Knowledge Protection Capabilities and their Effects on Knowledge Creation and Exploitation in High- and Low-tech Environments

Wolfgang Sofka[1] and Pedro Faria[2]

[1]Centre for European Economic Research (ZEW), Mannheim,
University of Hamburg, Germany

[2]IN+ Center for Innovation, Technology and Policy Research and Instituto Superior Técnico – Technical University of Lisbon, Portugal

Preliminary version. Please do not quote.

Abstract

We investigate the role of knowledge protection capabilities for firms' decisions to invest into new knowledge production through R&D activities and their success in exploiting it by appropriating the economic returns. We model these knowledge protection capabilities comprehensively encompassing both formal methods such as patents as well as strategic ones such as secrecy. We argue theoretically that formal knowledge protection capabilities set incentives for investing in R&D in both low- and high-technology environments because they provide tangible representations that signal its value and increase the resource availability from investors. Strategic protection capabilities, though, should be more beneficial for knowledge exploitation in low-tech environments where formal methods are not obtainable or efficient. We test these hypotheses for a harmonized dataset of more than 1,600 firms from Portugal and Germany. Our findings indicate that strategic protection capabilities are in fact more beneficial for exploiting knowledge in low-tech environments while formal ones lead to superior results in high-tech environments. However, the effect of formal knowledge protection capabilities on R&D investments can only be supported in high-tech environments. The management decisions for investing into new knowledge creation in low-tech environments appears not to be driven by protection capabilities. In that sense, it is much less strategic in nature. Important management and policy recommendations are derived based on these results.

1 Introduction

The resource based view of the firm emphasizes that the basis for firms' competitive advantage is established on a set of unique, and difficult to imitate firm level resources and capabilities (Lado et al., 1992). The knowledge based view extends this perspective by focusing on unique knowledge as the most valuable resource (Lippman and Rumelt, 1982). Knowledge provides firms with a platform for deciding which resources to develop, combine or discard (Liebeskind, 1996; Ndofor and Levitas, 2004). The investment in knowledge protection strategies can prevent or limit outgoing knowledge flows that could hamper firms' competitive advantage. Therefore, the protection of the results obtained from the investments in new knowledge is one of the most important aspects of management decisions on innovation.

We provide a comprehensive perspective on these knowledge protection capabilities encompassing both formal (legal) instruments (such as patents or copyrights) as well as strategic ones (such as secrecy or lead time). We argue conceptually that both elements of a firm's knowledge protection capability influence management decisions on exploiting existing resources. Both formal and strategic knowledge protection capabilities allow firms to create an (at least temporary) monopoly on the use of their innovations. This reduction in competition allows them to generate additional rents (Liebeskind, 1996).

Knowledge protection capabilities can also influence management decisions on investment in knowledge creation activities. The link between firms' expected appropriation of innovation returns and their R&D investment decisions has already been established by Arrow (1962). Nevertheless, we do not expect that strategic methods influence this management decision. We argue that only formal knowledge protection methods imply a growth of the financial resources available for new R&D projects. The tangible nature of formal knowledge protection methods allows a more accurate evaluation of the R&D activities by firms and stakeholders.

We also suggest that the effects of knowledge protection strategies on innovation management decisions differ significantly with regard to the technological challenges and opportunities as part of a country's appropriability regime. We argue that the limited degree of novelty in low-technology innovation environments leads to an increased availability of technological alternative which favour substitution in competition and make strategic knowledge protection capabilities more effective in knowledge exploitation than formal ones. In countries with more technological opportunities, it is expected that formal knowledge protection capabilities enable firms to exploit their knowledge more successfully than strategic knowledge protection capabilities. This distinction seems to be especially relevant as major parts of the empirical literature focus either solely on patenting for knowledge protection or investigate only high-tech countries such as the USA, Germany, Switzerland or Belgium.

We address these issues empirically with data from the European Community Innovation Survey 2001 (CIS) for more than 1,600 firms from Portugal and Germany. The harmonized survey provides us with the unique opportunity to compare the of firm's knowledge protection on a firm's resource portfolio in host country environments that differ significantly.

