Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities: An Empirical Test

Udo Zander • Bruce Kogut
Institute of International Business, Stockholm School of Economics, Sweden
The Wharton School, University of Pennsylvania, Philadelphia, Pennsylvania 19104 *and the Centre de Recherche en Gestion, Ecole Polytechnique, Paris, France*

Abstract

The capabilities of a firm, or any organization, lie primarily in the organizing principles by which individual and functional expertise is structured, coordinated, and communicated. Firms are social communities which use their relational structure and shared coding schemes to enhance the transfer and communication of new skills and capabilities. To replicate new knowledge in the absence of a social community is difficult. A classic demonstration is the well-studied problem of the transfer across country borders of manufacturing capabilities that support production of new product innovations.

We show in this article that the degree of codification and how easily capabilities are taught has a significant influence on the speed of transfer. What makes the question of knowledge codification particularly interesting is that firms compete not only through the creation, replication, and transfer of their own knowledge, but also through their ability to imitate the product innovations of competitors. The capacity to speed the internal transfer of a production capability to new markets (e.g., those in other countries) is, consequently, of fundamental significance in a competitive environment. In the attempt to speed the internal transfer of knowledge, the dilemma arises that capabilities which can be easily communicated within the firm are more likely to be easily imitated by competitors.

This relationship is tested by analyzing the effects of the ease of codifying and communicating a manufacturing capability not only on the time to its transfer, but also on the time to imitation of the new product. The determinants of the time to imitation are found to be the extent to which knowledge of the manufacturing processes is "common" among competitors, and the degree of continuous recombination of capabilities leading to improvement of the product or the manufacturing process. We support this interpretation by a discussion of the results from field research.

A wider implication of these findings is the proposition that the transfer and recombination of organizational capabilities are the foundation of an evolutionary theory of the firm. A critical element limiting the expansion of a firm is that the competitive value of codifying knowledge leads to the selection of organizing principles that are not functional in all competitive environments. The pressure of speed is of critical importance to understand the evolutionary advantage of nonoptimal rules of coordinated action within a social community.

(*Organizational Capabilities*; *Knowledge*; *Imitation*)

That innovation is the central feature of competition in capitalist economies is a widely-held view. It is especially emphasized in the work of Schumpeter (1942) and the evolutionary theory of the firm of Nelson and Winter (1982). Due to the force of competition and changes in consumers' wants, the firm's long-run survival and growth depend on its ability to develop new products and new methods of organization. Yet, what is frequently underemphasized is that the expansion of an innovation rests upon the capacity to replicate the capability of the production and sales of the new service or product. This replication can occur by the voluntary transfer of this capability within the firm or to other firms (e.g., by a license), or by the unwanted imitative efforts of competitors. Transfer and imitation of the organizational capabilities are the twin elements of competition in innovative and growing markets.

In an earlier article, we proposed that the firm should be understood as a repository of social knowledge, where a competitive set of capabilities is replicated over time while subject to imitation. This present article examines a central proposition that the characteristics of social knowledge should influence the time to transfer and the time to imitation of major product

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and process innovations. In general, the knowledge of the firm can be categorized into "information" and "know-how." It consists of the competence of individuals and of the organizing principles by which relationships among individuals, groups, and members to an industrial network are structured and coordinated. These principles of coordination of individual and functional competence generate the capabilities of a firm.[1]

In the examination below, these capabilities concern the ability to manufacture major industrial innovations. The issues we explore lie at the core of an evolutionary theory of the firm. In such a theory, the competitive dynamics of an industry are driven by the rates of the transfer and imitation of new products and organizational capabilities.[2] In this dynamic perspective, internal transfer and imitation of an organizational capability are alternative mechanisms of serving a market. They, in this regard, represent joint processes of diffusion whose paths are partly determined by the ease of the replication of underlying knowledge. Other factors obviously influence the rates of transfer and imitation. Particularly important, as discussed below, is the degree to which firms share common manufacturing capabilities, on the one hand, and the degree to which they differ in their distinctive abilities to *recombine* their knowledge to improve the innovation, on the other.

In the first part of the paper, the perspective that capabilities of the firm consist of the cumulative experience in understanding a class of knowledge and activities is developed. Subsequently, drawing on the work of Rogers (1980) and Winter (1987), a set of dimensions by which to characterize a firm's capabilities (e.g., Codifiability and Teachability) is developed. Through questionnaires, data on the transfer and imitation times of 35 major Swedish innovations were collected. The questionnaire responses were then used to construct scales describing the *manufacturing capability* used for the production of these innovations. The time to transfer of manufacturing capabilities to new sites and the time to imitation by competitors were then regressed on these scales.

Strong support is found for the effects of different characteristics of capabilities on the time to transfer, while results for imitation are mixed. The empirical tests confirm that the degree to which capabilities are codifiable and teachable influences the speed of their transfer. These factors are not important for determining the rate of imitation. Imitation rates are influenced by the extent to which important aspects of the capabilities are possessed by many firms and by the ability of the innovator to improve the product. These results support the broader argument that firms exist and compete on the basis of their abilities to create, further develop, and transfer capabilities.

Knowledge of the Firm and the Dissemination of Capabilities

The transfer of technology is a topic that has received considerable attention. The term is often misleading, because technology is frequently associated with the application of scientific knowledge. Yet, these applications represent a special case of a wider phenomenon. Technology, as the many case studies on transfer of manufacturing know-how to other countries show, consists of the principles by which individual skill and competence are gained and used, and by which work among people is organized and coordinated.[3] The successful transfer of technology results in the receiving unit implementing *new techniques of production*. These capabilities can be used and economically exploited in the marketplace. Transferred knowledge can reside in design, production, installation, sales and distribution, operation and maintenance, or management.

Much as skills define the competence of individuals, organizing principles underlie the capabilities of a firm. The relationship between principles of organization and capabilities can be seen in revolutionary innovations of this century in the area of work organization. As Chandler (1977) has documented, the Taylorist principles of incentives and staff organization supported the capability to accomplish standardized production at lower costs. The Toyotist principles of decentralized authority and lateral communication across functions, buyers and suppliers generate the capability of speed and flexibility.

Organizing principles underlay what firms can do. To be flexible requires rules by which work is coordinated and by which information on the market is gathered and communicated. Just-in-time manufacturing, designing for manufacturability, or decreasing time to the market are capabilities which presuppose a certain social knowledge regarding who is competent, how work is coordinated, and what information is shared.

The endeavors of firms to create, apply, and replicate this social knowledge do not proceed with the purpose of rapid public dissemination. Largely, the construction of knowledge in a firm should be more idiosyncratic, reflecting the firm's particular history and experience. Technology is indeed often firm-specific, differentiated knowledge about specific applications, which is largely cumulative within firms.[4] Moreover, through experience, a multiunit firm develops a set of rules or higher-ordered organizing principles by which new capabilities are created, improved, and transferred in the organization.

There are also other important aspects of developing capabilities which are idiosyncratic to individuals and to small groups.[5] Competitive pressures create a value in developing a capacity of replicating knowledge within the firm faster than the similar efforts of competitors. When a new market is created through an innovation, a central limiting force on the growth of the innovating firm is the speed by which competitors imitate the new products.[6] In the simplest evolutionary models, profit-seeking firms imitate in response to the prevailing market signals that it is profitable to do so. As a form of public information, market signals are not always sufficient to engender imitation. In many cases, imitation requires the acquisition of new know-how, that is, of new ways of doing things.

It makes sense that the competitive pressures of imitators create an incentive for the innovator to expand rapidly by speeding the voluntary transfer of what is commonly called technology. Here lies the interesting dilemma that a technology that is easily transferred and replicated may also be easily imitated. Since the transfer and imitation are alternative and exhaustive mechanisms by which capabilities are disseminated, they should, as Winter (1987) has argued, be linked in their ease through which the relevant knowledge can be identified and communicated.

