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Research Article

The Influence of Knowledge Attributes on Innovation Protection Mechanisms

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This article deals with the appropriability of technological innovations. Specifically, it looks at how certain attributes of technological knowledge (codifiability, teachability, complexity, observability and dependency) may influence the choices that firms make among different protection mechanisms (patents, secrecy, lead time, learning curve and complementary resources). Based on a sample of 670 innovations developed by Spanish industrial firms, it is found that dependency and, to a lesser extent, codifiability are the attributes that have the most influence the choice of appropriation method. Copyright © 2004 John Wiley & Sons, Ltd.

INTRODUCTION

Firms' innovative potential depends on their ability to create new knowledge and disseminate it throughout their organization so as to introduce it into new processes, products and services (Nonaka and Takeuchi, 1995). Firms that can make use of and develop their innovative potential gain a competitive edge over the rest. Retaining their advantage over the long term largely depends on their ability to protect their knowledge from imitators. However, it is a fact that firms often encounter great difficulty in establishing ownership rights to some of their technological knowledge (Geroski, 1995). It has been shown that the knowledge, and thus the profits, that innovative activities generate often cannot be wholly appropriated.

The concept of appropriability refers to the ability of the owner of a resource to obtain a return equal to the value generated by that resource (Teece, 1987; Levin *et al.*, 1987). Here, appropriability refers to the conditions that enable the protection of technological knowledge generated by innovative activities. Such conditions depend on a range of factors. Some are exogenous, such as the institutional framework, the legal system, the structure of the industry in which the firm competes and the attributes of the technological knowledge itself. Other factors, such as decisions made by firms as to which means of protection to use, are plainly endogenous.

Among exogenous factors, those connected with the attributes of technological knowledge have become especially significant in recent years. Evolutionary economics (Nelson and Winter, 1982) and the resource-based approach (Barney, 1991) have stressed that technologies emerging from the innovation process do not possess the features of 'information' as suggested by certain neoclassical views (Arrow, 1962). Rather, technology significantly involves learning and accumulated knowledge. Conceiving of technology as knowledge allows for a view of firms as learning organisms that accumulate knowledge in their 'memory', transformed into day-to-day routines in their organization (Nelson and Winter, 1982). Adopting this perspective, it has been found that certain attributes of technological knowledge (codifiability, teachability, complexity, observability, and system dependence) play a key role in the process of creation (Nonaka and Takeuchi, 1995; Spender, 1996), transfer (Zander and Kogut, 1995; Roberts, 2000) and diffusion of innovations (Rogers, 1962).

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To date, there is a dearth of studies on how these attributes might affect the innovation protection mechanisms that firms decide to use. To what extent do knowledge attributes influence a firm's protection decisions? What means of protection are most useful in protecting the different types of knowledge? To answer these questions, the following section explores the relationships between certain knowledge attributes and the main means of protecting innovations that firms can potentially use. Next, in the third section, we assess these relationships based on a sample of 670 innovations developed by 367 Spanish firms. The fourth section presents the results of the previous analyses and, finally, the fifth section sets out the main conclusions.

KNOWLEDGE ATTRIBUTES AND MEANS OF PROTECTION

Means of protection

Firms innovate and try to create new knowledge to improve and develop new products and/or production processes in the hope of enhancing their future profits. Unlike most productive investments, investments in innovation (such as in R&D) are hard to protect. Some of the knowledge generated in innovative activities can be easily replicated at virtually no cost. The possibility that rapid diffusion of innovations may diminish expected profits is a strong disincentive to innovative activities.

The means of appropriation are the mechanisms that firms use to protect their innovations against imitation by their competitors. These mechanisms can be classified into two groups. First, we have the legal protection measures provided by the system of intellectual property rights (copyrights, patents, trademarks) and, second, we find a wide variety of alternative mechanisms such as industrial secrecy, the exploitation of technological leadership, moving quickly down the learning curve or the appropriate exploitation of complementary resources. In the following we provide an outline of how each of these mechanisms operate.

