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Knowledge-based Entrepreneurship: The Organizational Side of Technology Commercialization*

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abstract

New knowledge with commercial potential is continually created in academic institutions. How is it turned into economically valuable businesses? This paper argues that the transfer is an entrepreneurial process. To understand this, the actions and the constraints characteristic for the entrepreneurial reshaping of the division of labor must be recognized. In the case of knowledge-based entrepreneurship, specific constraints result from the peculiarities of scientific knowledge – epitomized by contrasting tacit and encoded knowledge. Scientifically trained labor is required for transferring both forms of knowledge. However, the mode of transfer differs crucially and shapes the organizational form of commercializing new scientific knowledge.

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I. Introduction

New knowledge which shapes and supports technological advance continually emerges in the academic institutions. It is a result of publicly financed, scientific problem solving. As such, its generation is not (primarily) guided by application interests. However, such knowledge usually carries some commercial business potential. National economies differ substantially both in their capacity to exploit the opportunities and in the pace of doing so. These differences have been found to be a major source of competitive advantages in global markets (Porter 1990). New production technologies and products drive the process of economic growth and allow innovation rents to be appropriated. In recent years, one question has therefore attracted increasing interest both in economic research and in politics (Nelson 1993, Edquist and McKelvey 2000, Salter and Martin 2001). How does new knowledge from scientific research find its way into the commercial part of the innovation system? How does it support technological advance?

In this paper it will be argued that the transfer is essentially an entrepreneurial process. On the one hand, to understand that process, it is necessary to recognize the kind of actions and services involved in the entrepreneurial reshaping of the division of labor. In general, entrepreneurship requires command over suitable resources. In the case of knowledge-based entrepreneurship these are, in particular, resources enabling the access to, and the exploitation of, new technological knowledge. Therefore, an essential part of entrepreneurial activity here is the organization of the knowledge transfer from academic research to commercial production and marketing activities.

On the other hand, the entrepreneurial process cannot fully be grasped without recognizing the constraints under which it operates. Entrepreneurship always faces obstacles such as barriers to entrepreneurial entry, lack of qualified resources, and/or organizational rigidities. Depending on entrepreneurial skills, some of these can be overcome, some cannot. Difficulties like these vary with the institutional and political conditions in the different national economies. They can impede the entrepreneurial commercialization of new technologies (Henrekson and Rosenberg 2001) just as much as they can impede any other entrepreneurial activity. In the case of knowledge-based entrepreneurship, there are, however, additional obstacles. They result from the peculiarities of scientific knowledge and its mode of transfer. It will be claimed here that the attempt to overcome them shapes the manner in which the commercialization of new technologies is organized (Zellner 2003).

To explain this, it is useful to introduce the common distinction between tacit and encoded (or implicit and explicit) knowledge which goes back to Polanyi (1967). Encoded knowledge exists in the form of written information. It is accessible to commercial users as long as their training allows them to understand context and content. Tacit knowledge, in contrast, can only be acquired by experience on the job – in the case of scientific tacit knowledge by conducting scientific research. This knowledge is hard, or even impossible, to encode and therefore has to be carried in embodied form. However, in a rapidly progressing research environment, state-of-the-art tacit knowledge is constantly changing. Privately held tacit knowledge is therefore subject to relatively rapid decay unless it is quasi automatically up-dated on the job in a continued involvement in scientific research.

Technological and disciplinary fields differ with respect to what form of knowledge is relevant for commercial applications, and so, too, does the actual organization of the knowledge transfer. Yet, in any case, the service of scientifically trained personnel is necessary to achieve the transfer. This very special resource requirement implies substantial overhead costs for the venture, unless the entrepreneur is able to provide that service in person (as in the case of start-up firms run by former researchers as entrepreneurs). This fact may explain why the transfer and commercial exploitation of technological knowledge indeed tends to be a matter of either small entrepreneurial start-up firms or large, incumbent firms (Cohen, Nelson and Walsh 2002).

In the first case, the knowledge transfer is accomplished by the entrepreneur who embodies the necessary technological knowledge in person when setting up the business. In the case of the large, incumbent firm, by contrast, technological expertise that is complementary to the organizational capabilities already existing has to selectively be acquired on the labor market. Usually this is done by expanding the existing R&D staff – a specialized organizational unit a firm can afford to support only if its operations are on a large scale (cf. Keck 1993 and Reinhardt 1997 for historical examples). The two contrasting forms of firm organization represent very different stages of organizational development (Witt 2000, Rathe and Witt 2001). They therefore have different strengths, face different problems, and pursue different entrepreneurial strategies in exploiting knowledge-based business opportunities. However, both organizational forms compete for the same resource: the human capabilities needed to realize the knowledge transfer.