The ability to transform tacit capabilities into a comprehensible code, understood by large numbers of people, is derived from the collective experiences of members to a firm organized by persisting rules of coordination and cooperation.[7] The relationship of accumulated experience in facilitating the communication and understanding of a new technology is a consistent finding in studies on the transfer of technology. Teece (1977) found that the costs of technology transfer were determined by the age of the technology, the recipients' previous experience with transferring the technology, and the number of firms using similar technologies. All three variables point to a latent factor involving the codification of knowledge (Teece 1981). Since older technologies are better codified, they are less costly to transfer. Experience with transferring the technology points to the importance of learning how to codify the technology effectively for subsequent transfers.[8]

An interesting and overlooked factor is suggested by Teece's (1977) finding on the negative association between the number of other firms using the technology and the costs of transfer. In effect, technologies which are widely diffused are less costly to transfer, because, one can speculate, the knowledge of their properties is well-understood and codified. This finding has come out in other studies as well. For example, Contractor (1981) found that technology transfer (via licensing) to a country increases with the sophistication of its manufacturing and engineering base.[9] The relationship between past use and ease of the transfer underscores the explanation advanced by Hall and Johnson (1970), Westphal et al. (1985), and Pavitt (1985), that the cumulative experience with a technology is a critical factor determining the learning capability of the recipient to understand new technologies.[10] An issue related to imitation is that because firms differ in their history of experience with different technologies, they will vary in the costs for understanding and assimilating new technologies.

Experience is important both at the individual and organizational level. From studies on individual learning, we know that new skills are more quickly learned the more they share elements with already acquired knowledge. In their study of the acquisition of computer programming and calculus skills, Singley and Anderson (1989) concluded that procedural knowledge (e.g., riding a bike) is more slowly forgotten than declarative knowledge (e.g., facts or propositions). The trade-off is that procedural knowledge is useful to a more limited number of activities. For learning radically new applications, declarative knowledge of a theoretical nature proved more robust.

The reason procedural knowledge is easily remembered and yet useful is probably due to the facility by which it can be stored in chunks. It is easier to remember modules than to figure out new ways to recombine many propositions. In an intriguing experiment, Cohen and Bacdayan (1991) found that their subjects tended to repeat similar sequences of actions; procedures often consisted of a learned repertoire of associated behaviors. Importantly, due to the experimental condition of penalizing slower decisions, these learned sequences were used when more optimal, even when obvious alternatives were available.

The pressure of competition is the pressure of limited time to decide. Firms rely upon routinized behaviors because they are efficient ways of doing things given what they already know how to do. The classic study of Bavelas (1950) reported that different structures of communication among subjects to an experiment influenced the number of errors (performance) and morale. Moreover, the initial distribution of resources and communication structures greatly affected the ability to arrive at an optimal solution.

It is not surprising that given the difficulty of arriving at optimal solutions for relatively simple tasks in small groups, the pressure of competition forces behavior toward the reiteration of learned behaviors that have been successful in the past and that speed the coordination among individuals. Technology transfer from developed to developing countries has often been found inappropriate to the receiving country (Davies 1977). It follows from our reasoning that they are inappropriate because firms transfer the procedures they already know how to do.

The Dimensions of Knowledge

We have developed the argument that the accumulation of experience in an activity leads to the facility to communicate and understand the relevant knowledge. This facility, in turn, should reduce the cost of acquiring new related capabilities and speed the time to transfer and imitation. Usually, the effect of experience has been framed in terms of its relationship to the costs of transfer and imitation or, more commonly, on the frequency of transfer. We propose, instead, to analyze directly the effects of the extent to which capabilities can be communicated and understood on the time to their transfer and imitation.

Technologies and innovations have, of course, been described and measured according to several dimensions in previous studies. There have been, however, few investigations of the effects of these characteristics on the rate of dissemination, whether by voluntary transfer or imitation. Rogers (1980) and, more recently, Winter (1987) have proposed similar ways by which to link the attributes of an innovation to the rate of dissemination. While these approaches have not been tested on the rate of dissemination, they offer consistent advice on the properties of a technology that should influence the degree to which an innovation can be communicated and understood.

In his major work on the diffusion of innovations, Rogers (1980) proposed five dimensions by which innovations can be described: "relative advantage" (or "profitability"), "communicability," "observability," "complexity," and "compatibility." The latter indicates the similarity of the innovation to current experience, knowledge, and values. More recently, Winter (1987) suggested a similar taxonomy, which identified four dimensions of a firm's knowledge: "tacit/articulable," "observable/not observable in use," "complex/simple," and "dependent/independent of a system." The first dimension is further broken down into whether the knowledge is articulated (e.g., whether records are kept), and whether it can be taught. It is suggested that even if knowledge is tacit, it may be taught by apprenticeship.

We follow the Rogers and Winter taxonomies by developing five central constructs by which to characterize a firm's knowledge at the levels of individual competence and group and organizational capability. These constructs are "*Codifiability*," "*Teachability*," "*Complexity*," "*System Dependence*," and "*Product Observability*." The fifth construct, "Product Observability," developed in reference to imitability, captures the degree to which the technology is common to a network of industrial competitors; observability of the technology is important for the imitation by reverse engineering (i.e., copying the components by inspection), but should not be important for voluntary capability transfer.

The five constructs are ways to measure the degree to which a capability can be easily communicated and understood. These constructs measure different qualities of the knowledge of the firm. It would be nonsensical to believe that there is a single dimension called tacitness. Neither is there a reason to believe that there is a body of knowledge that is univariate across levels of analysis of the individual, the organization, and the network.

"Codifiability" captures the degree to which knowledge can be encoded, even if the individual operator does not have the facility to understand it; software controlling machinery is a good example. "Teachability," to the contrary, captures the extent to which workers can be trained in schools or on the job; it reflects the training of individual skills. "Complexity" picks up the inherent variations in combining different kinds of competencies; knowledge, no matter the education of the worker, is simply more complex when it draws upon distinct and multiple kinds of competencies. "System Dependence" captures the degree to which a capability is dependent on many different (groups of) experienced people for its production. "Product Observability," finally, captures the degree to which capable competitors can copy the manufacturing capability, because they are able to manufacture the innovation once they have understood the functions of the product.

These characteristics of knowledge measure different aspects that underlie the facility by which manufacturing capabilities are transferred and imitated. To test for the effect of these characteristics on the rate by which a capability is transferred or imitated, we created a design, described below, that employs the time to transfer and the time to imitation (or, more precisely, their hazard rates) as the dependent variables. These measures differ from Teece's calculations of transfer costs (Teece 1977), as well as from the more common measures of counting the number of transfers adopted by countries (Contractor 1981), or the age of the technology at the time of imitation (Mansfield 1985). Our method has the advantage of avoiding the problems of estimating transfer costs, as well as of incorporating censored observations, i.e., those capabilities that were not transferred or imitated.

To summarize, our design is to analyze the following central proposition:

P1. *The more easily a capability can be communicated and understood, the shorter the times to transfer or imitation.*

The dimensions used to measure the ease of communication and understanding are "Codifiability," "Teachability," "Complexity," and "System Dependence."

There are, of course, other factors than the ones just mentioned which influence the time to transfer and imitation. As reported above, previous studies on the transfer of technology have argued that a large number of firms using a similar technology suggests that the capability to receive and assimilate the technology is widely spread. Another possibility, suggested by our argument, is that competition should encourage rapid expansion by capability transfer, as well as imitation, due to the threat of competitive preemption in the market. This leads to our second proposition:

P2. *The more there are competitors engaged in developing similar products, the shorter the times to transfer and imitation of the capability.*

It is important to note that the comparison between the transfer of manufacturing capability and imitation is inexact, for imitation may be possible even if the innovator's manufacturing knowledge remains proprietary. The importance of manufacturing varies by innovations. In some industries, the key capability is knowledge of the customers' needs; knowledge of how to manufacture may be "common" among competitors.[11] One way to address this aspect of the determinants on imitation is to assess directly the degree to which principal aspects of a manufacturing capability are well dispersed among a group of competitors. The extent to which imitators can pull from a general pool of knowledge regarding how to manufacture this product should influence imitation.