This paper is structured as follows. Section 2 presents our conceptual framework on knowledge protection methods with a special focus on the knowledge based view of the firm. It concludes with the development of hypotheses based on this discussion. Section 3 presents the empirical study for testing these hypotheses; the results follow in section 4. We draw conclusions in section 5.

2 Theoretical framework

We choose the knowledge based view of the firm as the starting point for our theoretical argumentation. Our primary focus is on firm's capabilities for protecting their valuable knowledge from spilling over to competitors. We will review the literature on the types of knowledge protection as well as the underlying mechanisms. On the one hand, it enables firms to exploit the knowledge and appropriate the economic returns from their investments into knowledge production. On the other hand, it creates incentives for management to invest into the creation of new knowledge. We develop hypotheses on how these effects differ in high- and low-technology environments.

Knowledge protection capabilities as part of the knowledge based view of the firm

The knowledge-based view of the firm is derived from the broader resource based perspective. The resource-based view has received much attention in recent academic discussion (Barney, 1991; Conner, 1991; Peteraf, 1993; Wernerfelt, 1984). According to the resource-based view, competitive advantage stems from a firm's control of valuable and rare resources which enable it to provide superior value to its customers and creates market opportunities (Lado et al., 1992). Unique knowledge can be considered as the most valuable resource (Grant, 1996). It provides firms with a basis for decisions on what resources to develop, refine or discard (Liebeskind, 1996; Ndofor and Levitas, 2004). Firms can achieve superior performance if they are able to prevent the imitation or substitution of the resources and their underlying knowledge (Lippman and Rumelt, 1982). Management has strong incentives to protect the results so that the firm's investments in knowledge creation activities do not become available to other firms without any costs (Arrow, 1962). In that sense, firms are not passive actors when it comes to protecting their knowledge. They can invest into the development of protection capabilities that can prevent or limit outgoing knowledge flows. We envision firm's knowledge protection capabilities as organizational structures and processes for achieving this. These may imply the build-up of legal competencies for applying and enforcing patent rights or organizational rules that set, monitor and enforce confidentiality. We will return to the elements potentially encompassing firm's knowledge protection strategies in the analytical framework.

Firm’s knowledge protection capabilities have dual effects on a firm’s resource portfolio. On the one hand, it enables them to exploit existing resources. On the other hand, it creates incentives for investing into the creation of new ones. The former perspective has received more attention in management and economics literature (see for example Levin et al., 1985; Mansfield, 1986). Knowledge protection capabilities allow firms to create an (at least temporary) monopoly on the use of a certain product, process or technology. This reduction in competition allows them to generate additional rents (Liebeskind, 1996).

However, knowledge protection capabilities are not limited to exploitative purposes. They have a separate, constitutive component by encouraging management to invest into the development of new resources and knowledge through R&D. The link between firms’ expected appropriation of innovation returns and their R&D investment decisions has already been established by Arrow (1962). Investments in R&D and innovation are inherently uncertain, i.e. success depends upon several factors outside of the firm’s control. This dynamism of the environment may stem from the technological developments, demand uncertainties or competitor moves (see for example Miller and Friesen, 1982). Firms will never be able to eliminate all of these uncertainties. A certain level of uncertainty provides the basis for entrepreneurial opportunity from introducing novel products or services (Freel, 2005). However, the capabilities of firms to protect their knowledge from spilling over to competitors should reduce some of these uncertainties. Firms with established knowledge protection capabilities have therefore stronger incentives for investing in knowledge production through R&D.

Knowledge protection capabilities in high- and low-technology environments

Several studies on knowledge protection or appropriability issues investigate the topic solely based on patent statistics (e.g. Griliches, 1990; McGahan and Silverman, 2006). We focus our review on parts of the literature that investigate both formal forms of knowledge protection such as patenting but also strategic ones like secrecy or lead-time. See Table 1 for an overview.