Patents

The patents system, by establishing ownership rights in the results of the innovation process, legally protects innovators against imitators. It assures that the patent owner enjoys a temporary monopoly during which the investment can generate a return. Thus the patent system is a stimulus to innovative activity. Patent owners can also sell to others their right to use a patent in exchange for royalties. However, serious doubt has been cast on the effectiveness of these legal mechanisms. Levin *et al*. (1987) have enumerated a range of reasons why in most industries patents are not used as means of protection against imitators:

(1) In many industries imitators can legally copy 'around' the patented technology, as it is generally difficult to prove that the imitator has made a copy (e.g., complex electronic systems).
(2) Some innovations are very hard to patent, because proving their novelty is very expensive (e.g., complex, mature technologies).
(3) In some technological domains advances emerge so quickly that patenting is meaningless (e.g., micro-electronics).
(4) In some instances, the information included in the patent restricts its efficacy, and the means of protection used tends to be industrial secrecy (e.g., petrochemical processes).
(5) In other situations, innovations are not protected legally because the complexity of the technology makes the cost of copying it, in terms of money and time, almost as high as the cost of developing the technology in the first place (e.g., electronics, aerospace, industrial machinery).

Therefore, firms tend to use alternative, more effective means of protection.

Alternative means of protection

Secrecy. Keeping technological knowledge secret means preventing any essential element of that knowledge from spilling over outside the firm. If an innovation can be protected by secrecy, it is a highly attractive mechanism because the possessor of the secret can appropriate its returns indefinitely. The problem is that, in practice, the secret provides effective protection only if innovations cannot easily be observed—for instance, when product innovations involve high technological barriers, or in the event of process innovations that can be kept away from public view (Von Hippel, 1988).

Lead time. This method is based on the advantage gained by a firm when it is able to develop and market an innovation before its competitors. This lead time derives from the fact that a firm with an initial leadership position possesses knowledge not held by competitors coming to the market later on. The leader's objective, having gained its lead, is to retain it over the long term. The issue raised in the literature is whether a firm can sustain that edge in the long run (Makadok, 1998). In general, actions aimed at exploiting technological lead time by means of large investments in marketing and customer care have proved effective in some industries, such as semi-conductors. In addition, innovative firms can dampen the incentives to imitation with dissuasive measures, such as threatening potential imitators with reprisal or investing in reputation and creating an image of quality and reliability (Grant, 1996). Furthermore, constant incremental improvement of innovations is one of the means that a firm can use to retain its lead time (Malerba and Torrisi, 1992; Torrisi, 1998).

Moving quickly down the learning curve. The learning curve reflects the fact that the manufacturing time of a product becomes progressively shorter the larger the number of units produced. This reduction in the time necessary for performing an activity is evidence of the learning accumulated up to a given time. It reduces the unit cost of direct labour and thus the overall product unit cost. The learning effect has been observed in most industries for decades (Abernathy and Wayne, 1974; Hirschmann, 1964). Firms able to garner cost advantages from a dominant position on the learning curve are thus able to face imitators successfully.

Control of complementary resources. Technological knowledge cannot generate income of its own accord. In most cases, exploitation of technological knowledge requires the command of a range of complementary resources. Almost invariably, in order to place a product on the market successfully, a firm needs to possess certain production, marketing and after-sales service capabilities (Teece, 1987). Firms that have established effective control over certain complementary resources will be able to appropriate the results of their innovative activities to a greater extent than their competitors. The importance of this appropriation tool has been shown by a wealth of studies (Levin *et al*. 1987;[1] Teece, 1987; Tripsas, 1997).

The attributes of technological knowledge

Interest began to be taken in the attributes of technological knowledge with the research of Nelson and Winter (1982), which was the starting-point of the evolutionary school of economic thought. These authors introduced into the literature of economics and business management the concept of tacit knowledge (Nelson and Winter, 1982), building on the studies made by the philosopher of science Michael Polanyi (1962, 1966). Later, other highly influential works made use of the concept of tacit knowledge (Dosi, 1988, Nonaka and Takeuchi, 1995) and other attributes of knowledge were identified (Rogers, 1962; Winter, 1987; Reed and DeFillippi, 1990; Zander and Kogut, 1995). Table 1 shows the main attributes of knowledge that have been identified and studied in the literature in recent years.

Most papers agree that the main dimensions present, to some extent or other, in any kind of technological knowledge are the following:

(1) the degree of codification, or how amenable the knowledge is to being reduced to information (codifiability);
(2) the degree of teachability;
(3) how observable it is when used and applied (observability);
(4) the degree of complexity;
(5) its dependency on other knowledge.

We set out below a definition of each dimension, and discuss how each dimension might affect appropriability conditions; we also describe our working hypotheses.