P3. *The more the principal aspects of the manufacturing capability have spilled over the boundaries of the firm, the shorter the time to imitation.*

Finally, we also look at the effect of continuous improvement in innovations as a way to deter imitation. As argued by Gilfillan (1935), Usher (1971) and Abernathy and Utterback (1975), innovations at the time of introduction undergo a period of incremental improvement. Whether it pays to invest in appropriating a technology is also a question of how rapidly it becomes obsolete. Imitation is often deterred based upon the *combinative capabilities* of a firm to innovate incrementally on its innovations (Kogut and Zander 1992). The ability of the innovating firm to improve the product should deter imitation, even if important aspects of the manufacturing capability are widely diffused.

P4. *The more the innovating firm has subsequently improved the product or the production process, the longer the time to imitation.*

Empirical Design

The Sample

To test the thesis that the transfer and imitation of capabilities are related to the dimensions of the underlying knowledge, we developed a questionnaire instrument to distribute to project engineers knowledgeable of the history of a major innovation. The innovations were identified from a study by Wallmark and McQueen (1986) on 100 major Swedish innovations which achieved a major share of world markets.[12] To satisfy the need to observe the history of the innovation over a long period of time and to question engineers familiar with this history, the target sample was narrowed to innovations occurring after 1960; this process identified 44 innovations for which, due to multiple innovations, 20 firms were responsible. For each 44 identified innovations we sent out a questionnaire.

The respondents were selected by asking the technical director at the group level to identify key respondents.[13] The technical directors recommended individuals who were contacted by phone to verify their knowledge of the innovation and prepare them for the questionnaire. Multiple respondents for an innovation were not used, though, for some questionnaires, one individual scored the basic information and another answered the section dealing with the manufacturing process. (As the questions did not reflect on the performance of the respondents, the risk of misattribution is low.[14]) In nine cases, the respondents were the primary innovators. When an original innovator did not exist or was no longer accessible, individuals were contacted who had been directly responsible for manufacturing and product management internationally since the introduction of the innovation.[15] Of the 44 questionnaires sent out, a response rate of 80% was attained; the remaining 20% were similar in size and industry affiliation to the responding organizations. (For a list of the 35 innovations for which completed questionnaires were received, see Appendix 2).

Besides being a novel sample, the data on Swedish innovations had clear advantages. All of the companies are Swedish based, competing in industrial markets. Because Sweden is a small country, these companies were forced to expand in international markets. Transport and communication costs generally encourage the transfer of technology, and the enforceability of patents is less binding in world markets. These conditions increased the attractiveness of technology transfer and the possibility of imitation.

The focus on major innovations made it more likely to gather accurate information on the year of the first product delivery and the subsequent incidents of transfer and imitation. These data would not be as easy to reconstruct for less important or successful innovations. Since all of the innovations were chosen on the basis of their success, there is likely to be little variance in what Rogers called "relative advantage." This selection criterion, in one sense, imposes an implicit control for variations in demand and profitability. While restricting attention to very successful innovations, the sample may overstate the speed to transfer (successful innovations require more manufacturing capacity) and also affect the speed to imitation. As we are, however, not estimating the regressions on time to transfer and time to imitation simultaneously, this effect (which is common across the whole sample) should not bias the estimates.

Some factors which would have been of interest could not be easily investigated. In particular, we did not measure how widely spread the relevant technological capabilities of imitators and recipients of technology were or whether they understood the same codes; what is codified for one firm may thus be incomprehensible to the next. At present, we are not able to control directly for this possibility, but the problem may not be too severe. Since the firms were expanding first in developed markets, recipients and imitators originate in countries with comparable levels of technological capability. We assume, in the terminology of Hall and Johnson (1970), that general capabilities are present in developed countries to allow the assimilation of the technology and to pose the threat of imitation. Moreover, we introduce in subsequent regressions variables which indicate the degree of spillover of important aspects of the manufacturing capability.

The Questionnaire

The questionnaire was developed, first, through field research, which resulted in eight case studies of innovations developed in three firms.[16] Following these case studies, an initial instrument was drawn up and pretested on respondents from five of the case studies, as well as on academic colleagues from Swedish technical universities. (The instrument was written in Swedish, with all respondents being fluent in this language.) This process generated a two-part test instrument.

The first part of the questionnaire simply asked for factual data, e.g., the date at which the innovation was first introduced into the market, the number and timing of transfers, the occurrence of the first imitation, etc. These data provided the information required constructing the hazard rate specification for estimating the effects of the covariations on the time to transfer, as well as on the time to imitation.

The second part of the questionnaire drew upon a design common in psychometric studies. A list of questions was developed, and characteristics of manufacturing capabilities were measured by 43 questions regarding the nature of the firm's *manufacturing* of the innovation. Respondents marked on a seven-item scale, as recommended by Cox (1980). The decision to concentrate on manufacturing was motivated by the impracticality of seeking internal experts on all the relevant functions affecting the commercialization of an innovation. This decision poses no difficulty for the analysis of the transfer of manufacturing capabilities. It, however, turned out to be insufficient, as the latter results show, for the study of imitation.

Operationalizing the Characteristics of Knowledge

The items forming the construct measuring characteristics of manufacturing capabilities, technological competition, and the degree of knowledge diffusion among competitors are described in Appendix 1. For *Codifiability*, the items were designed to capture the extent to which the knowledge could be articulated in documents and software. This knowledge may be substantive, e.g., in blueprints, or it may be procedural, e.g., in a recipe for carrying out a task (Simon 1979, Kogut and Zander 1992).

Teachability was designed to capture the ease at the individual level by which knowledge, even when it cannot be formally articulated, can be taught to new workers. Capability transfer often requires the sending of engineers and workers from the originating plant to help in the building up of know-how in the sister plant.[17] To the extent that this know-how is easily taught, the transfer is more feasible and can be made faster.

Complexity proved to be one of the more difficult dimensions to operationalize. Simon (1979) avoided explicitly to give a definition, though his examples suggest the number of decomposed cells in a system as a measure of complexity. A complementary definition is the number of parameters required to describe the function of the technology. Tyre (1991) measures "technical complexity" as the number, novelty, and technological sophistication of new features and concepts in a technology. Along these lines, we defined complexity as the number of distinctive skills, or competencies, embraced by an entity or activity. As the knowledge being dimensionalized concerns manufacturing, we developed a variable by adding the scores on four items indicating the importance of four types of processes, as identified by Hayes and Wheelwright (1984). Thus, we decided upon an objective set of items which indicate the importance of different manufacturing methods. Our approach thus tries to measure complexity as the degree of multiple competencies used to manufacture a product.[18] The more complex a manufacturing capability, the more difficult it should be to transfer or to imitate.

With the dimension *System Dependence*, we tried to capture at the organizational level the extent to which transfer or imitation of a capability is impaired due to dependence on many different (groups of) experienced people for its production. Winter's (1987) idea of "dependence of a system" refers to the possibility for a technology to "stand alone." We developed this scale using items on the degree of dependence of manufacturing with other functions. Our measure is related to Tyre's (1991) measure of "functional overlap" which describes the number of lateral linkages between plant engineering and production personnel.

Product Observability was constructed from items concerning whether the manufacturing capability can be acquired by reversed engineering or from published reports. This construct is used only in the estimates for imitation, since a firm that voluntarily transfers its manufacturing does not need to resort to reverse engineering or generally available documents.

