It is important also to mention various creativity techniques, in particular morphological analysis, which Hauschildt describes as "structuring concepts for the generation of alternatives" (Hauschildt 1997, p. 311 ff.). In the above sense, these therefore support the principle of generation.*

Because of the multi-dimensionality of "complexity" referred to above, sustaining competitiveness requires the pursuit of both the technological development of the "product architecture" and the performance of the individual elements or modules of a product which are connected in the architecture of the product.

In particular, when the interfaces between the components or the causes of the improvement in their performance are difficult to ascertain from the outside, this again forms a basis for specificity. In so far as the increase in complexity also entails coverage of shrinking market segments, down to one-piece production, the number of transactions decreases (Tidd 1997, p. 6 ff.). So does the number of possible transactions where external sourcing of components is attempted. For both these reasons, it is therefore to be expected that with growing complexity an increasing share of the value added of the product will be generated within the firm.

The resulting coordination costs are seen as one of the main obstacles to economic efficiency. For single product firms, Gutenberg did not consider coordination costs (Robinson 1936, p. 87) as being a factor limiting the size of the firm "under any conditions and in any magnitudes likely to occur in practice" (Gutenberg 1956, p. 35). However, such an effect cannot entirely be ruled out and - which appears more crucial here - the argument does not take into account the case of variable complexity or multiple types of products. *An example of the shift of cost levels is the success factor for book clubs. In 1948 it consisted of a close link to a printer, which could deliver the desired titles on time and promised additional incremental profits. Forty years later printing has become a commodity which is offered on a competitive basis. Thus, efficient book clubs do no longer operate their own print shops. Another example: "As Apple grew ... so did the 'team'. Specialization became necessary, and with it a need for more coordination. Now teams split off ... and some tasks ... got done twice while others ... went neglected"* (Penzias 1989, p. 183).

Tidd suggests that firms which find themselves in the situation described above gear their communication and information relationships

too much to the performance of the modules and assume that the traditional architectural knowledge will persist (Tidd 1997, p. 7); they can then be forced out of their competitive position by new architectural ideas. Research and development activities in successful firms will therefore extend to both aspects of complexity. However, the appearance of disruptive technologies and the manufacturer's disregard for them (on the grounds already stated with respect to the first quadrant and in the field of technology, in particular, because of the existence of the well-known "not invented here syndrome" (Katz, Allen 1982, pp. 7-19)) attack the position achieved. A necessary condition for recognizing radical and disruptive innovations can be met by investment in research, if this is used to build the potentials for identifying and absorbing external knowledge (Brockhoff 1997).

The creation of a special organizational unit for the development of new technology and its later exploitation is advised (Christensen 1997, p. 20, 101 ff., 197 ff.), in order not to lose the opportunity of innovation by being too strongly bound to the past. This unit will tend to move the firm back towards quadrant I, although on a different technological level from that which the firm had originally held.

A second reason for instability once more lies in the fact that knowledge cannot generally be completely protected in the long term. In particular, knowledge about the technical interfaces between modules (and therefore the basis for architectural innovations) would, as manufacturing becomes increasingly standardized (thus creating market entry barriers through economies of scale and scope), have to be documented or passed on to many owners of knowledge. This increases the chances of an unintentional leakage of this knowledge, especially since, in the case of successful activity, systematic efforts will be directed at the absorption of this knowledge by external competitors (Lange 1994).

A third reason for the instability of the situation described here could be that, despite the fact that the knowledge components to be combined can be identified unambiguously and cost-effectively, their in-house development for productive exploitation is associated with higher costs than development or delivery from outside the firm (Brockhoff 1997). *An example can be cited here, too: The search for a supplier for sodium perborate, which Henkel needs for the production of its leading brand detergent Persil, led to Degussa AG. In*

order to secure the supply Henkel held an indirect share in Degussa AG until 1997¹.

