Science linkage, market orientation and the value of patented inventions*

Cédric Schneider†
KU Leuven
and
Copenhagen Business School

April 16, 2008

Abstract

This paper analyzes the choice between alternative sources of knowledge in patented inventions. Inventors can use scientific and/or market-oriented sources of knowledge. We formally test whether these two types of knowledge acquisition are complementary or substitutable in the value of patented inventions. The results suggest that simultaneous exploitation of different knowledge inputs is "subadditive" since inventors would have to manage assimilation and integration of disparate items of knowledge from multiple technology contexts.

Keywords: patents, R&D, scientific and market-oriented sources of knowledge, substitutability, complementarity.

JEL: O31, O32, L10

* **Acknowledgments**:

† **Address**: KU Leuven, department of Managerial Economics, Strategy and Innovation, Naamsestraat 69, 3000 Leuven, Belgium; email: `csc@cebr.dk`

1 Introduction

Basic science has long been understood to be a major input of technological progress and economic growth. For instance, Jaffe (1989) and Adams (1990) find that basic science, public expenditures or fundamental knowledge are crucial determinants of innovation by private corporations and economic growth. The uncertainty associated with Research and Development (R&D) activities and the growing complexity of the knowledge creation process has led many firms to acquire technologies outside their boundaries to complement their own R&D efforts (Cassiman and Veugelers, 2006). However, very little is known about the channels through which different sources of knowledge affect a firm's performance. This is in large part due to the fact that a firm or an invention's linkages to external sources of knowledge do not always leave a publicly accessible "paper trail". In this respect, recent research has used patents and the references to the non-patent literature (NPL) they contain in order to analyze the effect of an invention or firm's science linkage on innovative performances, generally measured by forward citations to a focal patent or firm. For example Cassiman et al. (2008) in an analysis at the patent level, find no effect of NPL references on forward citations, but find that the firm's science linkage has more explanatory power for patent quality. In the same vein, Nagaoka (2007) finds that firms having a high number of citations to scientific publications also have portfolios of patents of higher average quality.

This paper builds on the latter stream of research by analyzing the effect of scientific knowledge at the patent level. Patent data are supplemented with the results from a survey which enables me to use more direct measures of a patent's reliance to science and other sources of knowledge as well as a more precise measure of the value of patents. The paper has two objectives. The first more general objective is to identify to what extent scientific sources of knowledge affect the value of patented inventions. The second more specific motivation is to study the synergies between scientific sources of knowledge and private, market-based sources of knowledge. I argue that the type of knowledge sourced can determine the private value of an invention. The knowledge utilized for the invention is characterized on two dimensions, its scientific orientation and its linkage with market-oriented actors. More specifically, I will test wether "scientific" and "private", market oriented sources of knowledge are complements or substitutes in the value of inventions. On the one hand, using private sources of knowledge to complement scientific linkages could ease the market acceptance of the innovation. But on the other hand, existing studies show that there can be diseconomies in pursuing multiple R&D strategies. I will apply the test of supermodularity/submodularity to answer the question whether or not firms gain from using both sources of knowledge simultaneously.

2 Background and hypotheses

The positive impact of basic research on industrial performance has gained a wide acceptance and became of great interest to economists and policy makers alike. The seminal work of e.g. Griliches (1984), Jaffe (1989) or Adams (1990) have underlined the contribution of scientific activities on social welfare. Since then, a growing literature on Industry-Science Links (ISL) has complemented the beforementioned studies.

However, little is known about the interplay between these scientific spillovers and other sources of knowledge. Instead of studying the effect of scientific knowledge in isolation, I will study the interaction of scientific knowledge with other potential sources of knowledge that may affect a firm's performance. In other words, I will test whether scientific and market-oriented sources of knowledge are complement or substitutes in the value of patents. An invention's science linkage can take multiple forms, ranging from formal collaboration with universities or faculty consulting (Jensen et al., 2007), to informal collaboration such as attendance at university seminars or the use of scientific publications by the inventors. Similarly, market-based knowledge acquisition can take the form of formal or informal collaboration or communications with market-oriented actors such as competitors, suppliers, or customers.

Competing hypotheses on the complementarity or substitutability of these sources of knowledge can be drawn from the economics and management literature.