To control for the effect of competition on speeding the time to transfer and imitation, the variable *Parallel Development* was used. It is measured by the count of competitors perceived as engaged in parallel efforts aimed at developing a similar product at the time of the innovations' release. (A summary of the described variables and the predicted relationships with the times to transfer and to imitation is given in Table 1.)

Table 1 Predicted Signs of Independent Variables

Variable	Predicted Sign: Probability of Early Transfer	Predicted Sign: Risk of Early Imitation
CODIFIABILITY	+	+
COMPLEXITY	−	−
TEACHABILITY	+	+
SYSTEM DEPENDENCE	−	−
PARALLEL DEVELOPMENT	+	+
PRODUCT OBSERVABILITY		+

A central issue for imitation, as discussed above, is the extent to which there is already a common manufacturing capability among competitors. To test for these effects, we constructed three measures to capture the extent to which aspects of manufacturing capability spills over quickly and easily among firms. *Proprietary Equipment* is constructed from items indicating the extent to which machinery and software developed and kept within the company embody principal manufacturing capabilities. *Outsourced Equipment* indicates the extent to which machinery or software purchased from external vendors embody principal manufacturing capabilities. The third measure, *Key Employee Turnover*, is derived from the question whether any of the firm's knowledgeable manufacturing employees had left the firm (coded as one or zero).

An important finding in the literature has been that one of the most significant deterrents to imitation is the capacity of the innovating firm to improve consistently on its original design (Levin et al. 1987). The measure *Continuous Development* is constructed to capture the importance of subsequent improvements of the innovation through recombining current knowledge. It is created by taking the maximum standardized value of how important subsequent modifications are perceived to be for preventing imitation.[19]

Construction of the Measures

The constructs derived from the questionnaire items were measured by forming scales derived from questions that were chosen a priori to contribute to the same construct. The scales were constructed by trans-forming the responses into a standard normal deviate, with zero mean and variance of one. Then, the standard scores were summed to form a scale score. By standardizing the scales and locating the mean at zero, it is easier to interpret the results as the effect on the time to imitation or transfer from a departure from the mean. In Table 2, the descriptive statistics for the variables are reported.

To test for reliability, Cronbach alphas were calculated for each scale, with the recommended 0.7 used roughly as a cutoff (Nunnally 1978). Cronbach alphas are derived by averaging the inter-item correlations of the off-diagonal entries of the correlation matrix and adjusting these correlations for the number of total items. An increase in either the average correlation or the number of items improves the alpha score. This test has been shown to set the lower bound to the reliability of an unweighted scale and, consequently, provides a conservative estimate (Novick and Lewis 1967). Questions with low item-to-total correlation were deleted; reliabilities for the final constructs ranged from 0.61 to 0.785.

Because of the high number of items to sample size, discriminant validity could not be estimated by confirmatory factor methods. It is important to verify that the constructs related to the ability to communicate and understand a capability consist of items which are distinctive. We estimated, therefore, the average correlation of intraconstruct items as a "within measure" and the average correlation of each construct's items with each other construct's items as a "between measure." (See Table 3.) The "within" average correlation is higher than the "between" average correlations, providing a reasonable indication of the discriminant validity of these constructs.[20]

Table 2 Descriptive Statistics

Variable Name	Mean	Standard Deviation	Lowest	Highest
1 CODIFIABILITY	0	2.91	−6.54	3.75
2 COMPLEXITY	0	2.42	−4.66	3.81
3 TEACHABILITY	0	3.70	−7.13	7.20
4 SYSTEM DEPENDENCE	0	2.79	−8.34	5.01
5 PARALLEL DEVELOPMENT	0	1	−0.84	4.00
6 PRODUCT OBSERVABILITY	0	2.43	−3.57	5.57

Correlation Matrix

	1	2	3	4	5	6
1	—					
2	−0.16	—				
3	0.02	0.23	—			
4	0.03	0.28	−0.18	—		

Table 3 Average within/between Correlations

	COD	TEA	SYS	OBS
COD	0.373			
TEA	0.108	0.434		
SYS	0.132	0.178	0.316	
OBS	0.145	0.282	0.079	0.484

Codifiability = COD
Teachability = TEA
System Dependence = SYS
Product Observability = OBS

Specification of the Statistical Model

As stated earlier, we understand capability transfer and imitation as diffusion processes determined by a common, though not exclusive, set of factors. We estimated the effects of the covariates on the rates by which manufacturing capabilities were transfered to new sites and by which innovations were imitated. These rates, when expressed as the probability of transfer or imitation *conditional* on no previous event, are called hazard rates. In Table 4, we show these rates for the years following introduction of the innovation in the market.

A natural test would be to correlate the hazard rates for imitation and transfer. This problem is statistically very complicated, as the data are censored, i.e., some innovations were not imitated or transferred by 1988 when the period of observation ended. For our purposes, we rely upon a regression format to test whether the covariates act similarly upon the hazard rates for transfer and for imitation.

To do this, we rely on techniques of likelihood estimation, under which the data are used to generate estimates of the coefficients which maximize the likelihood of the functional specification. Since we are not interested in the exact timing of the event, we specify the hazard model as a partial likelihood. (To specify a parametric function would raise unnecessary questions

Table 4 **Hazard Rates of Major Swedish Innovations**

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	> 20
Int																					
Transfers	0.17	0.07	0.11	0	0.04	0.09	0.05	0.05	0	0	0.05	0.06	0.06	0.07	0	0.08	0.10	0	0.29	0.20	0.25
# at Risk	35	29	27	24	24	23	21	20	19	19	19	18	16	14	13	12	10	9	7	5	4
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	> 20
Imitation	0	0.03	0	0.06	0.13	0.11	0.04	0.05	0	0.14	0	0	0	0	0.07	0	0.27	0.13	0.14	0.33	0.25
# at Risk	35	35	33	33	31	27	23	22	21	21	18	17	16	16	15	11	11	8	7	3	2

events into a baseline hazard rate and an exponential term incorporating the covariates. Partial likelihood simply discards the baseline hazard rate and treats the coefficient term as depending only on the order in which the events occur. In our case, the method rank orders technologies in terms of the sequence of transfer or imitation times, as measured from when manufacturing first started. This specification is semiparametric, for the baseline hazard is entirely general, but the covariates are specified as raised to an exponential and act multiplicatively on the baseline hazard.

The log likelihood function is constructed as the sum of the likelihoods that a capability will be transferred or imitated given that j technologies are at risk:

$$L = \Sigma_i \left[B'X_i - \Sigma_{j \in Ri} B'Xj \right] \qquad (1)$$

where L is the log likelihood and $\Sigma_{j \in Ri}$ is the sum over all j technologies at risk at time i, X is the covariate vector, and B is a vector of coefficients. (As the baseline hazard is the same for all technologies at risk, it has canceled out from the expression.) The estimates have been shown to be asymptotically consistent (Efron 1977). As long as censored observations are large, ties do not pose any estimation problems (Allison 1984; Cox and Oakes 1984). Our data satisfy this criterion. A positive sign to an estimated coefficient (B) represents that an increase in the variable increases the hazard of transfer or to imitation; a negative sign indicates the converse.

Empirical Results

Description of the Data

The innovations in our sample have generally been exploited rapidly in international markets. On average, around 50% of production has been sold overseas within one year after the introduction of the new product. At the time of measurement in 1989, over 70% of the new products were manufactured in at least one plant outside Sweden. In total, 85 transfers had been made, with the average number of transfers per innovation being three.

The median time to transfer was five years; without correcting for censored observations, the average was eight years. Reflecting the trade and investment patterns of Swedish firms, the most important recipient countries were the USA (nine transfers), Canada (seven), France (seven), Australia (seven), Japan (six), England (four), and Norway (four).