The competition for human capabilities takes place in a self-sorting process among the scientists and engineers who are about to migrate from academic research into the private sector. They can realize the commercial value of the knowledge they have acquired in academic research either by setting up an own entrepreneurial start-up venture or by becoming employees in someone else's entrepreneurial business. Accordingly, they either become the subject or the object of knowledge-based entrepreneurship. Yet, in either case, the peculiarities of scientific knowledge and its transfer mode imply constraints for exploiting knowledge which are changing systematically over time. As will turn out, the – differing – responses to these constraints result in organizational arrangements which seem to be characteristic concomitants of the commercialization of new technologies.

The paper proceeds as follows. To set the stage, section II focuses on the different forms of scientific knowledge and, correspondingly, of knowledge transfers. These represent the constraints for the entrepreneurial choices about how to carry knowledge across the institutional boundaries between science and commerce. Section III gives a brief review of the actions and services involved in the entrepreneurial reshaping of the division of labor. It then turns to the logic of the competitive process by which people sort themselves into entrepreneurs and employees. The understanding of this sorting also helps to explain certain features of the knowledge transfer process. Section IV looks into the case of start-up firms. Special attention is given to the problems they encounter with the manner in which they organize the transfer of tacit knowledge – problems that may, in the longer run, undermine their capacity to exploit new knowledge-based business opportunities. Section V explores the problems which large, incumbent firms face with their way of organizing the knowledge transfer under pressure from the competitive sorting process. A connection with human resource development plans is made which – in the form of career path options offered to scientifically trained staff – turns out to be a major organizational provision taken to account for these problems. Section VI offers some conclusions.

II. The Nature of Scientific Knowledge and its Transfer Conditions

Scientific research creates new knowledge in basically two different forms. These forms also differ with respect to the manner in which knowledge is transferred across the institutional boundary between scientific research and commercial application. One form is propositional knowledge. It is the object of most empirical studies of knowledge transfer (cf. Grupp 1998). Propositional knowledge can be encoded and stored by means of some information medium like, e.g., a written document. Transmitted by the information medium, it can, in principle, be acquired by all potential recipients in parallel when they gain access to the medium and command sufficient interpretative knowledge. Once published, encoded technological knowledge can be used indiscriminatingly for commercial purposes by any interested party. No personal contact is required with those who originally created the knowledge and disclosed the information about it.

Indeed, the innovation performance and long-term competitiveness of firms in high-technology environments seems to hinge critically on their capacity to monitor and tap, in an anonymous form, scientific and technological developments that have originated elsewhere (Cohen and Levinthal 1989, Rosenberg 1990). This means that new propositional knowledge emerging in academic research and more generally in the international innovation systems needs to be traced. Its usefulness, in terms of complementarities to the firm's own capabilities, needs to be assessed. Prerequisite for doing so is that the firm has sufficient cognitive "absorptive capacity", i.e. sufficient own knowledge to understand context and meaning of the information transmitted. [1] The transmission of knowledge in encoded form is, however, not possible for all aspects of scientific research. Besides theoretical and empirical insights (whose publication in scientific journals constitutes the main objective of academic research), a variety of other forms of knowledge are essential to the scientific process. They are mainly differentiated from the former by their procedural characteristics and imply a substantial degree of tacitness.

These additional, tacit elements of scientific knowledge can be classified according to their specificity and the role they play in the generation of new scientific knowledge (Zellner 2003). Scientific skills presuppose the command of methodological knowledge about experimental procedures and research strategies applied in the respective (sub-)disciplines. Furthermore, scientific skills include the analytical skills necessary for the recognition, formulation and solution of complex problems. (Even though these analytical skills are substantially less specific to the discipline and are difficult to observe, they represent one of the most important ingredients in the expansion of scientific knowledge.) In addition, the operation of the physical infrastructure of the research process requires a substantial amount of practical, procedural knowledge. This includes knowledge about, and experience with, physical instrumentation and laboratory equipment. (In fact, progress in, e.g., experimental physics or chemistry is often based on the development of a specific experimental set-up which sometimes also absorbs the bulk of the resources invested). Finally, an ever more important prerequisite of scientific research today is knowledge of how to use information technologies and how to develop own applications in the form of the design of simulations and software programming. The substantial requirements for data analysis and processing have made modern scientific research one of the high-end users of hardware technology.