First, scientific and market-based sources of knowledge can be complementary. Scientific knowledge acquisition is presumably directed toward radical or explorative innovations that would require complementary inputs to enhance market acceptance. The economic literature on R&D collaboration shows that determinants and motives of R&D cooperation indeed differ significantly across cooperation partners (Belderbos et al., 2004). Belderbos et al. (2006) further find that university and customer collaborations are complementary, since the latter enhance acceptance and diffusion of radical, innovations. Nekar and Roberts (2004) find that firms that engage into new product commercialization also need a strong product market orientation, what they call "a general combinative capability" in order to achieve a positive result in terms of sales.

On the other hand, the literature on R&D collaboration shows that some firms suffer from diseconomies in pursuing multiple cooperation strategies (Belderbos et al., 2006). This type of reasoning could also apply to knowledge acquisition due to the complexity of managing diverging innovation strategies. This hypothesis is validated by Phene et al. (2006) who find that simultaneous exploitation of different knowledge inputs by firms does not generate breakthrough innovations, as measured by the top 2% most cited patents. Using technological knowledge from different sources can be "subadditive", since it may lead to information overload and diseconomies of scale. These harmful consequences may occur as a firm tries to manage assimilation and integration of disparate items of knowledge from multiple technology contexts.

3 Knowledge acquisition and the test for substitutability/complementarity

The literature has identified two methodologies to test for complementarity or subsitutability (Athey and Stern, 1998; Cassiman and Veugelers, 2006, 2007). The production function and the adoption approaches.

3.1 The production function approach

The study of complementarity/substitutability can be traced back to the theory of supermodularity/submodularity (Milgrom and Roberts, 1990). The first empirical methodology in this paper follows the "production function" approach (Athey and Stern, 1998). Suppose there are two potential sources of knowledge, D_1 and D_2 and an innovation function v that measures the value of the focal patent. Each source of knowledge can be used by the inventor during the invention process ($D_s = 1$) or not ($D_s = 0$), with $s \in \{1, 2\}$. The following definition draws from Cassiman and Veugelers (2006):

The function $v_i(D_{1i}, D_{2i}, X_i)$ where X is a vector of controls is supermodular and D_1 and D_2 are complements if:

$$v_i(1, 1, X) + v_i(0, 0, X) \geq v_i(1, 0, X) + v_i(0, 1, X) \tag{1}$$

i.e., using a source of knowledge while the other source of knowledge is already being used has a higher incremental effect on performance than using a source of knowledge in isolation.

Similarly, the function $v_i(D_{1i}, D_{2i}, X)$ is submodular and D_1 and D_2 are substitutes if:

$$v_i(1, 1, X) + v_i(0, 0, X) \leq v_i(1, 0, X) + v_i(0, 1, X) \tag{2}$$

In order to test for the existence of subsitutability or complementarity between scientific and private sources of knowledge, I estimate equation (2) with the following specification:

$$v_i = \alpha + \delta X_i + \beta_{10} S_{10i} + \beta_{01} S_{01i} + \beta_{11} S_{11i} + \varepsilon_i \tag{3}$$

where the S_{si} are exclusive dummies indicating the sources of knowledge chosen by the inventor of patent i, $\forall s \in \{1, 2\}$ and X is a vector of control variables. More specifically, the four dummies represent the different innovation strategies: an inventor can use *scientific* knowledge only S_{10i}, *private* knowledge only S_{01i}, both S_{11i} or none of them S_{00i}. The dummy S_{00i} is normalized to zero in order to include a constant. thus, the complementarity test between both sources of knowledge is:

$$\beta_{11} \underset{\leq}{\geq} \beta_{01} + \beta_{10} \tag{4}$$

3.2 The adoption approach

This approach is an indirect test of the existence of either complementarity or substitutability. The procedure consists of regressing the non-exclusive categories (D_{1i} and D_{2i}) on exogenous control variables (Z_i) in a bivariate probit model. In principle, two complementary activities will be positively correlated. However, Arora (1996) shows that unobserved heterogeneity (or missing variables) can bias the estimation result and the subsequent conclusion. This approach enables to test the nature of the relation between both knowledge sources through exogenous sources of variation.

4 Data

4.1 Sample

The data was compiled from two sources. First, I used the results of the so-called "PatVal" survey for Denmark, that contains information on 495 patents granted by the European Patent Office (EPO), with priority dates between 1993 and 1997. The PatVal project is a European-wide survey of inventors, which primary aim was to assess the economic value of European patents, by asking questions related to the personal characteristics of one of the inventors listed in the selected patents. A summary of the key findings of the Danish PatVal survey can be found in Kaiser (2006). Giuri et al. (2007) provide a summary of the PatVal survey for six other European countries.[1]

[1] France, Germany, Italy, the Netherlands, Spain and the United Kingdom.