Imitations showed a time profile similar to that of transfers. Despite that all the innovations in the study were protected by patents, approximately two-thirds of the products have been imitated by competing firms. In a vast majority of these cases, the imitating firms had been important international competitors with a long experience in the industry.[21] Rarely, local competitors had copied the new product, while newly established firms, licensees, joint venture partners, subcontractors, or customers had almost never introduced a product based on the same technology.

For the innovations that had actually been imitated, the median time to imitation was five years, with the average being eight years. These medians are larger than those reported by Mansfield (1985) and Levin et al. (1987).[22] A possible explanation is that our sample is drawn from a listing of successful and significant innovations. The nationalities of the imitating firms were diverse, roughly similar to the countries of the first transfers.

Transfer of Manufacturing Capabilities

The results regarding the determinants of the time to transfer are interesting in that they show that certain characteristics of manufacturing capabilities can be

Table 5 Partial Likelihood Estimates of Covariates to Log Hazard of Transfer

Variable Name	Probability of Early Transfer
CODIFIABILITY	0 19
	(2 15)**
COMPLEXITY	0 03
	(0 27)
TEACHABILITY	0 19
	(2 68)***
SYSTEM DEPENDENCE	0 08
	(0 76)
PARALLEL DEVELOPMENT	0 81
	(3 36)***

*** $P < 0\ 01$ (*t* statistics in parentheses, two-tailed tests)
** $P < 0\ 05$
* $P < 0\ 10$

Table 6 Partial Likelihood Estimates of Covariates to Log Hazard of Imitation

Variable Name	Risk of Early Imitation
CODIFIABILITY	−0 11
	(−1 37)
COMPLEXITY	0 18
	(1 43)
TEACHABILITY	−0 10
	(−1 46)
SYSTEM DEPENDENCE	0 10
	(1 20)
PARALLEL DEVELOPMENT	−0 08
	(−0 30)
PRODUCT OBSERVABILITY	0 09
	(0 75)

*** $P < 0\ 01$ (*t* statistics in parentheses, two-tailed tests)
** $P < 0\ 05$
* $P < 0\ 10$

used to explain variations in transfer patterns. Estimates for transferability are given in Table 5. The strong results for *Codifiability* and *Teachability* act as a bellwether. These two constructs provide the most direct insight to the degree to which capabilities are tacit and difficult to communicate, and have significant effects on the hazard of transfer; the more codifiable and teachable a capability is, the higher the "risk" of rapid transfer.

Parallel Development has a highly significant effect (as measured by the coefficient and *T*-statistic) on the hazard of transfer. This result underscores clearly that a high level of "technological competition" and the fear of losing the technological edge to competitors speeds the transfer of capabilities. The strong result regarding Parallel Development is especially interesting given the relative neglect of this type of variable in earlier studies of technology transfer.[23]

The coefficient estimates to *System Dependence* and *Complexity* are insignificant.

Imitation and Generalized Knowledge

Results for imitation, given in Table 6, show that the characteristics of the manufacturing capability *do not* affect the hazard rate. This result suggests that the view of capability transfer and imitation as mirror phenomena needs to be refined. It is easy to see by our earlier discussion why this is the case, though the implications are not, as discussed below, fully reflected in the wider literature.

The imitation of innovations does not necessarily involve the imitation of capabilities, while transfer, by our definition, is the replication of manufacturing capabilities. By this reason alone, imitation and transfer are not identical phenomena.

In many industries, manufacturing capabilities may be widely diffused among the principal competitors. Successful imitation is often determined more by the access to a broad range of capabilities (e.g., how to design, test, modify, manufacture, market, and service the product). Moreover, industry conditions, such as reputation, government policy, and retaliation, will also influence imitative activities.

The omission of the effect of competitors' capabilities on imitation can be partly addressed by capturing the extent to which manufacturing knowledge is common to a group of competitors. Imitation should be quicker in industries where important capabilities, whether embodied in individuals or in machines, are more accessible. Possessing knowledge of manufacturing has little importance if this knowledge is widely dispersed.

We capture the extent to which certain aspects of the manufacturing capabilities are common knowledge by regressing the hazard of imitation on measures of labor turnover, inside sourcing of equipment and software, and external sourcing of specialized machinery and software. Simultaneously, we include a measure of the degree to which the innovator improves the prod-

Table 7 Partial Likelihood Estimates of Covariates to Log Hazard of Imitation

Variable Name	Risk of Early Imitation
PROPRIETARY EQUIPMENT	−0.19
	(−1.28)
OUTSOURCED EQUIPMENT	0.11
	(0.71)
CONTINUOUS DEVELOPMENT	−0.31
	(−1.94)*
KEY EMPLOYEE TURNOVER	1.08
	(1.99)**

*** $P < 0.01$ (*t* statistics in parentheses, two-tailed tests)
** $P < 0.05$
* $P < 0.10$

uct or the production process in response to imitative threats.

The results, presented in Table 7, indicate that the degree to which important aspects of manufacturing capabilities spill over among firms has a significant effect on the speed by which innovations are imitated. As in Tables 5 and 6, we use a conservative two-tailed test although our hypotheses are directional. *Key Employee Turnover* is significantly associated with faster imitation times. The coefficient to *Continuous Development* is just shy of significance at the 0.05 level. The result suggests that building on current capabilities creates an effective deterrent to imitative efforts. The use of *Proprietary Equipment*, i.e., machinery and software developed and kept within the company lowers the risk of early imitation, but the result is weak. The sign to the coefficient of the variable *Outsourced Equipment* is as expected, but the result is not significant.

Insights from the Field

The case of imitation can be further understood by turning to the field research that preceded the study. Consider the following examples derived from an in-depth study of three innovations in rock drilling and pulp and paper drying (innovations 13, 22, and 32 in Appendix 2.) The three innovations, the compact pulp dryer, the flash dryer, and the hydraulic rock drills, display quite different characteristics of manufacturing technology, although they were developed in similar firm environments.

Fläkt's[24] compact pulp dryer (the FC dryer) and Atlas Copco's[25] hydraulic rock drill have not been transferred outside Sweden. Manufacturing has been centralized in Sweden, with some sales and after-sales service assigned to the foreign subsidiaries.

As to the FC dryer, the decision to centralize manufacturing was driven by the difficulty to codify the information by blueprints and by the difficulty to teach manufacturing employees.[26] Production has depended upon well-trained, experienced manufacturing teams which worked for long periods of time together.

In the case of hydraulic rock drills used for the piercing of hard rock in mining, the competence to design, manufacturing and improve the metallurgical qualities of the parts was heavily dependent on a few key employees.[27] For example, it was not uncommon that design engineers brought blueprints down to the shop floor for revision by key employees, who applied their hands-on experience to correct flaws in the proposed design.

To manufacture Fläkt's flash dryer[28] used to sort and fluff pulp for paper production, it was possible to write comprehensive manuals describing the manufacturing technology and the relatively uncomplicated nature of manufacturing. The accumulated knowledge about designing the dimensions, which is the more problematic part of building the flash dryer, was codified and stored in a computer program. The data and software, drawn from the cumulative experience from worldwide installations, have never been transferred to foreign units but are kept at central level in Sweden. Easily imitated, access to the computer-driven system is highly restricted.

Examining information from the three innovations, there is no clear relationship between the characteristics of manufacturing technology and imitation by competitors. The examples consist of two innovations where manufacturing was complex and based on the competence of manufacturing personnel (the FC dryer and the hydraulic rock drill). In the third innovation (the flash dryer), manufacturing was uncomplicated and easy to understand and communicate.

However, complexity and the requirement of personal skills in manufacturing did not prevent imitation of the hydraulic rock drill. In spite of the uncomplicated and easily understandable manufacturing technology, the flash dryer was not imitated. The case of the flash dryer illustrates how the codification of critical knowledge does not necessarily increase the risk of imitation. The software and database, containing critical information about different installations and how they work, are tightly held secrets based on cumulative learning; Fläkt has been aggressive in driving competitors out of business.