All these forms of knowledge are hard, or even impossible, to encode and, hence, cannot be

[11] Cf. Cohen and Levinthal (1989). The entrepreneur in a knowledge-based business venture may, but does not have to, possess that cognitive absorptive capacity in person. To the extent to which new technological developments are documented and accessible in the form of encoded knowledge, the entrepreneur can link up with them by hiring suitably trained human resources (as part of the overall resources) who have acquired the necessary cognitive absorptive capabilities in academic education and research.

transmitted to potential recipients by information media. [2] Their acquisition by individual scientists is based on repeated practice and continuing interaction with senior scientists, usually in the context of non-commercial research activities. For many technologies like, e.g., in molecular biology and chemistry, these tacit knowledge components represent an important part of what is needed to accommodate – and ultimately to commercially exploit – the state-of-the-art technological knowledge.

Since transmission in encoded form is not possible here, a different transfer mode is relevant. Knowledge of this form, often containing substantial procedural elements, can only be carried from scientific research to the commercial sphere by scientists and engineers who migrate from academia to business. They embody the forms of tacit knowledge mentioned after acquiring them "on the job" in non-commercial research where these skills and technicalities are developed and refined in a usually costly and time intensive way not subject to profitability considerations. Thus, the attraction of scientifically trained staff to business firms does not necessarily only serve the purpose of creating cognitive absorptive capacity in these firms. It also enables the firms to get a hold of tacit state-of-the-art knowledge from scientific research which cannot be transferred in other ways.

However, by the very mode of transfer – the physical migration of the knowledge carriers into the commercial sphere – the knowledge carriers are cut off from the further development of that knowledge in the academic sphere. Even with considerable communication effort, it is, in most cases, not possible for a scientist who has left academic research to keep up with the rapid development of the tacit knowledge components there. Therefore, the problem of transferring tacit state-of-the-art knowledge can always only temporarily be solved. To retain the tacit knowledge transfer, ever new cohorts of scientists and engineers from academic research need to be attracted into the commercial sphere with a frequency that depends on the decay time of the tacit knowledge they embody.

This organizational feature of the tacit knowledge transfer causes a problem. In many national innovation systems the boundary between the academic and the commercial sphere is not equally permeable in both directions. Moreover, it tends to be the less so, the less close a scientist's field of

[22] There is yet another reason playing a role here. Besides the limits to codification that are inherent to the elements of knowledge discussed, there are institutional factors that can inhibit the codification of knowledge that is instrumental to the production of propositional knowledge. Academic science is based on an incentive system that rewards priority in disclosure (Dasgupta and David 1994; David 1998). To the extent that scientific skills and technicalities confer a competitive advantage to individual scientists or their laboratories, the incentives to encode and disclose such knowledge are probably limited or even negative. This observation may be particularly relevant to skills and technicalities that are specific to the (sub-) discipline or line of research.

specialization is to applied research. This means that the return option for scientists who cross the institutional boundary between the academic and the commercial sphere is more or less uncertain. The question therefore arises of whether they can be induced to take such a potentially irreversible step in their professional development. If their employment prospects with the hiring firm were limited to that period of time during which their tacit knowledge is at the state of the art, these people might be reluctant to accept an offer from a business firm. This is especially true for the most talented researchers and/or if that period of time is only a relatively short episode in a professional life span.

The problem for the commercial employer thus is how to create additional incentives for non-academic employment without raising to a prohibitive level the costs of acquiring state-of-the-art tacit knowledge. The problem is particularly difficult, because the contribution a scientifically trained employee will actually make to the firm's future profitability cannot be judged safely at the time of hiring the employee. Moreover, the future employee's effort in exploiting complementarities between her/his embodied knowledge and the knowledge that exists in the firm organization cannot easily be observed and, hence, is difficult to contract. Before discussing in more detail what provisions are taken to account for this problem, it is useful, however, to consider in the next section who the potential migrants to the corporate R&D departments are. As mentioned in the introduction, this is decided in a competitive self-sorting process that determines how people can exploit the knowledge they have acquired in academia.