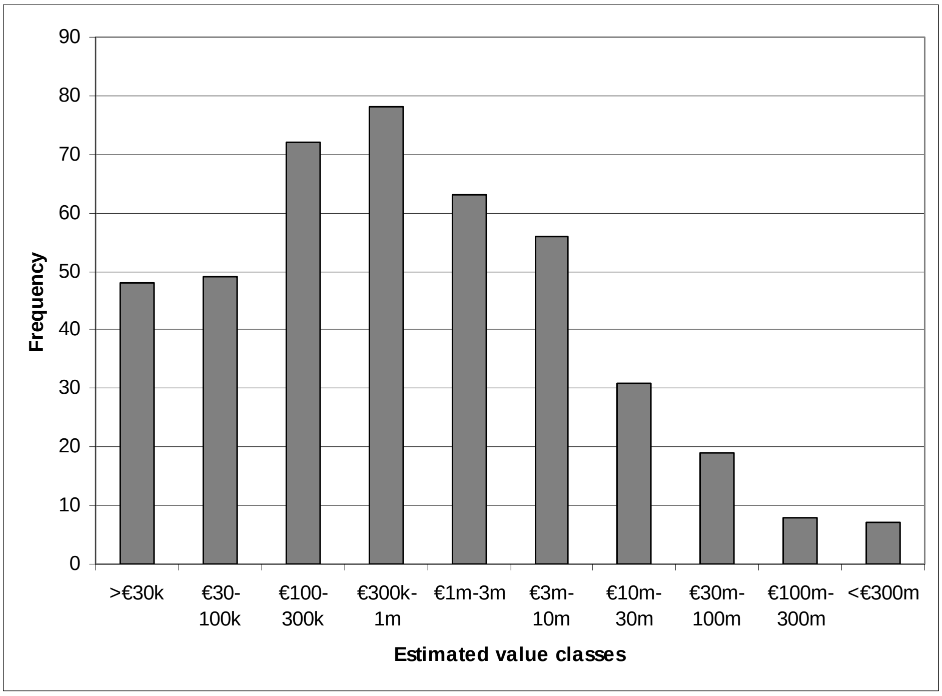
4.2 Dependent variables

The dependent variable quantifies the monetary value of the patent as estimated by the inventor. More precisely, the **present value of the patent** is based on the inventor's answer to the question *"Suppose that on the day in which this patent was granted, the applicant had all the information of the value of the patent that is available today. In case a potential competitor of the applicant was interested in buying the patent, what would be the minimum price the applicant should demand?"*. A set of ten interval responses was offered to the respondent: less than €30.000, €30.000-100.000, €100.000-300.000, €300.000-1 million, €1-3 million, €3-10 million, €10-30million, €30-100 million, €100-300 million, more than €300 million. The robustness of this indicator is discussed in Gambardella et al. (2006) who validate this variable by comparing it with common alternative indicators, e.g. the number of forward, citations, the number of backward citations, the number of claims and the family size of the patent. Moreover, a similar type of measure has been used and validated in different studies in the past (see e.g. Harhoff et al, 1999). Figure 1 shows the distribution of the value intervals which exhibits the usual skewness of patent values.

4.3 Explanatory variables

To characterize patents for which **scientific sources of knowledge** was used, a dummy variable was created that indicates whether the inventors used university laboratories and faculty, public research institutes or scientific literature as a source of knowledge for the research that led to the patented invention. Similarly, inventors can use **market sources of knowledge**. This dummy was created if the inventors claimed to have used customers or product users, suppliers or competitors as a source of knowledge. From these two dummies, four exclusive categories were created, for patents in which none of the sources of knowledge was used (S_{00}); inventions for which only scientific information was used (S_{10}); inventions for which only market based information was used (S_{01}); and inventions that combine both scientific and market knowledge (S_{11}). These variables are summarized in Table 1.

Figure 1: Patent value classes



In the remainder of the analysis, the disaggregated categories will not be used since it would give too many cases to consider, given that we have to create an exclusive dummy for each possible combination of sources of knowledge used[2]. Thus I will only focus on the two broader categories: scientific and market sources of knowledge. The correlation matrix at the right of Table 1 shows that there are strong correlations among the subcategories, which suggests that they can be aggregated.