Other variables related to actions taken by the firms to protect the technology affect imitation patterns. As the flash dryer case shows, secrecy sometimes relates to codified knowledge, but it might also relate to the retention of key employees. There are indications in the hydraulic rock drill case, and also in Fläkt's earlier generations of dryers, that the losses of key employees were detrimental to keeping the technology from the hands of competitors. The loss of skilled engineers also negatively affected the ability to refine the product or the manufacturing process.[29]

In all three examples, continuous improvements of products and manufacturing processes were cited as discouraging would-be imitators. As illustrated by Fläkt in the flash and FC dryer case, the product was continuously developed after the introduction of the innovation. The perception was that competitors might have the capacity to imitate individual generations of the product, but that they could not keep up with a high pace of product development.

Conclusions

The empirical analysis points to both simple and more complex conclusions. The transfer of manufacturing capabilities is influenced by the degree to which they may be codified and taught, and the threat of market preemption. Both the nature of the capabilities and the nature of industry competition matter.

The principal difficulty in the argument which we have advanced regarding imitation is not the logic, but the empirical complexity. Imitation encompasses a complex comparison between the full array of the capabilities of the innovator and competitors. The requisite aspects of manufacturing capabilities may be widely spread among competitors, each of which may be competing upon differentiated and cumulative experience.

There is an insightful lesson in these simple conclusions from a complex matter. The capability to produce a product is obviously different from the nature of the product itself. There is no reason to believe that a given product quality, or attribute, must map uniquely onto a set of capabilities. For example, cars are manufactured by many different production methods. Of course, the mapping of product qualities onto capabilities is not unbounded; we do not expect craft production methods of 1890 to produce high volumes of low-cost cars. But the variations in wage and capital costs, and in the accumulation of firm-specific experiences, can generate a substantial heterogeneity in the organizing principles and capabilities in a market.

In this study, we have been able only circumspectly to examine the dynamics by which knowledge evolves over time. The ability to improve a product, we know from the field research, rests on the recombination of already learned skills. In fact, the evidence suggests that a set of capabilities serves as a platform into other markets and related product areas.

This study has concentrated largely on the horizontal transfer of knowledge from one manufacturing site to another. The analysis of the transfer of manufacturing capability, and the relationship of this capability to imitation, is limited only to a single function. We have omitted considerations of the structuring of roles and the attribution of power in an organization. If we are to understand why capabilities are "inert," such as happens in adopting radically new ways of doing things, we need have a better understanding of problems of collective choice and coordination. However, understanding the resistance to change only as a problem of stalemate among different groups inside a firm provides limited, albeit important, insight into inertia.

An organization is, obviously, more than a collection of disjointed manufacturing sites and functional groups. There is, in this larger sense, an organizing knowledge that provides a unity to the firm. At this point, we offer only the guess that the partition of firm knowledge into modular "chunks" of expertise is valuable for speeding the coordination and codification of diverse capabilities. Modular components of the firm can be seen as an efficient decomposition of knowledge into learned sequences (or chunks) of behavior that serve to speed coordination and communication among groups. Understanding how modular capabilities can be recombined may well lead to a better theory linking incremental innovation to the design of organizational knowledge.

The assembly of diverse functions within a single firm raises the question of why coordination and communication between functional groups are better handled within a firm than between specialized firms. We have proposed that the appropriate vantage point by which to analyze this question is to understand the firm as competing on the speed by which knowledge is created and communicated. Why this replication is qualitatively altered at the boundaries of a firm is a central issue in understanding long-term differences in the growth among firms.

The claim that firms act as social communities for the creation and communication of knowledge requires a more explicit description of the motivation and cooperative choices of the individual members. It also requires an understanding of the basis of social knowledge and shared language.[30] It may be that an appeal to the idea of an individual as a reed but a thinking one, is a necessary precondition to developing a pragmatic notion of social knowledge and its accumulation. But sufficiency will certainly require also the development of a notion of the inherent sociality of sometimes selfish individuals. As far removed as it may seem from the concerns of knowledge and organizational capability, the presumptions of people as selfish and sociable, as myopic and pragmatic, form the logical foundations of the views of firms as social communities.

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Appendix 1. The Constructs and Variables

CODIFIABILITY
Perceived Codifiability
1. A useful manual describing our manufacturing process can be written.
2. Large parts of our manufacturing control are embodied in standard type software that we modified for our needs.
3. Large parts of our manufacturing control are embodied in software developed within our company exclusively for our use
4. Extensive documentation describing critical parts of the manufacturing process exist in our company
Coefficient alpha: 0.678

TEACHABILITY
Perceived Teachability
1. New manufacturing personnel can easily learn how to manufacture the product by talking to skilled manufacturing employees.
2. New manufacturing personnel can easily learn how to manufacture our product by studying a complete set of blueprints
3. Educating and training new manufacturing personnel is a quick, easy job.
4. New manufacturing personnel know enough after a normal high school education to manufacturing our product.
5. New manufacturing personnel know enough after vocation training to manufacture our product.
Coefficient alpha: 0.785

COMPLEXITY
Different Types of Manufacturing Processes
How important are the following to manufacturing:
1. Processes for changing physical characteristics of a material (for example chemical reactions, refinement, heat treatment).
2. Processes for changing the shape of material (for example casting, pressing, rolling, bending).
3. Processes for giving materials certain dimensions (for example turning, milling, drilling, sawing).
4. Processes for assembling different parts to a whole (for example welding, soldering, gluing, screwing).

SYSTEM DEPENDENCE
Perceived Importance of System Dependence:
1 It is impossible for anyone in our firm to know everything about the entire manufacturing process
2. To get high product quality it is very important that our manufacturing personnel has long experience from the specific plant where they are working.
3. Workers in important parts of the manufacturing process have to be in constant contact with engineers or product quality will go down.
Reversed
4 Our product can be manufactured in a unit isolated from all other production without quality being influenced at all.
Coefficient alpha: 0.637

PRODUCT OBSERVABILITY
Perceived Product Observability
1. A competitor can easily learn how we manufacture our product by analyzing descriptions of our product in product catalogues, etc.
2 A competitor can easily learn how we manufacture our product by taking it apart and examining it carefully.
3 A competitor can easily learn how we manufacture our product by testing in use.
Coefficient alpha: 0.772

PARALLEL DEVELOPMENT
Extent of Parallel Development
1. Were any of your competitors engaged in developing products similar to yours at the time of your innovation?
- □ No
- □ Yes, # of competitors: ____

PROPRIETARY EQUIPMENT
Perceived Use of Proprietary Equipment
1 Large parts of our manufacturing technology are embodied in machines built within our company exclusively for our use.
2. Large parts of our manufacturing control are embodied in software developed within our company exclusively for our use.
Coefficient alpha: 0.61

OUTSOURCED EQUIPMENT
Perceived Use of Outsourced Equipment
1. Large parts of our manufacturing technology are embodied in machines that are tailor-made by other firms for our purposes.
2. Large parts of our manufacturing control are embodied in software tailor-made by other firms for our purposes.
Coefficient alpha: 0.97

CONTINUOUS DEVELOPMENT

Perceived effects of continuous development

1. Continuous modification has been very important in preventing imitation of our product.

2. Continuous development of the manufacturing process has been very important in preventing imitation of our product

LOSS OF KEY EMPLOYEES

Extent of loss of key employees

1. Have any of your skilled manufacturing people left your company to the benefit of competitors after the introduction of the product?