III. Competition Between Business Conceptions: the Entrepreneurial Sorting Process

The mode of transferring new knowledge from non-commercial research to commercial R&D, production, and marketing activities depends, it has been argued, on whether the knowledge to be transferred is tacit or encoded. In both cases, however, for the transfer people are required who have previously acquired the corresponding knowledge and capabilities in academic training and research. These people play a central role as interpreters of encoded information and/or as carriers of the state-of-the-art tacit knowledge. Making them available for the commercial sphere and, thus, organizing the knowledge transfer, is a core element of knowledge-based entrepreneurship. In fact, the service provided by knowledge-based entrepreneurship has yet other, equally important aspects. [3]

In order to trigger the transfer it is necessary, first, for someone to see business opportunities in

[33] Like in Penrose's classical definition, entrepreneurial services are contrasted here "...with managerial services which relate to the execution of entrepreneurial ideas and proposals and to the supervision of existing operations" (Penrose 1959, p. 32).

new scientific knowledge. This is an often overlooked, genuinely entrepreneurial, achievement (Witt 1998). Newly discovered scientific insights and techniques do not by themselves suggest new products or production processes that may be commercially successful. Such opportunities have to be imaged by combining at least some ideas about the new technology with conjectures about market conditions (Shane 2000). Once a more or less concrete business conception has been created it must, second, be realized by attracting resources and coordinating their interactions.

In the case of knowledge-based entrepreneurship these are, in particular, knowledge resources. Sometimes they may even be embodied by entrepreneurs (who have been scientists). Yet this is not necessary. The entrepreneur can always try to access technological knowledge by hiring human resources properly trained to accomplish the knowledge transfer across the institutional boundaries. Where firms already exist, a third entrepreneurial task is to integrate the newly mobilized technological knowledge into the established organization and, where necessary, to adjust the business conception. Only if new knowledge can be made complementary to already existing organizational capabilities can it successfully be exploited by the firm. This may sometimes require major organizational restructuring.

A question that arises, and that is particularly important for understanding the conditions of the knowledge transfer process, is who will be, or become, the entrepreneurs trying to accomplish these tasks? In principle, everyone who has thought up a business conception for exploiting new technological knowledge commercially could make an attempt to hire employees and other resources. And large numbers of business conceptions can be imagined. What determines which of these are indeed turned into concrete ventures? As has been claimed elsewhere (Witt 1987), the answer to these questions is a competitive self-sorting process that precedes the founding of a new firm or the signing of an employment contract.

In the context of knowledge-based entrepreneurship, the key role in the competitive self-sorting process is played by those scientifically trained researchers who are about to migrate from academia to the commercial sphere. As one alternative, they are offered (non-entrepreneurial) employee positions, preferably in R&D, as catalysts of the knowledge transfer discussed. The offer is, of course, based on the expectation that the future employee is ready to acquiesce to the entrepreneurial business conception pursued by the entrepreneur(s) of the hiring firm. As another alternative, these migrating researchers can, by using their technological knowledge and capabilities, develop an own business conception and consider realizing it as entrepreneurs. In this case, they would found an own technology-oriented start-up enterprise and try to attract the complementary resources.

The decision about who sorts, and how, has many facets. Economic reasons are not necessarily the most important ones. However, they do have an influence. As an entrepreneur, a migrating scientist would have to tackle the two tasks just mentioned: attracting resources and coordinating their interactions in a way that is conducive to realizing the own business conception. Accordingly, the own coordination skills have to be assessed, as would the profitability of the own business conception. The income stream that is imagined to be retained after paying the hired resources has to be compared to the income stream to be earned by accepting an employee's position in someone else's firm; and so too have the expected workloads and the non-pecuniary features of the two alternatives. For the subjective opportunity cost assessment the question of how much – and how long – the own, embodied knowledge will be valued by the future employer is obviously important. Indeed, it may be decisive in the case of a potentially decaying state-of-the-art tacit knowledge. A hiring firm may therefore be compelled to provide a long-term professional perspective.

Thus, even though there is no market for entrepreneurial business conceptions, something like an anticipated (and necessarily very subjective) market contest is actually taking place when scientists and engineers who leave academic institutions sort themselves into entrepreneurs and employees in knowledge-based business ventures. The subjective opportunity cost assessments, and thus the outcome of the contest, may, of course, turn out to be wrong. For this reason, the results of the sorting process are not always stable. A start-up firm may not succeed and will then go out of business, bringing its founder back on the labor market. Conversely, someone who has become an employee in a firm in a first sorting may later reconsider that decision. Based, e.g., on a better assessment of the value of the own embodied knowledge and/or changed market conjectures, the chances of own business conception may be rated better than before. If this happens, a former scientist may want to leave the firm and set up something of her/his own.

IV. Start-up Firms and the Decay of Founder Knowledge

To become an entrepreneur, and to found a technology-oriented start-up firm, is one way in which a migrating scientist can contribute to the knowledge transfer from academic science to the commercial sphere. This organizational solution of the transfer problem, which has attracted considerable political interest (cf., e.g., BMBF 2001), is of course, confined to knowledge and capabilities acquired by, and embodied in, the entrepreneur in person. [4] Initially, the fate of a start-up firm is independent of which of the two forms of knowledge, tacit or encoded, are transferred. In both cases, the founding entrepreneurs exploit the knowledge they embody in order to realize innovative production processes or products. If successful, start-up firms find their niche in the markets – perhaps even a growing niche or market.