Codifiability

Codifiability is undoubtedly the most central dimension of knowledge, which is why it is the feature most often studied. The codifiability of knowledge represents the extent to which a given knowledge item can be reduced to information by means of drawings, formulae, numbers or words. Based on the degree of codifiability, two knowledge categories have been defined: explicit[2] and tacit.[3]

Explicit knowledge is wholly articulated, precisely codified and perfectly decipherable. The main ingredient of explicit knowledge is information, and thus transmission is not difficult. Examples of this knowledge type are enormously varied; nonetheless, they can be grouped into the following four categories (Badaracco, 1991): (a) knowledge contained in documents, plans or databases; (b) knowledge contained in production machinery and equipment; (c) knowledge

[1]This method is used in the research of Levin *et al*. (1987) under the name 'sales and service efforts'.

[2]Different terms have been used interchangeably in the literature to refer to explicit knowledge: *articulable* (Winter, 1987; Nelson and Winter; 1982), *codifiability* (Zander and Kogut, 1995), *migratory* (Badaracco, 1991), *information* (Kogut and Zander, 1992), *specific* (Dosi, 1988) and, of course, *explicit* (Grant, 1996; Nonaka and Takeuchi, 1995; Polanyi, 1962; Spender, 1996).

[3]Tacit knowledge has also been termed *know-how* (Kogut and Zander, 1992) and *inserted knowledge* (Badaracco, 1991).

Table 1 Main characteristics of technological knowledge

Characteristics of technological knowledge	Rogers (1962)	Nelson and Winter (1982)	Souder and Shirivastava (1985)	Winter (1987)	Cohen and Levinthal (1990)	Reed and DeFillippi (1990)	Garud and Nayyar (1994)	Nonaka and Takeuchi (1995)	Zander and Kogut (1995)	Grant (1996)	Spender (1996)	Galunic and Rodan (1998)	Saviotti (1998)	Norman (2002)
Codifiability		×	×	×		×	×	×	×	×	×	×	×	×
Communicability	×													
Compatibility	×													
Complexity	×			×	×	×	×		×	×				
Dependency				×			×		×					
Dispersed												×		
Easy to understand			×											
Observability	×			×					×					
Profitability	×													
Individual											×			
Specificity												×		
Teachability			×	×					×					
Time experience					×								×	
Usability			×											

contained in certain raw materials, such as chemicals and pharmaceutical products or special alloys; and (d) that part of knowledge retained in individuals' minds.

Tacit knowledge, on the other hand, is knowledge that cannot be reduced to information, and thus cannot be codified. Most technological knowledge has a significant tacit component, and hence cannot be transmitted entirely even by a person already in possession of it, because as individuals we all 'know more than we can explain'. The body of tacit knowledge encompasses all things that one knows how to do but cannot articulate in words or other means. Tacit knowledge is knowledge that arises from personal action and experience, and is therefore difficult to share with others.

Explicit knowledge, like information, involves two difficulties in terms of protection: (1) being by its nature a public good, hence there is no rivalry in consumption; and (2) the mere act of placing the knowledge on the market makes it available to all potential users. In general, highly codified knowledge cannot be appropriated through market transactions, except insofar as they are protected by patents (Grant, 1996). Thus, the higher the degree of codification of an item of knowledge, the more efficient the legal means of protecting it. Therefore, we put forward the following hypothesis:

> *Hypothesis 1a*: The higher the degree of codifiability of an item of knowledge, the more firms will tend to protect the item through the use of patent.

Tacit knowledge, however, being markedly idiosyncratic, is easier to protect within an organization. Tacit knowledge builds up at all company levels (individual, group and the firm as a whole), and is embedded in the relations among such levels. Imitators find it very difficult to copy tacit knowledge. Hence a firm can more easily appropriate its tacit knowledge than its explicit knowledge, because, as the former is not articulated, it is more readily protected against imitators. It has been pointed out that the appropriation of tacit knowledge is only achieved through applying it to production activities (Grant, 1996). So, to protect tacit knowledge, which is essentially impossible to patent, it is necessary to use alternative protection mechanisms such as secrecy, capitalizing on lead times or through the development of ongoing improvements.

The following hypothesis can therefore be framed:

> *Hypothesis 1b*: The lower the degree of codifiability of an item of knowledge, the more firms will tend to protect it by alternative means.