Table 1: descriptive statistics (1)

Sources of knowledge	N	Mean	Std. Dev.	Min	Max	1	1.1	1.2	1.3	2	2.1	2.2	2.3
Non-exclusive dummies													
1. Scientific sources of knowledge	410	69.02%	0.463	0	1	1							
1.1 Universities	430	34.19%	0.475	0	1		1						
1.2 Public research institutes	426	23.00%	0.421	0	1		0.333	1					
1.3. Scientific publications	445	69.21%	0.462	0	1		0.431	0.244	1				
2. Market sources of knowledge	416	81.97%	0.385	0	1	0.134	0.053	0.131	0.074	1			
2.1 Customers, product users	458	74.45%	0.437	0	1	-0.050	-0.095	0.094	-0.154		1		
2.2 Suppliers	431	45.94%	0.499	0	1	0.079	0.073	0.240	0.026		0.332	1	
2.3 Competitors	437	57.67%	0.495	0	1	0.086	0.033	0.179	0.068		0.308	0.199	1
Exclusive dummies													
S11	396	58.08%	0.494	0	1								
S10	396	10.35%	0.305	0	1								
S01	396	23.23%	0.423	0	1								
S00	396	8.33%	0.277	0	1								

4.4 Control variables

Throughout the analysis, the **monetary cost** of the invention will controlled for. The questionnaire asked for the estimated amount spent for the invention that led to the patented invention. This is an important variable, since large scale projects are likely to lead to more valuable patents. Gambardella et al. (2006) already show that there is a systematic correlation between the scale of resources invested in the project and the value of its output. In addition, three dummies indicating whether any of the applicant of the patent is a **small firm** (with less then 100 employees), a **medium firm** (with a number of employees between 100 and 250) or a **large firm** (more

[2] If n is the number of categories, we need to create 2^n exclusive dummies.

than 250 employees).[3] Firm size might affect the "quality" of the invention, but the sign of this effect is not obvious. On the one hand, small firms might suffer from deficiencies in economies of scope and/or scale compared to larger corporations and on the other hand they may produce innovations of higher "value" because they have a reduced bureaucratic burden in comparison to large companies (Acs and Audretsch, 1987; Cassiman and Veugelers, 2006).

In addition, the analysis will control for year and technology fixed effects. Patent values might be influenced by variations over time, due to changing technological opportunities over the years, and technology areas due to the fact that inventions in some technology areas are intrisically more valuable. For these reasons, I include dummies for different **application years** and six **technology class** dummies using the so called OST-INPI-FISI classification, provided by the "Office des Sciences et Techniques" (OST), the French Patent Office (INPI) and the Fraunhofer ISI Institute, which is based on a concordance with the International Patent Classification (IPC) assignments.

Table 2: descriptive statistics (2)

Variable	N	Mean	Std. Dev.	Min	Max
Controls					
Estimated cost/1.000.000	491	5.495	112.830	0	2500
Large firm (<100 employees)	495	64.04%	0.480	0	1
Medium firm (100<employees<250)	495	9.49%	0.293	0	1
Large firm (>250 employees)	495	18.18%	0.386	0	1
Application years					
1993	495	2.020%	0.141	0	1
1994	495	25.657%	0.437	0	1
1995	495	19.798%	0.399	0	1
1996	495	18.990%	0.393	0	1
1997	495	22.828%	0.420	0	1
1998	495	10.707%	0.310	0	1
Technology classes					
Electricity-electronics	495	8.081%	0.273	0	1
Instruments	495	11.313%	0.317	0	1
Chemicals, pharmaceuticals	495	24.646%	0.431	0	1
Process engeneering	495	18.990%	0.393	0	1
Mechanical engeneering	495	26.667%	0.443	0	1
Others	495	10.303%	0.304	0	1

[3] There was actually no observation with a university-owned patent in the survey used in this paper. In Schneider (2007), I show that there were only eight patents applied for by Danish universities or public institutions at the EPO in the period 1978-1998.