However, depending on the pace of progress in non-commercial scientific and technological research, improvements and diversifications in the firm's processes and/or product may sooner or later become feasible. A continued transfer of new technological knowledge would then be useful or even necessary to keep up with competitors. In the case of technological knowledge that is accessible in encoded form, the founding entrepreneurs can support the transfer themselves, provided they continue to use their existing cognitive absorptive capacity to adopt the new knowledge and, where necessary, to up-date that capacity. Thus, if run by former scientists, even comparatively small business ventures do not necessarily have a disadvantage in keeping up with technological developments and in exploiting new commercial opportunities in this case.

A different situation arises where new technological knowledge is largely tacit and where the state of the art needs to be transferred in embodied form. Former scientists, who founded their start-up firm with the current state-of-the-art capabilities they acquired previously may then face problems. Due to the peculiar conditions of the transfer of tacit knowledge discussed in Section II, they are cut off from the further development of the technology in the sciences and may sooner or later experience decaying relevance or up-to-dateness in their tacit knowledge. When the products and process with which their start-up succeeded age and improvements and/or diversification are needed, they will lack the required up-dated knowledge base unless they find ways of attracting migrating scientists or engineers who embody what has then become the state-of-the-art knowledge. [5]

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[44] For the transfer to succeed, the innovation – new knowledge-based products and/or production processes – introduced by the start-up venture do not necessarily have to be profitable. Due to the public good features which new technologies at least partially have it is sufficient for them to be introduced into the markets and to allow profitable business later, perhaps by firms other than the start-up venture that introduced the innovation. For the question of how scientists, who migrate at a future point in time, perceive their alternatives in the entrepreneurial sorting process – and, hence, their willingness to also try a start-up – the fate of earlier knowledge-based founding activities may, of course, be decisive, cf. Fornahl (2005).

[55] Small firms, particularly those in science-based industries, often try to nurture and maintain links with academic institutions in the form of consulting and/or collaboration projects. These efforts underscore the firms' continuing dependence on tacit knowledge. However, as discussed, they presuppose that the firms have a sufficient absorptive capacity. Precisely for this reason, maintaining such organizational links is not a permanent substitute for a repeated physical migration of scientists. To ensure a sustained knowledge transfer, the firms' absorptive capacity needs to be kept up-to-date by occasionally

The attempt to attract such resources means participating as a potential employer in the contest in which a new generation of researchers migrating from academic institutions sort themselves into entrepreneurs and employees. As mentioned, the problem for all commercial employers is to create incentives for these people, first, to indeed leave academic research and, second, to become employees (rather than self-employed). At the same time, these incentives should not drive the costs of acquiring state-of-the-art tacit knowledge to a prohibitive level. From the point of view of the migrating scientists and their subjective opportunity cost assessment, the question of how much – and how long – the own, potentially decaying state-of-the-art tacit knowledge they embody will be valued by the future employer is a crucial variable. Hence, an important incentive for them to sign on with a firm is a professional long-term perspective offered by an employer that is independent of a possible future knowledge decay.

Such a long-term perspective is provided by a career path option for scientifically trained R&D staff which allows employees to proceed at a certain stage from technical to managerial tasks and to maintain or even increase income.[6] An entrepreneur who can offer professional career options therefore has a competitive advantage over other entrepreneurs who cannot. However, in order to be able to make a credible personal promotion promise, the entrepreneurial start-up must have already grown to an organizational size where it can create profitable employment opportunities for scientifically trained managers. In many industries a pace of growth of the firm sufficient to meet this requirement may be hard to achieve.

If so, other ways of attracting the latest brand of scientific expertise into the firm to strengthen its capabilities have to be found. One of these, though, in a sense, an expensive one, is the following. In order to be able to compete in the contest, entrepreneurs who have founded a start-up can offer partnerships to migrating former scientists, particularly if the firm organization is still small. In view of the uncertainties about the actual value of the tacit knowledge to be acquired, such a step is not without risks. It can occasionally be observed when the future partners already know each other from their work in the scientific institution from which they migrate.

If even this option is not feasible while the competitive pressure to adopt state-of-the-art tacit

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acquiring new state-of-the-art embodied knowledge.