Teachability

This attribute concerns the feasibility of teaching and communicating an item of technological knowledge. It is to be borne in mind that teachability is independent from codifiability (Winter, 1987). Teaching explicit knowledge is generally unproblematic; for tacit knowledge, however, it is indispensable that there be both a practical component and personal communication. The more teachable an item of knowledge, the faster it can be transferred and imitated. This hinders full appropriation of the returns on knowledge, and influences the choice of protection mechanism. In general, firms use legal procedures; hence the following hypothesis can be put forward:

> *Hypothesis 2a*: The higher the teachability of an item of knowledge, the more firms will tend to protect it under patent.

Non-teachable knowledge, however—although no knowledge is strictly non-teachable—is very difficult to transfer. Its transfer requires long periods of experience and practice shared among knowledge possessors and learners. It is thus common for firms to have no need for protecting such knowledge through the use of legal procedures, and to appropriate it by other means.

> *Hypothesis 2b*: The lower the teachability of an item of knowledge, the more firms will tend to protect it by alternative means.

Observability

This dimension reflects the extent to which technological knowledge can be observed and detected by potential imitators. In general, the observability of an item of knowledge depends on the type of innovation to which it gives rise. When such knowledge materializes as a service innovation (e.g., a new financial product), observability is perfect, and imitation by competitors almost instant. But if it materializes as a product innovation, it is not so readily observable. Only reverse engineering techniques can help detect and assimilate the technologies that are necessary in the creation of the new product. Finally, if the knowledge item gives rise to a process innovation and becomes part of the firm's operating routines and procedures, observation is virtually impossible.

Tacit and non-teachable knowledge is difficult to observe, but this does not mean that all explicit and teachable knowledge is perfectly observable. Therefore, the observability of a knowledge item is independent of the previous dimensions, and affects its transfer and the speed of its diffusion. In general terms, observable knowledge is quickly transferred, easily accumulated and hard to protect within an organization (Zander and Kogut, 1995). Therefore, there is an incentive for firms to use legal means of protection for knowledge having this characteristic.

> *Hypothesis 3a*: The higher the observability of a knowledge item, the more firms will tend to protect it under patent.

Less observable knowledge, on the other hand, is less amenable to diffusion, and thus firms can protect it using alternative means alone.

> *Hypothesis 3b*: The lower the observability of a knowledge item, the more firms will tend to protect it by alternative means.

Complexity

Intuitively, one might suggest that the complexity of an item of technological knowledge is connected with the volume of information required to characterize it (Winter, 1987). In operational terms, complexity can be defined as the number of distinctive skills or competences of which the firm is in command and are needed to apply the new knowledge (Zander and Kogut, 1995). According to this definition, the complexity of a technology used in a product or service can be estimated on the basis of the number of competences required to produce it. Alternatively, complexity has been defined in terms of the different parameters needed to describe the functions that the technology performs.

Plainly, all items of knowledge possess varying degrees of complexity. It seems natural to think that the simpler a knowledge item, the easier it is to observe and, very likely, to teach. But some kinds of complex knowledge may also be readily observable and teachable. Having pointed out these *caveats*, we assert that, in broad terms, simple knowledge is more amenable to transfer and thus to imitation. Therefore, firms will prefer to protect such knowledge through the use of legal procedures.

> *Hypothesis 4a*: The lower the complexity of a knowledge item, the more firms will tend to protect it under patent.

Complex knowledge, on the other hand, is generally slow to transfer, and thus easier to protect using mechanisms controlled by the firm, since complexity hinders imitation.

> *Hypothesis 4b*: The higher the complexity of a knowledge item, the more firms will tend to protect it by alternative means.

Table 2 Foreseeable relationships

Innovation protection mechanisms	Characteristics of technological knowledge				
	Codificability	Teachability	Observability	Complexity	Dependency
Patents	+	+	+	−	−
Secrecy	−	−	−	+	+
Lead time	−	−	−	+	+
Learning curve	−	−	−	+	+
Complementary resources	−	−	−	+	+

Dependency
This feature concerns the relations of dependence of a knowledge item with respect to other knowledge. It reflects the extent to which new knowledge depends on the knowledge possessed by different individuals or groups within and outside the firm. The development and use of certain knowledge items often depend on the participation of people with different types of knowledge. For instance, new products are developed by the main subcontractors and employees in different company departments (Zander and Kogut, 1995). Independence, for its part, can be viewed as the extent to which a knowledge item operates in an essentially self-contained way.