☐ No

☐ Yes, in the year(s): ___

Appendix 2. List of Innovations

1. EXCHANGEABLE INDUCTOR FOR STEEL MELTING 1960 (ASEA)
2. PRESSDUCTOR 1960 (ASEA)
3. EMULSIFIED FATS FOR INTRAVENOUS INJECTION· INTRALIPID 1960 (KABI VITRUM)
4. RAIL-BOUND HAULING CAR FOR MINES 1961 (HÄGGLUND & SÖNER)
5. RUBBER DETAILS FOR ROTATING DRUMS 1961 (SKEGA)
6. MILK STERILIZER 1961 (ALFA-LAVAL)
7. MACHINE FOR FLUIDIZED FREEZING OF FOODSTUFFS: FLOFREEZE 1961 (FRIGOSCANDIA CONTRACTING)
8. QUINTUS TYPE STEEL PRESS FOR USE IN THE ASEA-STORA PROCESS 1962 (ASEA)
9. AIR CUSHIONED LAWN MOWER 1963 (ELECTROLUX)
10. CROSS CABLE 1963 (ERICSSON)
11. MATRIX PRINTER 1964 (FACIT)
12. BETA-BLOCKER: APTIN 1965 (HÄSSLE)
13. PULP DRYER WITH AIRBORNE PULP WEB: TYPE FC 1966 (FLÄKT)
14. DRUG FOR EXPANSION OF BRONCHI: BRICANYL 1966 (DRACO)
15. THYRISTOR-CONTROLLED SPIN CONTROL SYSTEM FOR LOCOMOTIVES 1967 (ASEA)
16. ISOSTATIC PRESS FOR STEEL PROCESSING 1967 (ASEA)
17. EXPLOSIVE: DYNAMEX 1967 (NITRO NOBEL)
18. GEL FOR FILTERING: CNBr-METHOD 1967 (PHARMACIA)
19. HIGH RESOLUTION COPYING MACHINE MULTINEX 1968 (MISOMEX)
20. BALL BEARING: HUB 3 1969 (SKF)
21. ORE TRANSPORTER: HAGGLOADER 1969 (HÄGGLUND & SÖNER)
22. FLASH DRYER FOR PULP 1969 (FLÄKT)
23. SEMI-SYNTHETIC PENICILLIN: PENGLOBE 1970 (ASTRA)
24. SELECTIVE BETA-BLOCKER· SELOKEN 1970 (HÄSSLE)
25. ROLLER BEARING: CC 1972 (SKF)
26. VENTILATION SYSTEM: OPTIVENT 1972 (FLÄKT)
27. IGNITION MECHANISM FOR EXPLOSIVES: NONEL 1972 (NOBEL)
28. MACHINE FOR FEEDING METAL SHEETS: DOPPIN-FEEDER 1972 (VOLVO)
29. VENTILATION SYSTEM: DIRIVENT 1974 (FLÄKT)
30. HIGH TEMPERATURE STEEL 153 MA & 253 MA 1974 (AVESTA JERNVERK)
31. CHEMICAL FOR WOUND TREATMENT: DEBRISAN 1975 (PHARMACIA)
32. HYDRAULIC ROCK DRILL 1975 (ATLAS COPCO)
33. TELEPHONE SWITCHING SYSTEM: AXE 1976 (ELLEMTEL)
34. STAINLESS STEEL: 245 SMO 1976 (AVESTA)
35. SELF-EMPTYING RAILWAY CAR FOR ORE 1978 (LKAB)

Endnotes

[1]See Kogut and Zander (1992). We have been struck by the similarities of this argument to the discussion of expert systems by Hatchuel and Weil (1992) of "savoir-faire," "savoir-comprendre," and "savoir-combiner." See also Starbuck (1992).

[2]This perspective shares obvious similarities with the resource school of thought, especially Barney (1986), Reed and DeFillippi (1990), and Dierickx and Cool (1989). We tend to agree with Foss (1992) that this perspective is nested within a broader evolutionary approach. Indeed, Nelson and Winter (1982) lay out a broad schema for looking at competitive dynamics with imitation.

[3]The classic study in this vein is Hall and Johnson (1970).

[4]Pavitt (1985) and Kogut and Zander (1992).

[5]Drawbacks to developing capabilities idiosyncratic to individuals and small groups are clearly transparent in studies of R & D cultures, where moving technology from the laboratory to operations is often impaired by differences in the values and work habits of researchers and others in the corporation. See Allen (1977), Tushman (1977), and Dougherty (1990).

[6]See Anderson and Tushman (1989), Mitchell (1989), and Lieberman (1989).

[7]Of course, some codes extend beyond the boundaries of the firm, as exemplified in the rules designed to diffuse knowledge within a scientific community. The understanding and acceptance of scientific facts, as Kuhn (1962) and his antecedent Fleck (1935) point out, are socially determined through the construction of a set of values widely held among an international scientific community. It is a subtle point, and one we cannot pursue here, that the efficiency of these rules for communication may well be responsible for the tendency to fail to understand other interpretations.

[8]Davidson and McFetridge (1984) also find this effect, as well as that experience in internal transfers encourages more internal transfers in the future. This suggests that only once a firm has invested in codifying knowledge for the purpose of licensing are external transfers subsequently promoted.

[9]There have been, of course, many qualitative and historical studies which demonstrate this relationship; almost any study on why technology is imitated by some countries and not others has noted the importance of indigenous experience and capabilities See, for example, Westney (1987)

[10]The above studies focused on the horizontal transfer of technology from one plant to another. Importance of communication and codification is apparent also in studies on the costs and time of the vertical transfer of knowledge within organizations. In her study of the transfer of new technologies within a corporation, Leonard-Barton (1988) concluded that adoption was accompanied by an intense interaction between the user and the research and development (R & D) project team

[11]"Common knowledge" is usually meant to refer to symmetries in information among players to a game. In our case, we extend it to symmetries in capabilities. We thank Jacques Girin for stressing this point.

[12]As a criterion for inclusion of an innovation, Wallmark and McQueen used the annual turnover generated by the innovation. To be classified as a major innovation, the annual revenues had to be at least 20 million Swedish Crowns (roughly USD 3.5 million) in real terms. Growth rates of revenues also had to be significant. In addition, the innovation had to be patentable in accordance with Swedish Patenting Law, and at least one significant patent had to exist.

[13]Given the large size of the firms where innovations in the sample originated, several technical directors were contacted by phone in each case. The invariable consensus on part of the contacted directors as to the right person to send the questionnaire to supports our confidence in the in-depth knowledge and the accuracy of the respondents.

[14]It was, obviously, impossible to collect time-varying observations on the technology over time. A potential source of noise, then, is that the manufacturing technology is not stationary. This problem, which should only worsen our results, may not be too severe if the rates of technological change are roughly similar.

[15]In a large majority of these cases, the same person had been responsible for the product since it had been introduced. In the cases where management had changed, the person having spent the longest time as manufacturing/product manager was selected as a respondent. In all cases, the respondents had detailed knowledge of the historical development related to the innovation, since the introduction and exploitation of the innovation had been the dominating and most exciting part of their career.

[16]See Zander (1991). We would like to thank Erin Anderson and Gordon Walker for their assistance in the questionnaire design, and Robert House for his comments on the reliability and validity tests.

[17]See Hall and Johnson (1970).

[18]For an interesting and somewhat related measure, see Granstrand and Sjölander's (1990) measure of the width of the technology-base of a firm: the sample average of the number of engineering categories represented in a firm.

[19]By taking the maximum, this measure replicates the scale in Levin et al. (1987).

[20]Only the correlation between proprietary equipment and codifiability violated this rule, but the two constructs were not entered simultaneously into the same regression It is, by the way, not unexpected that they should be correlated.

[21]In no case did the same competitor imitate several of the innovations in the sample.

[22]In these studies, imitation has been found to be surprisingly rapid. The median time to imitation varies across studies between roughly one to three years, though with considerable industry variation. These rates have been shown to be slightly slower for processes, as implied by the findings on R & D and productivity.

[23]For an exception, see Stobaugh (1988).