This shows in a particularly striking way that firms have difficulties to stay in position II of the knowledge spectrum. Moving towards position III they will aim to secure relationships as long as the knowledge has to become common and shared by many. If a precise description of the object of a transfer is not possible, as in the case of necessary research and development, then instead of a contractual obligation it is advisable to attempt to build trust-based relationships (Ring, van de Ven 1994, p. 93). This is especially true in the development of complex systems which have parts which interact with each other, and therefore do not allow an exact prior formulation of the final technical interfaces or their characteristics. Trust is "produced through interpersonal interactions that lead to social-psychological bonds of mutual norms, sentiments, and friendships" and is supported by the motivation "to seek both equity and efficiency outcomes because of the desire to preserve a reputation for fair dealing that will enable ... to continue to exchange transaction-specific investments under conditions of high uncertainty" (Ring, van de Ven 1994, pp. 93-94). These descriptive statements have, however, only rarely been analyzed in time-series studies of development for real situations which are characterized by partners changing their employers quickly, where there is a high level of environmental variability, where inflexibilities in the labor market exist, etc. Perhaps, the securing of stability among partners through trust building is not quite as effective as supposed (i.e., it causes relatively high costs), because one observes that when discontinuous technological change occurs, contractually secured forms of cooperation (joint ventures, technology licensing agreements, and various forms of R&D consortia) are preferred to generate knowledge (Lambe, Spekman 1997, pp. 102-116). Trust building might need to be supplemented by formal legal agreements (which could then be interpreted as a cost-saving measure). *This is shown by the ABS case: in 1965, Daimler-Benz AG hinted to Robert Bosch GmbH that it should address itself to the*

¹ The GFC Gesellschaft für Chemiewerte mbH holds more than 25% of Degussa AG; Henkel KGaA had a holding of 46 % in GFCmbH, the remaining shares were held by Dresdner Bank AG and the Münchner Rückversicherungs-Gesellschaft.

development of an anti-locking system (Bingmann 1994, p. 780). It also supported Bosch's acquisition of Teldix in 1973, where corresponding developments were already well advanced (Bingmann 1994, p. 786 f.). Intensive discussions took place between Daimler-Benz and Bosch in "weekly meetings", but without the conclusion of a binding development contract or marketing contract. Although Bosch had agreed to an - undefined - lead time for the use of ABS by Daimler-Benz, in 1977 the company offered the development to other auto manufacturers as well at a stage when it was practically functional and ready for scale production. One week before the planned press presentation by Daimler-Benz, Bayerische Motorenwerke (BMW), aware of Daimler-Benz's timing, launched a press release with its own announcement of ABS. "The breach of the decades-old 'Good Faith' process led to a substantial loss of trust in Robert Bosch GmbH on the part of Daimler-Benz, which was still being referred to as 'ABS-Trauma' in 1988" (Bingmann 1994, pp. 789-790). It seems that Bosch gambled its trust capital because by that time competitors were hot on its heels with their own developments, and rapid establishment of its own development in the market to amortize the development expenses could not be guaranteed if it only supplied one firm.

Assuming that Bosch's behavior was rational, this can be explained by considering opportunity costs. Obviously, the sum of future transaction costs between Bosch and Daimler-Benz as well as the opportunity costs of delayed information and supply to other automotive manufacturers if the company had been committed to this partnership for a certain period were higher than the comparative costs. These are made up of the (higher) transaction costs arising from supplying to several auto manufacturers as well as the opportunity costs for lost follow-up business. The situation is represented in figure 2.

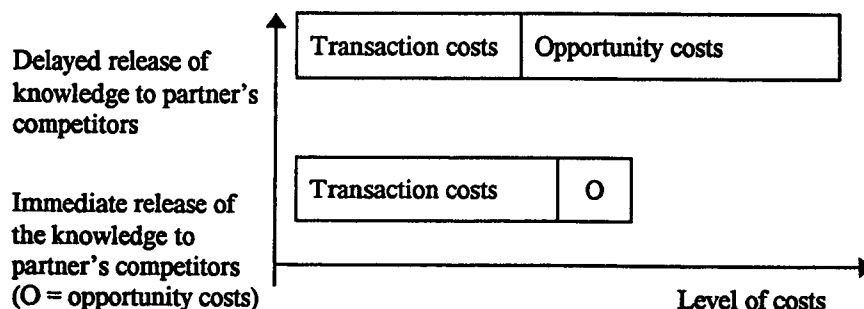


Figure 2: The cost situation

If we are to assume a decrease in the transaction costs with increasing length of a relationship (because of the reduction in uncertainty as well as the larger number of transactions), then cooperating firms would have to continue their commitment or replace it with even more favorable market conditions. The departure from the adopted development direction can be explained by taking opportunity costs into account in addition to the transaction costs.

In conclusion, we find that a position in quadrant II is not stable either. It is technologically vulnerable and changeable. The economic consequences can then force abandonment of the position.