Although dependency and complexity are distinct, there are certain relationships between them. Obviously, the greater the number of different skills required to apply a knowledge item, the higher its dependency on such skills. In other words, complex knowledge tends also to be dependent. Independent knowledge items are generally quickly transferred and readily imitated. Therefore firms will choose to protect them by legal means.

Hypothesis 5a: The lower the dependency of a knowledge item, the more firms will tend to protect it under patent.

The more an item of knowledge depends on a set of other items, however, the slower it will be transferred, and hence the easier it will be to protect by alternative means.

Hypothesis 4b: The higher the dependency of a knowledge item, the more firms will tend to protect it by alternative means.

Table 2 summarizes the relationships proposed by our hypotheses.

METHODOLOGY

Sample

To test our hypotheses, we conducted a survey of Spanish industrial firms that have a proven performance of innovative activity. The sample was drawn from the CDTI[4] (Centre for the Development of Industrial Technology) database, which holds details of all firms that have received funding from that body. After excluding services firms and refining the data, we obtained a sample of 2030 small and medium-size enterprises. We sent them all a questionnaire aimed at identifying the main features of their technological knowledge and the means they used to protect such knowledge from imitators.

The unit of analysis for this research paper is technological knowledge; therefore, firms were asked to associate their responses to the two chief innovations (knowledge items) that they had developed in the last 5 years. Questionnaires were filled out by R&D Department Heads or CEOs. The information-gathering process was completed in March 2001. By that date, we had received 406 questionnaires, of which only 367 were deemed valid. Finally, based on the completed survey questionnaires we were able to analyse 670 innovations.

Measures

Survey responses enabled us to measure directly the variables relating to protection mechanisms. Thus, the decision to take out a patent was measured by a single question with straightforward yes/no answer, thus generating a dichotomous nominal variable.

On the other hand, to measure the extent to which alternative means of protection—secrecy, lead time, moving quickly down the learning curve and use of complementary resources—had been used, we thought it best to use two successive, interrelated questions.

The first question aims to identify the extent to which the firm uses the relevant appropriation

[4]The CDTI is a body attached to the Spanish Ministry of Science and Technology, and promotes technological innovation and development in Spanish companies. This ensures that the firms studied were carrying on innovative activities.

tool, while the second aims to establish the firm's assessment of the effectiveness of that tool. This means that the effectiveness of a means of appropriation was assessed only by the firms that had considered that tool in their strategy for protection against imitation. To this end, in fact, subsequent analysis only dealt with innovations for which the answer to the first question—on the extent of use of the given mechanism—scored 4 or 5 on a 5-point Likert scale. Only in these cases was the response to the second question—on the effectiveness of the given method of appropriation—added to the data set for analysis. Innovations for which the response regarding the extent of use scored 1 to 3 were excluded.

To measure the five attributes of technological knowledge, we adapted a questionnaire used by Zander and Kogut (1995). All questions required responses on a 5-point Likert scale. Measurements were obtained by weighting the values of the questions defining each attribute.

Data analysis

To test hypotheses 1a, 2a, 3a, 4a and 5a, given that the dependent variable (patenting) is a nominal dichotomous variable and the independent variables (knowledge attributes) are ordinal, we performed our analysis using logistic regression. Using this technique, we aimed to estimate the probability of a given technology being patented, in view of the values of the variables relating to its knowledge attributes. In addition, so as to enhance the robustness and reliability of the results, we made two measurements of degree of association (Contingency Coefficient and Cramer's V) and conducted an analysis of the difference between averages.

To test Hypotheses 1b, 2b, 3b, 4b and 5b, given that the dependent variable (sum of values of variables relating to alternative means of protection) and the independent variables (knowledge attributes) are ordinal, we based our analysis on multivariate regression. Further, so as to enhance the robustness of the results, we tested the degree of association among the various protection methods and knowledge attributes taken individually. We constructed a contingency table with a battery of four measures of association (gamma, Sommer's D, Kendall's Tau-B and Spearman's correlation coefficient).