[66] In large firms, the transition from technical to managerial tasks is a distinct career feature (Biddle and Roberts 1993). It amounts to a change from the manipulation of objects or processes to the coordination of other employees. While the demarcation between corporate functions may not always be sharp in these terms (e.g., when someone takes on project responsibility in mainly technical functions like R&D or production), it is *the* major qualitative change in a career.

knowledge is high and is increasingly reducing the business prospects of the entrepreneurial knowledge-based firm, there is always a default strategy. The founder entrepreneur can escape from further decline by trying to sell the start-up venture and to “cash in”. Scientists who embody the tacit knowledge that would be needed and who are about to migrate usually lack the financial resources to purchase a firm. However, other (sometimes rival) companies may acquire the business and merge it with their existing activities. If the acquiring firms do not already have the organization size necessary to be able to offer attractive career terms in the competition for the needed tacit knowledge, mergers and acquisitions may be the way to reach that size.

V. Incumbent Firms and the Role of Intra-organizational Career Paths

As a matter of fact – notwithstanding the recent attention paid to entrepreneurial start-up firms as an effective mechanism of knowledge transfer – a significant, or perhaps the largest, share of new technological knowledge is transferred to, and exploited by, large, incumbent firms. These firms have grown out of entrepreneurial founding activities in the past. As many examples from business history show, the origins have often been classical cases of what would now be called knowledge-based start-ups, e.g. in the electrical, pharmaceutical, chemical, and many other industries (cf., e.g., Heuss 1946, Galambos and Sewell 1995, McKelvey 1996, Murmann 2003, Buenstorf and Murmann 2003). The survival and growth of these firms was based on entrepreneurial business conceptions which informed and motivated the application of a technology in the form of new products and processes. Those business conceptions were the basis on which knowledge resources and other resources could be acquired, coordinated, and used to create commercial value.

However, over time, what were initially innovative products and processes are always in danger of becoming easily and cheaply copied standard practice. Even worse, if not improved or replaced these products and processes are prone to being outdated by further technological progress elsewhere. The continued involvement of large, incumbent firms in the further commercialization of new technology (often outside the technological field in which they started) therefore follows an own logic. It is different from, and more complex than, the immediate grasping of a market opportunity in start-up ventures. While start-ups usually aim at gaining a foothold in the market and expanding the business, large incumbent firms usually try to maintain or improve a competitive advantage they have been able to attain in the past. In dynamic markets, this means that they have to keep track of the latest technological developments relevant to their industry and to spot commercial application opportunities that may be emerging from these. This is no trivial task. In fact, large firms face two kinds of problems in doing this.

First, unlike a migrating scientist founding a start-up venture as an entrepreneur who can exploit the latest brand of technology by her/his own embodied knowledge and capabilities, large firms have to find ways to acquire and absorb the most recent technological knowledge. The second problem which large, differentiated firm organizations face is that spotting technological opportunities requires considerable coordination efforts. (This is obviously different from the case of small start-up firms in which the entrepreneur integrates all necessary functions into one person.) The various people in charge of conceiving of new business opportunities, of deciding about them, and of actually (re-) organizing the internal resources, all need to be coordinated. New technological knowledge has to be aligned with the firm-specific knowledge, capabilities, and routines that have been accumulated in the past.[7] Moreover, as a consequence, the adjustment of (up to now successful) business conceptions may be necessary and has to be mastered.

The second kind of problems all relate to the services of knowledge-based entrepreneurship as discussed above. After all, entrepreneurship is no less important for large, hierarchical firms than for the small start-up venture. However, in large, hierarchical firm organizations, the entrepreneurial function is divided and distributed over various people who have the role of sub-entrepreneurs. These are usually paid managers at different layers of the hierarchy who provide managerial and some entrepreneurial services in one person. They need to be coordinated with an overarching, socially shared business conception as the cognitive frame for their various, distinct operations in order to ensure that the entire organization will not lose corporate coherence and will not risk frictions resulting from rivaling orientations (Witt 2000). This is easier to accomplish when those performing an entrepreneurial function have been "socialized" inside the firm (cf. Penrose 1959, chap. IV, who claims that the availability of such personnel *inside* the firm is a limiting factor in the expansion and diversification of the firm).

Under these conditions, an ingenious option for large firms is to try to solve the two problems – that of securing a continued knowledge-transfer and that of accounting for its organizational coordination – with one and the same measure. This measure is the intra-organizational career paths for scientifically trained employees which lead from technical to management functions. [8] In offering such

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[77] Occasionally, the latter may be more of a burden than an asset for pursuing new business opportunities inside the organization. Taking a strategic management perspective, Leonard-Barton (1995) observes that the firm's "core capabilities" can sometimes turn into "core rigidities," as they become strongly embedded in the people who deploy their competencies in specific ways. Leonard-Barton not only identifies cognitive biases and "signature skills" as obstacles to change, but even asserts that there are rigidities arising from "knowledge-base-specific values."