4.3 Disseminated knowledge in complex products (III)

In digression from position II we posit that the knowledge required for manufacturing product modules is no longer monopolized. If we assume that efficiently designing and bridging interfaces between modules of complex products can be a special technological competence, then in the case of small sales volumes of products which may even be constructed according to the individual demands of the purchaser, a collaboration between several firms in production may be cost-efficient. Tidd has formulated the thesis: "Technological and market complexity is positively associated with network participation" (Tidd 1997, p. 4). In such a case, the most economic solution to satisfying the customer can be, for example, the formation of a working group or a network of firms with a lead firm. Depending on the design of the relationships, different forms of hybrid organizations of networks of firms are created.

Network organizations exploit specialization and thus information asymmetries. In particular for the lead firm, one assurance against the opportunistic exploitation of information asymmetry in such organizations could be to select a broader range of research and development activities than what is required by production. In addition to the knowledge which is necessary for internal activities, knowledge should be provided by research and development that is necessary for the identification of technological alternatives for the externally produced modules. *High transaction costs were incurred by Hoechst AG until 1925, when it tried to rely on external knowledge and co-operations. These costs resulted from profit sharing agreements with the external possessors of knowledge, and they were greater than the costs of internal personnel. This led to the company's establishing*

Hoechst's own R&D laboratory. When some of the competencies later had to be transferred to IG Farben laboratory in Leverkusen this was again seen as a disadvantage (Wimmer 1994, p. 149 ff.). In other words: at least a partial reduction in information asymmetry is viewed as economically reasonable, in order to limit the temptation of partners to behave opportunistically. Therefore, the degree of specialization in research and development should be lower than that in manufacturing. Different degrees of specialization are not uncommon between the marketing departments and production departments of system manufacturers. The same idea is here transferred onto a further functional area.

The situation described here may not be stable either. On the one hand, deviations are to be expected because, as a result of increasing sales volumes, standardization of the modules and their interfaces becomes possible and necessary. As a result, special skills in interface structuring might get lost. On the other hand, such standardization may also enable an increase in sales. It is to be expected that for both these reasons the transaction costs will decline, so that the situation described in quadrant IV may arise.

It is also noteworthy that the function of the lead firm can get lost through particular efforts by the supplier in the innovation process. Direct suppliers and system suppliers in the automotive industry can be differentiated by, amongst other things, the fact that the latter show higher product innovation skills, patentability, and readiness for know-how transfer in the research and development processes. At the same time, however, they are subject to less intervention by the car manufacturers in their research and development and their process innovations (Gaitanides 1997, p. 750). They therefore try to counter the dissemination of knowledge by monopolizing their own knowledge. If we take into consideration that the system suppliers earn higher returns than the direct suppliers (Gaitanides 1997, p. 741), then this is indicative of a stronger position vis-à-vis auto manufacturers. The originally leading role of the auto manufacturer is, correspondingly, weakened in relative terms. This, in turn, can be an incentive to standardize the interfaces, in order to place suppliers under competitive pressure.

4.4 Disseminated knowledge in non-complex products (IV)

As a consequence of standardized interfaces, several firms will offer modules in competition as the knowledge required for each module is increasingly disseminated. The definition of the interfaces makes division of labor in invention easier. Then, it will no longer be only the system leader who combines the modules for his customers: the customers themselves will put the modules together from complementary parts. In comparison to the total bundle of outputs which arises as a result of this, each module is less complex. *Examples are tuner, receiver, tape drive and speakers instead of a "radio" or a truck with different tires, units and chassis all made by different manufacturers at the customer's order. In the computer industry, it was found that: "After thirty years of progress at a rate of 25 percent per year and after internationalization of the know-how required, many of the hardware technologies in computing and telecommunications are available as commodities. Therefore, these technologies in themselves are no longer the source of comparative advantage that they once were" (Armstrong 1996, p. 152). Elsewhere it is stated: "Rather than every computer company in the world designing and building its own proprietary parts, independent suppliers provided standard building blocks. As a consequence, a wide array of companies could build machines that performed across a broad spectrum of price and performance features" (Yoffie, Pearson 1991, p. 4).* If the technological interface problems cannot be resolved by a manufacturer which assembles the elements, this can result in serious competitive disadvantages from the customer's point of view (Yoffie, Pearson 1991, p. 6). If the problems are solved in a way which is visible to the outside world, however, competitors are given the opportunity to imitate the output, e.g., *in the computer market, the "IBM clones"*. If standardization occurs, competitive advantages can no longer be derived from technology developed in-house, but must be obtained from other outputs (e.g., services, consultancy, reliability, upwards compatibility). The exploitation of technologically based advantages might be shifted to the suppliers of the modules (*"Intel inside" is then put on the computers*), who will take a position within their markets in accordance with quadrants I or II as described above. In such a situation, it appears extraordinarily difficult to regain the position of the technology-developing lead firm once the role of "assembler" has been accepted. *The example of the failure of the development of the Apple Lisa computer demonstrates this. In con-*