DISCUSSION AND RESULTS

Patents and knowledge attributes

Table 3 sets out the β-coefficient values for the logistic regression of the patents variable over the five variables reflecting knowledge attributes. We used the stepwise procedure to select the variables to be included in the linear equation. The statistics used to select and exclude variables were RAO efficient scores and Wald's statistic, respectively. As with linear regression, a variable is selected if the p-value of the test (H_0: $\beta = 0$) is less than 0.05, and is excluded from the equation if the p-value is greater than 0.1.

The results show that the higher the codifiability and teachability of a technology, the stronger a firm's tendency to patent it. This verifies Hypotheses 1a and 2a. Indeed, it seems clear that only fully codified knowledge can be patented, and thus codifiability is a necessary condition for patenting. This result also suggests, however, that firms in the sample are more likely to patent technologies with a relatively low level of tacitness. Such knowledge, being 'information', is readily imitated, and, as our theory proposes, alternative protection mechanisms will be relatively ineffective. A similar argument could be stated for teachability. The easier it is to teach a technology, the stronger the tendency will be to patent it.

The dependency of a knowledge item on other knowledge is the attribute that most influences a decision to take out a patent, but in the opposite sense to that foreseen by Hypotheses 5a and 5b. These hypotheses, as stated, suggest that (1) firms will prefer to protect their highly dependent technologies by alternative means, especially through control of complementary resources; and (2) the

Table 3 β-coefficient values of the regression[a]

	Codifiability	Teachability	Observability	Complexity	Dependency	R^2
Patents[b]	+0.297	+0.244			+0.325	0.37
Alternative protection mechanism[c]	−0.196		−0.208		+0.228	0.36

[a] p-value < 0.05.
[b] β-coefficient values of the logistic regression.
[c] β-coefficient values of the regression.

lower the dependency, the stronger the tendency to use patents. The results point in the opposite direction, however: the higher the dependency of the innovation on other knowledge, the more firms tend to protect it under patent. This result may reflect the fact that the firms in the sample (mostly small and medium-sized) most likely do not exert full control over complementary resources (Teece, 1987) that would enable them to appropriate the returns on their innovation. Therefore, they have little choice but to use legal protection mechanisms such as patents.

Two knowledge attributes (observability, complexity) are not significant at the 95% level. This result suggests that the observability and complexity of a technology do not influence the decision as to whether to protect it under patent. Thus the conjectures underlying Hypotheses 3a and 4a have not been verified.

In addition, we tested with two association measures for contingency tables, using the Contingency Coefficient and Cramer's V. Although these coefficients do not reflect the direction of the relationship, association levels for significant relationships exceeded 20%. Moreover, the relationships—especially with the dependency variable—were shown to be significant using the difference between averages test. These tests confirm the logistic regression results.

Alternative protection methods and knowledge attributes

The last row of Table 3 sets out the results of the multiple regression between the dependent variable (use of alternative protection methods) and the various knowledge attributes (the independent variables). The dependent variable was constructed on the basis of the sum of values of variables relating to the four alternative methods of appropriation. We obtained a Tukey additivity coefficient of 0.7377 with a critical non-additivity level of 0.4913, which amply exceeds the required level of 0.05.

As with the previous regression, we used the stepwise method, with an entry criterion for each variable of a 0.05 significance level. The knowledge attributes that most influence the choice of alternative protection methods were shown to be codifiability, observability and dependency.

Further, to analyse the relationships between each alternative appropriation method (secrecy, lead time, learning curve, complementary resources) and knowledge attributes, we constructed a contingency table (Table 4), which sets out four measures of association: gamma, Sommer's D, Kendall's Tau-B and Spearman's correlation coefficient.[5]

Taken as a whole, these results allow for a clear assessment of Hypotheses 1b, 3b and 5b. The less codifiable a knowledge item, the less observable and the more dependent on other knowledge it is, the more effective are alternative protection methods against imitation.

As predicted by Hypothesis 1b, it seems reasonable to hold that technologies based on essentially tacit knowledge and requiring prior experience for their use will be easy to protect by any of the alternative appropriation methods, such as secrecy.

Technologies that are difficult to observe (Hypothesis 3b) and that require a wide range of other knowledge for suitable use (Hypothesis 5b) will also be difficult to imitate, and thus easy to protect by any of the alternative means of protection, such as taking advantage of lead time or suitably managing complementary resources.