[88] There may, of course, be still other motives for encouraging turnover within the firm organization through which employees with technical functions in corporate R&D are promoted to

options, large firms can, on the one hand, strengthen their attractiveness as employers for migrating researchers who are about to sort themselves into entrepreneurs and employees. As mentioned in the previous section, the prospect of professional in house promotion is an important source of motivation for getting migrating scientists to sign on with firms.[9] The offer of intra-organizational career plans can thus bolster the firm's effort to acquire the latest technological knowledge.

On the other hand, this measure at the same time allows large firms to build a resource base in house in which technical expertise and entrepreneurial talent can be combined. Employees differ in their abilities, their aspirations, their task responsiveness, their working attitudes, and, not least, their entrepreneurial talents. Since personal promotion is usually supposed to be contingent on the employee's demonstrated performance, there is time for an attempt to verify the employees' personal skills and abilities. [10] In this way, a sorting process like the one discussed in the previous section can be emulated within the firm's internal labor market. The firm can identify and seek to deploy the entrepreneurial talent of employees who are scientifically trained and have gained a background in the technical capabilities and procedures of the firm. (The importance of technological expertise in this combination is underscored

managerial ones. One of these may be the expectation that the individual creativity and productivity profiles of the former scientists in R&D decline after a certain age as they have been shown to do for academic researchers, cf. Levin and Stephan (1991). This motive is independent of the form of knowledge to be acquired by the firm. It suggests also offering career path options where scientifically trained staff is hired so as to create an absorptive cognitive capacity for the transmission of encoded knowledge.

[99] From the point of view of the hiring firm, there is yet another potential advantage to relying on this measure. Compared to an attempt to completely compensate the potential decay of embodied knowledge by monetary incentives, the career path option is less costly. In addition, the offer of personal promotion, emphasizing the stability of the employment relationship and possible assignment of increasing responsibility depending on performance tend to foster the employees' intrinsic motivation. Intrinsic motivation, in turn, is a precondition for the transfer of tacit knowledge among employees, and hence for coordination, cf. Osterloh and Frey (2000). In knowledge-*producing* functions, such as R&D, outputs is often difficult to attribute to individuals, rendering direct monetary compensation inappropriate or even detrimental. This is particularly true when tasks are ambiguous or multiple.

[1010] However, to be credible and, within limits, predictable for the employee, promotion plans have to a certain extent to be standardized and supported by examples of career trajectories that can be observed by those in lower hierarchical ranks. How the human resources should be managed and promoted within the firm organization to attain the multiple goals is a question to which justice cannot be done in this paper. There is evidence that scientists in corporate R&D rate non-scientific managerial work very differently, and not overwhelmingly positively (Bowden 2000). However, the relatively flat hierarchies in corporate R&D rule out the possibility of "pure" R&D careers for a significant number of people employed there. The rule therefore is that career success is inevitably associated with the transition to management (Biddle and Roberts 1993, Bowden 2000). Yet it is not certain that all scientifically trained employees in R&D can indeed be offered managerial functions at a later point in time. If the number of promotions is too small, this may strain the credibility of the career path option and, in turn, the firm's knowledge sourcing strategy based on recruitment.

by the fact that large firms often try to confer business competencies to employees with a background in the sciences and technology by providing the relevant courses and training sessions.)

During their individual careers, such employees would typically move along the spectrum from technical problem solving tasks towards problems that require entrepreneurial knowledge coordination across internal functional boundaries. The sequential exposure to functional areas in the organization means that knowledge and competencies can be accumulated which span many of the firm's internal tasks, projects, and functional areas. When the employee eventually ends up in an entrepreneurial position, the accumulated firm-specific experience allows the views from several sub-divisions to be integrated and diverging interests to be arbitrated. Particularly with respect to the integration of corporate R&D with other functional divisions in the firm, career trajectories starting in R&D can serve an important bridging function. Career trajectories create the personal basis for making formal and informal contacts. Moreover, people familiar with the differing sub-cultures of the divisions can mediate a better mutual understanding of needs and constraints and of goodwill in the informal interactions between those divisions. [11] With these exceptional capabilities, employees selected by personal promotion plans should best be able to conceive of, and assess, new business opportunities. They may be given the opportunity to develop an own business conception in a subdivision of the firm organization and to participate in the possible profits.