trast to developments which were immediately previous to this (but not Macintoshes), Apple itself wanted in this case to be involved again in the programming of the operating system (Swanger, Maidique 1985, p. 18). If a supplier cannot be quickly changed, its problems in maintaining or advancing a desired state of the art are naturally also problems for its customer, the "assembler". Delays in the supply of Motorola Chips in 1990 obviously did significant damage to Apple's image as the performance leader in PCs (Yoffie, Cohn, Levy 1992, p. 10). IBM, in contrast, kept on its own micro-chip production for internal use and secured its supplies from Intel by investing in the company (Coleman 1987, p. 1). Beyschlag produces 5 billion resistors per year for the automotive and the electronics industries. It relies on proprietary production processes, reliability and product quality, and engagement in problem solving together with their customers. An alternative for the powerful customer to secure its competitive position is to demand that the supplier must ensure that its products are interchangeable with others (Bingmann 1994, p. 800).

The manufacturers of the individual modules which are standardized at their interfaces will only aim for performance improvements in the modules if the customer can thereby improve the total performance of its system and wishes to do so. Otherwise, the realization of competitive advantages will focus on cost reductions prepared by process development, which as far as necessary will be passed on in the form of lower prices. Similar considerations also apply to the case where a dominant design has become established (Utterback 1994).

The stability of a situation shown in quadrant IV can also be disturbed by radical innovations, which in turn can lead to quadrants I or III, but at a new technological level and therefore, probably, with new market players.

Profit-maximizing module manufacturers or system suppliers may perceive their own situation as offering room for improvement and act accordingly. *When the planned establishment of a development laboratory in Germany by an American automotive industry system supplier was announced, whereby the "required closeness to the auto manufacturers" was to be achieved, acquisitions were also promised. Two reasons were given for this: firstly, obtaining more customers; secondly, reducing the dependence on individual customers (FAZ Jul. 19, 1997, p. 16). If this strategy makes the module supplier stronger, that is, makes it possible for the supplier to assert higher*

prices because control by competition is reduced, a firm may arrive once more at the point of technological backward integration of sub-contracted parts. Such a firm would be aiming to change its position from IV to II or even I for economic reasons.

5. Summary and further considerations

(1) It has been demonstrated that the situations considered in the four quadrants of the knowledge spectrum are not stable, but are vulnerable by technological innovations, amongst other things. The positions represent ideal types at prominent points on a continuum of knowledge dissemination and combinatorial knowledge use for product complexity. Some of the transitions between III and IV have already been described in more detail (Meyer 1994, p. 102 ff., 164). Because of the technology-related vulnerability of every situation described, it cannot be expected that all firms or even business units will develop towards a single position, as is sometimes maintained. An overview of the destabilizing influences discussed here is given in figure 3.

I:	Lower costs because of competing technology (parallel invention) Loss of specificity in the case of network effects High costs through differentiated technological progress and differentiated demand Being overtaken by radically new knowledge
II:	High coordination costs and neglect of innovations in the case of "architectural knowledge" No ability to protect knowledge permanently High costs of internal generation of knowledge High opportunity costs in the case of trust-based commitments to particular customers as development partners
III:	Opportunistic exploitation of information asymmetry High cost of securing "minimum knowledge" outside the range of core products Standardization of technological interfaces
IV:	Costs of securing a "minimum knowledge" for the "assemblers" of the parts Being overtaken by radically new knowledge Monopolization by the module manufacturers

Figure 3: Destabilizing influences on the positions in the spectrum of knowledge

(2) Broad knowledge dissemination and high complexity, as considered here, do not represent "natural" extremes of the respective scales. The dissemination of knowledge could in theory be extended to every person. This, however, is not practicable on economic grounds, amongst others. The maximum level of dissemination is determined by learning costs, storage costs of the knowledge, and the value of knowledge. Complexity could also increase further from any attained level. From an economic point of view, this is chiefly to be expected when the costs of coordination of the complexity-inducing elements of a product decrease. The development of electronic communications media could, in this sense, offer an opportunity for an increase in complexity. Whether this condition is then exploited in one firm or whether it leads to new forms of cooperation between firms is partly determined, in turn, by the dissemination of knowledge.