A point meriting further attention is that the dependency attribute is significant in the same direction both for use of patents and for use of all the alternative protection mechanisms. As indicated earlier, when discussing the results for Hypothesis 5a, the higher the dependency, the greater the use of patents. Hypothesis 5b is now also verified: the higher the dependency, the greater the use of all alternative protection methods. A plausible explanation of this might be that the dependency variable is imprinted with different types of effect. It reflects the fact that a complex system of resources needs to be operated in order to make full use of a technology or knowledge item. Some of these resources are in the hands of agents outside the firm, while others are under the firm's own control. For technologies where the former type of resources predominate, the firm has reasons to protect its knowledge under patent; otherwise, it will use alternative methods.

The regression analysis (Table 3) does not allow for testing hypotheses Hypothesis 2b and 4b. This means that teachability and complexity do not influence the decision to use alternative protection methods viewed as a whole. Nonetheless, the contingency analysis (Table 4) detects that the complexity of a knowledge item affects the choice of secrecy and lead time as protection mechanisms ($p < 0.05$ and $p < 0.01$ respectively). It also shows

[5]The four measures are used to measure the degree and type of association between two qualitative variables on an ordinal scale. Their values fall within the range (1,−1). Values approaching 1 indicate a strong positive association, while those approaching −1 indicate a strong negative association.

Table 4 Measures of association

Alternative protection mechanism	Characteristics of technological knowledge									
	Codifiability		Teachability		Observability		Complexity		Dependency	
Secrecy	−0.117***	−0.116***	−0.056*	−0.056*			0.089**	0.088**	0.101***	0.110***
	−0.157***	−0.135***	−0.067*	−0.071*			0.121**	0.104**	0.135***	0.138***
Lead time					−0.110***	−0.107***	0.115***	0.112***	0.104***	0.112***
					−0.144***	−0.127***	0.150***	0.131***	0.137***	0.140***
Learning curve									0.106***	0.122***
									0.135***	0.151***
Complementary resources			−0.060*	−0.060*	−0.097***	−0.094***			0.187***	0.200***
			−0.071*	−0.079*	−0.128***	−0.112***			0.246***	0.247***

Mesaures of association		
	Characteristics of technological knowledge	
Alternative protection mechanism	Sommer's D Gamma	Kendall's tau-B Spearman's correlation coefficient

*p-value < 0.10; **p-value < 0.05; ***p-value < 0.01.

that teachability has a moderate influence on secrecy and use of complementary resources ($p < 0.10$).

CONCLUSIONS

We have analysed the influence of five knowledge attributes (codifiability, teachability, complexity, observability, dependency) on firms' choice of innovation protection methods (patents, secrecy, lead time, learning curve, complementary resources). Table 5 shows the relationships that have emerged as significant.

The dependency of a knowledge item on other knowledge is the attribute exerting the strongest influence on all appropriation methods. It influences the use of patents and the use of each and every one of the alternative methods. A highlight of the results of this study is that the dependency variable influences all protection methods in the same direction: the higher the dependency, the more effective are patents, secrecy, lead time, moving quickly down the learning curve and the use of complementary resources.

The codifiability of a knowledge item, undoubtedly the most salient attribute, also influences decisions about means of protection. The study shows that, the more highly codified an item of knowledge, the greater the effectiveness of patents. Conversely, the larger the tacit component, the stronger the tendency to use alternative protection mechanisms.

Finally, this research is aimed at providing company management with a guide to key factors associated with the attributes of a firm's innovations.

Table 5 Relationships estimated

Innovation protection mechanisms	Characteristics of technological knowledge				
	Codifiability	Teachability	Observability	Complexity	Dependency
Patents	+	+			+
Alternative mechanism:	–		–		+
• Secrecy	–	–		+	+
• Lead time			–	+	+
• Learning curve					+
• Complementary resources		–	–		+

Identifying such attributes will enable the firm to choose the most effective appropriation method to protect its innovations against imitation.

In this regard, the variables that affect the effectiveness and use of patents as a means of protecting innovations are, in order of importance: dependency, codifiability and teachability. This confirms that, to be effective, legal protection must be backed up by certain knowledge attributes, such as the dependency of an innovation on other systems of knowledge, and its being readily codifiable and teachable.

The use of alternative methods, on the other hand, is affected by the following attributes: dependency, observability and codifiability. The more dependent a knowledge item on other knowledge, and the less observable and codifiable it is, the higher the effectiveness of alternative protection methods.

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