Indeed, it may be necessary for the incumbent firm to offer entrepreneurially minded employees such an opportunity in order to account for those cases where the initial sorting of migrating scientists into entrepreneurs and employees tends to be unstable. Some of the former scientists with an entrepreneurial talent may have initially underrated their capacity to create an own firm and have therefore become employees. In the meantime, they may have learned enough about their firm's knowledge base, about technological opportunities, including those not pursued by their employing firm, and about running a commercial venture. They may therefore have arrived at an improved own business conception. If so, they may be inclined to give it a try in a "second" sorting and, thus, to quit and to start what appears from outside as a spinoff (cf. Klepper 2001).

Even worse for the incumbent firm, with their improved business conception, the former

[1111] In the context of his analysis of Japanese telecommunications firms, Fransman (1999, p. 128) reports that engineers are regularly transferred between R&D and the operating divisions in either direction to facilitate the development and transfer of new technologies. The effects on knowledge coordination of that kind of job rotation seem to be similar. However, the temporary nature of job rotation excludes the motivational effects related with personal promotion plans as discussed before.

employees could try to attract and entice away other members of their former firm whose productivity they may have learned to appreciate. This would amount to a "fissioning" of a whole group of employees as it can occasionally be observed particularly in new, highly innovative, industries (Ziegler 1985). If the firm wants to prevent this, those employees who may be inclined to re-sort themselves have to be transferred to a more highly valued position in the organization. To ensure that they can still be profitably employed, this must usually be a higher position in the firm hierarchy with some entrepreneurial responsibility – precisely what the notion of a career commonly stands for. [12] Sometimes the site of the higher positions may, of course, be in affiliated companies or joint ventures.

VI. Conclusions

The knowledge transfer from academic research into commercial production and marketing activities is based, it has been claimed in this paper, on several entrepreneurial services. The transfer does not happen unless someone conceives of business opportunities in new scientific knowledge in the first place. Then these (often only vague) imaginings have to be transformed into conceptions of how to run a business firm. On that basis, resources – foremost the necessary knowledge resources – have to be attracted and coordinated. Where business organizations already exist, the new knowledge resources must, furthermore, be integrated with the organization's expertise and capabilities to yield a coherent business conception. It has been argued that each of these services is a core element of *knowledge-based* entrepreneurship.

Like all forms of entrepreneurship, knowledge-based entrepreneurship is confronted with certain constraints. However, there are some specific constraints that result from the peculiarities of scientific knowledge and its mode of transfer. These specific constraints – which only become apparent once the simplistic reduction of academic science to a knowledge output in encoded form is abandoned – have been center stage in this paper. It has been shown that they shape the way in which the commercialization of new technologies is organized. The procedural nature of the knowledge that typically underlies new scientific insights implies that it can only be acquired by being actively engaged in scientific research. In other words, such tacit knowledge is hard, or even impossible, to encode and therefore needs to be carried in embodied form. However, in a rapidly progressing research environment, state-of-the-art tacit

[1212] When Stephan (1996, p 1211) asks "why do companies adopt compensation strategies that impair the productivity of scientists by tying salary increases to the assumption of managerial responsibilities?" an answer may therefore be given as follows. This may not be a strategy discriminating against scientists in corporate R&D. Rather, it may be a strategy that raises the opportunity costs for those who could be tempted to opt out into an own (and possibly competing) spinoff firm as just described.

knowledge is changing constantly. Without the automatic up-date on the job in a continued involvement in scientific research, privately held tacit knowledge is therefore subject to a relatively rapid decay.

Depending on the form of knowledge, the proper entrepreneurial organization of the knowledge transfer varies. Two ways of organizing the transfer have been discussed here: start-up firms run by former scientists as entrepreneurs and large, incumbent firm organizations with specialized R&D staff. Both compete for the human resources needed to realize the knowledge transfer. From the point of view of the scientists and engineers who are about to migrate from academic research into the commercial sector that competition results in a self-sorting process. These former scientists can realize the commercial value of the technological knowledge they have acquired in academic research either by setting up an own entrepreneurial start-up firm or by becoming employees in the large, incumbent firms. As was explained, the constraints implied by the tacit, embodied form of knowledge force both organizational solutions to adopt particular knowledge transfer strategies. Start-up firms have to find measures to cope with the decay of the founder's knowledge as time elapses. The large, incumbent firms have to find ways to make migrating scientists decide in favor of becoming employees and to stabilize this initial outcome of the sorting process in order to prevent spin offs and fissoning at later stages.

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