[24]Fläkt is a leading producer of drying systems, heat recovery systems, ventilation controls, air pollution equipment and vacuum cleaning systems. In 1987, total group sales amounted to USD 2 billion, of which approximately 80% were generated outside Sweden. Today, more than $\frac{2}{3}$ of the worlds marketed pulp is dried using Fläkt equipment.

[25]Atlas Copco's traditional businesses are compressors, mining and construction equipment, industrial automation and production equipment. In 1987, 91% of group sales were generated outside Sweden, and almost 80% of the 19,000 employees worked outside Sweden. It has been estimated that the company earned some USD 250 million selling hydraulic rock drilling equipment only between 1973 and 1983.

[26]The FC dryer efficiently dries a continuously moving airborne pulp web through impinging hot air through "eye-lid openings" parallel with the web. The tensionless transporting of pulp on a weak air stream makes it possible to handle pulp webs with very low tensile strength.

[27]Hydraulic rock drilling technology has doubled drilling speed, reduced energy consumption by $\frac{1}{3}$, as compared to pneumatic rock drilling. The use of hydraulics has also reduced noise levels and environmental damage. In addition, it is estimated that the hydraulic technique reduces drill steel consumption by 50%.

[28]Flash dryers have gained an increasing share of the pulp drying market because of low investment costs and facilitated operations. In a flash drying system, pulp is de-watered, fluffed and dried in gases with much higher temperatures than normally used in a conventional web-type dryer.

[29]In some of the cases, key employees have been lost because of rather petty reasons, e.g., by moving production facilities to a new location.

[30]See Kogut and Zander (1992) and Girin (1990) for a discussion along the lines of viewing the firm as an "epistemic community" sharing a language and, hence, cognitive rules.

References

Abernathy, W. and J. Utterback (1975), "A Dynamic Model of Process and Product Innovation," *Omega*, 3

Allen, Thomas (1977), *Managing the Flow of Technology*, Cambridge, MA: MIT Press.

Allison, P. (1984), *Event History Analysis—Regression for Longitudinal Event Data*, Beverly Hills, CA: Sage Publications.

Anderson, Philip and Michael Tushman (1989), "Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change," *Administrative Science Quarterly*, 35, 604–633.

Barney, Jay (1986), "Strategic Factor Markets. Expectations, Luck and Business Strategy," *Management Science*, 32, 1231–1241.

Bavelas, Alex (1950), "Communication Patterns in Task-Oriented Groups," *The Journal of the Acoustical Society of America*, 22, 725–730.

Chandler, Alfred (1977), *The Visible Hand: The Managerial Revolution in American Business*, Cambridge, MA: Harvard University Press.

Cohen, Michael and Paul Bacdayan (1991), "Organizational Routines Are Stored as Procedural Memory: Evidence from a Laboratory Study," mimeo, University of Michigan.

Contractor, Farok (1981), *International Technology Licensing*, Lexington, MA: Lexington Books.

Cox, David and David Oakes (1984), *Analysis of Survival Data*, London, UK: Chapman and Hall.

Cox, Eli (1980), "The Optimal Number of Response Alternatives for a Scale: A Review," *Journal of Marketing Research*, 17, 407–422.

[illegible]

Economics, 32, 3, 253–264.

Davies, Howard (1977), "Technology Transfer Through Commercial Transactions," *Journal of Industrial Economics*, 26, 161–175

Dierickx, Ingemar and Karel Cool (1989), "Asset Stock Accumulation and Sustainability of Competitive Advantage," *Management Science*, 35, 1504–1513.

Dougherty, Deborah (1990), "Interpretative Barriers to Successful Product Innovation in Large Firms," mimeo, Wharton School, The University of Pennsylvania, Philadelphia, PA.

Efron, B. (1977), "The Efficiency of Cox's Likelihood Function for Censored Data," *Journal of Royal Statistical Society*, series B 34, 187–202.

Elster, J. (1983), *Explaining Technical Change—A Case Study in the Philosophy of Science*, Cambridge, UK: Cambridge University Press.

Fleck, Ludwik (1935), *The Genesis and Development of a Scientific Fact*, (trans. 1979), Chicago, IL: University of Chicago Press.

Foss, Nicolai Juul (1992), "Theories of the Firm. Contractual and Competence Perspectives," *Journal of Evolutionary Economics*, 3.

Gilfillan, S. (1935), *The Sociology of Invention*, Cambridge, MA: MIT Press.

Girin, Jacques (1990) "Problèmes du Langage dans les Organismes," in Jean-François Chanlat (Ed.), *L'individu dans l'organisation. Les Dimensions Oubliées*," Les Presses de l'Université Laval, Quebec, Canada.

Organization Science, 3, 383–397.

Kuhn, Thomas (1962), *The Structure of Scientific Revolution*, Chicago, IL: University of Chicago Press.

Leonard-Barton, Dorothy (1988) "Implementation as Mutual Adaptation of Technology and Organization," *Research Policy*, 17, 251–267.

Levin, Richard, Alan Klevorick, Richard Nelson and Sidney Winter (1987), "Appropriating the Returns from Industrial R & D," *Brookings Papers on Economic Activity*, 783–820.

Lieberman, Marvin (1989), "The Learning Curve, Technology Barriers to Entry, and Competitive Survival in the Chemical Processing Industries," *Strategic Management Journal*, 10, 431–447.

[illegible]

Mitchell, Will (1989), "Whether and When? Probability and Timing of Incumbent's Entry into Emerging Industrial Subfields," *Administrative Science Quarterly*, 34, 208

Nelson, Richard and Sidney Winter (1982), *An Evolutionary Theory of Economic Change*, Cambridge, MA: Belknap Press.

Novick, M. and G. Lewis (1967), "Coefficient Alpha and the Reliability of Composite Measurements," *Psychometrica*, 32, 1–13.

Nunnally, J. (1978), *Psychometric Theory*, 2d ed., New York: McGraw Hill.

Pavitt, Keith (1985), "Technology Transfer Among the Industrially Advanced Countries An Overivew," in Nathan Rosenberg and Claudio Frischtak (Eds.), *International Technology Transfer Concepts, Measures, and Comparisons*, New York: Praeger.

Reed, Richard and Robert DeFillippi (1990), "Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage," *Academy of Management Review*, 15, 1, 88–102

Rogers, E (1980), *Diffusion of Innovations*, New York. Free Press.

Schumpeter, Joseph (1942), *Capitalism, Socialism, and Democracy*, New York: Harper & Brothers.

Simon, Herbert (1979), "The Architecture of Complexity," *The Sciences of the Artificial*, Cambridge, MA: MIT Press; first published in *Proceedings of the American Philosophical Society* (1962), 106, 467–482

Singley, Mark and John Anderson (1989), *The Transfer of Cognitive Skill*, Cambridge, MA Harvard Press.

Starbuck, William (1992), "Learning by Knowledge-intensive Firms," *Change*, Harmondsworth, UK: Penguin.

Wallmark, Torsten and Douglas McQueen (1986), *100 viktiga svenska innovationer under tiden 1945–1980*, Lund, Sweden: Studentlitteratur.

Westney, Eleanor (1987), *Imitation and Innovation. The Transfer of Western Organizational Patterns to Meiji Japan*, Cambridge, MA: Harvard University Press.

Westphal, L., L. Kim and C. Dahlman (1985), "Reflections on the Republic of Korea's Acquisition of Technological Capability," in Nathan Rosenberg and Claudio Frischtak (Eds.), *International Technology Transfer*, New York: Praeger.

Winter, Sidney (1987), "Knowledge and Competence as Strategic Assets," in David Teece (Ed.), *The Competitive Challenge—Strategies for Industrial Innovation and Renewal*, Cambridge, MA: Ballinger.

Zander, Udo (1991), *Exploiting a Technological Edge—Voluntary and Involuntary Dissemination of Technology*, Stockholm, Sweden: IIB.

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