4.5 The adoption approach: in search of exogenous sources of variation

"Exclusion restrictions" are used to test the nature of the relation between scientific and market oriented sources of knowledge, i.e. variables that explain exogenous variation in the choice of the knowledge source. I hypothesize that innovators will be more likely to use scientific knowledge in science-intensive technology areas. Conversely, patentees will use market-oriented sources of knowledge in technology areas in which market reliance in more important. These variables are measured by the utilization of the sources of knowledge in the sample at the technology class level. More precisely, I generate two variables that measure the **science intensity** and the **market reliance** in a technology area by taking the average level of scientific and market sources of knowledge in 30 technology classes defined in the OST-INPI-FISI classification.[4] These 30 technology classes are simply a disaggregation of the six classes used so far in the analysis.

Searching for additional drivers of substitutability or complementarity is a daunting task since the theoretical literature does not provide further insights on this issue. Therefore, lacking strong theoretical priors, the results should be considered as indicative of existing relations between the modes of knowledge acquisition. The PatVal survey provides us with two interesting candidates to be included in the analysis. The first one is a dummy indicating whether **reputation** was important for patenting the invention. If reputation is important for the research unit, the inventor or the firm, they might be more inclined to carry out scientific research rather than market-based research which would presumably be directed toward immediate commercialization of the invention. The second source of exogenous variation is a dummy indicating whether the idea for the invention was directly related to the inventor's normal job (which is not inventing) and was then further developed in a research project (**not R&D inventor**). The presumption is that if the inventor's main occupation is not to do research, the science

[4] this approach is similar to Cassiman and Veugelers (2007) who study the interplay between embodied and disembodied technology acquisition.

linkage of the patent will be weaker. This scenario describes a process in which the invention is a by-product of a project which was not a targeted R&D project, but rather an unexpected invention which may be the result of market-based sources of information.

Brief descriptive statistics for these variables are provided in Table 3.

Table 3: descriptive statistics (3)

Variable	N	Mean	Std. Dev.	Min	Max
science intensity in tech.	410	0.690	0.225	0.250	1
Market reliance in tech.	416	0.820	0.108	0.536	1
Reputation	380	0.682	0.466	0	1
Not R&D inventor	480	0.150	0.357	0	1

5 Results

5.1 Production function approach

Since the dependent variable is interval coded, the model is estimated using an ordered probit with known thresholds (or interval regression). The interval boundaries are log-transformed to account for the skewness of the patent values distribution (Wooldridge, 2002). The lowest boundary of the first interval is treated as censored, since it is a corner solution in the firm's optimization program. Correspondingly, the upper bound of the last interval is also treated as censored, since it is set to $+\infty$.

The first set of results are presented in Table 4. The estimation results contain the two non-exclusive dummies and the controls to provide a baseline specification. The results suggest that large scale projects, as measured by the cost of the invention, are more likely to generate patent of high value. Similarly, medium and large sized firms are more successful in turning their invention into valuable assets. The significance of the two non-exclusive dummies suggest that they convey little information as such, except that the coefficient for scientific sources of knowledge is much larger in magnitude than the coefficient on market-oriented sources of knowledge.

Table 4: Estimation results (1) - ordered probit with known thresholds

	Coef.	S.D.	Coef.	S.D.	Coef.	S.D.
Scientific sources of knowledge					0.466	0.362
Market sources of knowledge					0.093	0.439
log(cost)	0.159***	0.040	0.159***	0.039	0.150***	0.047
Large firm			1.103***	0.386	1.316***	0.425
Medium firm			1.097***	0.519	1.328***	0.561
Small firm			0.567	0.419	0.705	0.474
Application years	Included		Included		Included	
Technology classes	Included		Included		Included	
Constant	-0.473	0.990	-1.543	1.014	-1.516	1.353
sigma	2.534***	0.115	2.504***	0.114	2.484***	0.118
Log-likelihood	-889.828		-885.188		-717.810	
Number of observations	429				349	
	48 left cens., 7 right cens.				39 left cens., 5 right cens.	

The second set of results include the exclusive combinations of scientific and market-oriented knowledge sourcing decisions. Overall the signs of the controls do not change and their magnitude does not differ very much.

Turning to the question of complementarity versus substitutability, the results show that the coefficient on S_{10} is the largest in magnitude, suggesting that patents with a scientific linkage only are of higher value on average. Overall, the coefficients on scientific knowledge sourcing only (S_{10}) and market-oriented knowledge sourcing only (S_{01}) are higher than the coefficient of the joint strategies adoption (S_{11}) suggesting that both practices are subadditive rather than complements. Inequality (4) is directly tested using a one-sided Chi2 test. The test, shown at the bottom of Table 5, confirms that both practices are indeed substitutes in the value of patents. This result suggests that simultaneous exploitation of scientific and market-oriented sources of knowledge results in suboptimal performance in terms of the value of the resulting patent. This means that there might be significant obstacles to managing several sources of knowledge simultaneously.