(3) Furthermore, it is interesting to observe that the direction and scope of research and development are neither confined to the range of activities of other functional areas of the firm, nor are they the same for all ideal types considered. This is significant for technology management of this function and general management. In reality, the more diversified a firm is, the harder it is to perceive this significance.

(4) Each business unit of a firm can find itself in one or another of the four quadrants and be attacked more or less strongly. Different research and development policies should be chosen accordingly. The considerations expressed here may also help to explain the trend observed in the last few years towards the formation of independently operating business units or the spin-off of independent companies from a firm.

(5) Finally, it is apparent that the transition between the situations described does not take place according to a mechanistic, sequential pattern. The advantageous transitions are rather determined by economic conditions which are in part technology-based and which can be formulated using the concepts of transaction costs and opportunity costs. If we posit that knowledge is not lost (which, however, can occur in individual cases, as shown by, e.g., the repeated reinvention of the process for manufacturing ruby glass), then transitions from III or IV to I and II with the same knowledge are not primarily explained by technology, but by economics. All other transitions can have both technological and economic grounds.

The view developed here digresses from those models that make plausible very specific successions of innovative activities. One example for such models is the Abernathy-Utterback-Model of product and process innovations (Utterback 1994). This model indicates movements from our field I towards higher complexity, particularly in the phase where process innovations become relatively more frequent than product innovations. Eventually, more disseminated information might also be observed in the model. However, we do not assume a definite phasing of such innovation types.

(6) To date, no studies are known which empirically describe the dynamics of these transition processes in terms of the factors of influence considered here.

A study of firms which offer complex systems (e.g., radar systems), that is, firms which could be positioned either in situations II or III as described above, or - for individual modules - in situation IV, offers initial indications (Paganetto et al. 1998). The authors consider four "structuring alternatives"². However, only four of the 16 possible transitions between these (observing two different points in time) are considered³. Particular attention is paid here on the one hand to development capacities and their ability to deliver the necessary level of technological progress cost-effectively (in particular to pioneer or be a follower in radical innovations). On the other hand, the production capacities for modules are considered, as well as the capability of realizing economies of scale (which does not promise crucial advantages in markets with a very small demand), of avoiding supply bottlenecks for critical resources or of keeping the relative factor costs low, and defining the technological interfaces between modules. One of the important conclusions drawn

² These are: (a) development internal, production internal; (b) development internal, production external, assembly internal; (c) development external, production external, some in-house development capacity; (d) development external, production external, no in-house development capacity.

³ The description is not quite clear. As far as can be ascertained, the following cases are considered: "persistence of vertical integration" from (a) to (a), whereby the structural alternatives in the footnote above are called by the corresponding letters; "de-verticalization" from (a) to (b), (c) or (d); "partial de-verticalization" from (b) to (c) or (d); "vertical integration" from (c) or (d) to (a) or (b); "re-verticalization", which corresponds to the last case, but refers back to a different case history.

from the observation of the transitions is that an "appropriate level of control over each technology" is necessary. This means, therefore, that even in the case of cooperations or the procurement of modules from outside a firm, the firm should maintain in-house the capability to judge technological progress competently as well as access to its results. This agrees with the idea considered above which posits that the breadth of the development tasks does not necessarily have to match the breadth of the production tasks. It appears that this necessity has not been considered in every one of the core competency-based reorganizations of the past years. Disadvantages arising from this are not immediately visible, but only after a time lag. They can, however, only be corrected at that stage by internal efforts which also have a delayed effect, or by the expensive acquisition of external knowledge, e.g., by acquiring a company. This is one of the dangers of neglecting the dynamics of technological competencies.

In our presentation, information drawn from reports and case studies has been used to support the reasoning. There has been no comprehensive empirical test of the main question: how do economically relevant characteristics of technological progress interact with a form of corporate organization designed to secure competitiveness and with markets? This question offers opportunities for further research.

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