Table 5: Estimation results (2) - ordered probit with known thresholds

	Coef.	S.D.	Coef.	S.D.
S11	1.567***	0.547	1.574***	0.541
S10	2.483***	0.767	2.538***	0.739
S01	1.603***	0.551	1.619***	0.545
log(cost)	0.129***	0.046	0.132***	0.046
Large firm			1.374***	0.417
Medium firm			1.212***	0.544
Small firm			0.725	0.459
Application years	Included		Included	
Technology classes	Included		Included	
Constant	-1.423	1.518	-2.760*	1.511
sigma	2.479***	0.121	2.439***	0.119
Test of no substituability:				
Chi2 (p-value)	9.48 (0.001)		7.72 (0.002)	
Log-likelihood	-716.806		-711.479	
Number of observations	349			
	39 left censored, 5 right censored			

5.2 Adoption approach

Table 6 present the results of the bivariate probit model. Since the direct test in the production function approach suggests that both modes of knowledge acquisition are substitutes, we are interested in finding contextual variables that might explain this relationship. We hypothesized that patents applied for in science intensive technology areas will be more likely to utilize scientific sources of knowledge. Conversely, patents in areas with stronger market reliance are expected to be positively related to market-based sources of knowledge. These hypotheses are confirmed by the data. Science intensity and market reliance in technology areas significantly increase the patentees choice of scientific and market-based sources of knowledge. However, these variables appear negatively (although they are not significant) in the probability to use the alternative source of knowledge: patents in science-intensive technology classes are less likely to use market-based sources of knowledge and vice-versa. This result is consistent with a substitutive relationship between market-based and scientific sources of knowledge.

Regarding the two additional exogenous variables, the results are consistent with our expectations. If reputation was important for patenting the invention, scientific sources of knowledge are more likely to be used. If the inventor is not a researcher, the invention is more likely to use market-based sources of knowledge. In addition, these variables negatively affect the inventors' choice to acquire the alternative source of knowledge. This is again consistent with a substitutive relationship.

Thus, these results are suggestive of a substitutive relationship between scientific and market oriented sources of knowledge but are not significant, therefore only providing weak evidence.

Table 6: Estimation results (3) - Bivariate probit

	Scientific sources of know.		**Market sources of know.**	
	Coef.	S.D.	Coef.	S.D.
log(cost)	0.073***	0.022	0.059***	0.020
Large firm	-0.049	0.335	0.433	0.309
Medium firm	-0.112	0.372	0.724*	0.416
Small firm	0.028	0.358	0.269	0.366
science intensity in tech.	3.427***	0.758	-0.764	0.867
Market reliance in tech.	-0.231	0.923	3.908***	1.052
Reputation	0.504***	0.197	-0.259	0.203
Not R&D inventor	-0.234	0.249	0.623*	0.351
Application years	Included		Included	
Technology classes	Included		Included	
Constant	-2.054	1.288	-3.414	1.408
rho	0.444 (0.147)			
Log-likelihood	-247.610			
Number of observations	320			

6 Conclusion

This paper analyzes the relationship between two alternative sources of knowledge acquisition. The inventors can use scientific sources of knowledge, stemming from universities, public research institutions or scientific publications. On the other hand, inventors can use sources of knowledge that are close to the market which can help enhancing the market acceptance of the product (or the technology). Using the testing framework developed in Athey and Stern (1998) and Cassiman and Veugelers (2006, 2007), I examine the nature of the relationship between these two types of knowledge acquisition. In addition, I also focus on exogenous sources of variation that affect the perceived relationship.

The first result shows that inventions using scientific sources of knowledge result in patent of higher monetary value. The test carried out in the paper reveals a substitutive relationship between the two sources of knowledge, suggesting that simultaneous exploitation of different knowledge inputs is "subadditive" since inventors would have to manage assimilation and integration of disparate items of knowledge from multiple technology contexts. Thus, firms are able to reap higher benefits from using one source of knowledge only.

Regarding the contextual variables affecting this perceived substitutive relationship, I find that the science intensity and the degree of market reliance in a focal technology area play an important role in explaining this relationship.

Given the lack of strong theoretical priors, future research should be directed toward more theoretical work to help explaining the choice and exploitation of different knowledge inputs.

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