Table 1: Major studies on firm’s knowledge protection and their effect on innovation

Authors	Country of empirical investigation	Major findings
Levin et al. (1985)	USA	Industries in which at least one knowledge protection strategy is effective have higher levels of innovative effort and output
Webster (2004)	Australia	Innovation intensity is positively influenced by the efficiency of the knowledge protection
Harabi (1995)	Switzerland	Effectiveness of the different protection methods differs according to the type of innovation developed and the industry of the firm
Harabi (2002)	Germany	Strategic knowledge protection methods

Authors	Country of empirical investigation	Major findings
		have a deeper impact on innovative performance than formal protection methods
Cassiman and Veugelers (2002)	Belgium	Level of effectiveness in appropriating the results from innovation activities is positively correlated with the decision to cooperate
Hurmelinna-Laukkanen et al. (2008)	Finland	Firms that generate radical innovations have a stronger knowledge protection strategy than firms that only invest in incremental innovations. More dynamic and competitive environments propel stronger knowledge protection strategies by firms

We draw two major conclusions from this exercise. First, there appears to be a consensus that non-patent protection mechanisms are as effective as formal ones. Secondly, empirical evidence appears to be almost exclusively available for high-tech countries such as the US, Germany, Belgium or Finland. We argue that innovation processes in high- and low-technology environments differ significantly. The effects of knowledge protection capabilities should therefore differ, too.

Low technology firms, sectors or countries are not strictly defined. The definition typically reflects the basic nature of their technology and innovative patterns (Hall, 1994). The rate of technological change in low tech environments is often times slower and more predictable than in dynamic high tech areas. Innovation in low tech sectors is therefore often times driven by incremental process improvements. These may stem from economies of scale and scope or increases in efficiency based on new equipment or materials provided by suppliers (Pavitt, 1984). In that sense, firms in these sectors spend less on R&D themselves. This criterion of R&D activity and intensity is often times used to classify a firm or sector as low tech (see for example OECD, 2007). This is also visible in differences in the type of knowledge high- and low-tech firms are dealing with (Grimpe and Sofka, 2009): Firms in high technology sectors benefit from knowledge with a high degree of novelty allowing from radical innovative steps which is provided by leading universities or specialized suppliers. Firms in low tech industries, though, deal primarily with customers and competitors as primary sources of knowledge. This knowledge is typically directly applicable to their context but limits the opportunities for technological differentiation in competition.

We suggest that certain characteristics of different knowledge protection capabilities will generate similarities as well as differences in high and low tech environments with regards to the effect they have on firm’s knowledge production and exploitation.

Types of knowledge protection capabilities

Harabi (1995) and Encaoua et al. (2006) provide exhaustive overviews on the different knowledge protection strategies. The nature of the different knowledge protection strategies has been classified by scholars in two broad categories: formal and strategic protection methods (Harabi, 1995; Encaoua et al. 2006; Laursen and Salter, 2005). The different knowledge protection methods provide protection for different types of knowledge. Besides, their effective and efficient application requires different types of competences and procedures within the firm.

Formal knowledge protection capabilities and patenting, as its most prominent form, have received most attention in the literature. By providing temporary monopoly rights on the usage of an invention (e.g. patent) or its replication (e.g. copyright), formal knowledge protection strategies are built around knowledge protection based on legal intellectual property rights regimes (Arrow, 1962; Liebeskind, 1997). Patenting, trademarks, copyrights or designs patterns are the most significant forms of formal knowledge protection. The legal protection is provided by governmental agencies (e.g. patent office) that also validate the knowledge degree of novelty. Consequently, formal methods imply a codification and disclosure of the knowledge (Gallini, 2002; Encaoua et al., 2006). Hence, firms require employees with the competencies to codify the relevant knowledge in the application process. This application needs to adhere with the requirements of the legal body granting protection rights. Often times this requires dual competencies in technological as well as legal domains. Errors in this process are costly as intellectual property rights may not receive appropriate protection or infringe other inventor's rights. The latter may result in costly litigation processes (see for example Cremers, 2009). A dedicated group of service providers such as specialized patent lawyers has emerged to facilitate these processes as firms find them often time outside of their traditional spectrum of business acumen. What is more, the demands on the management of formal knowledge protection rights do not end with its grant. Firms have to remain active to ensure its effectiveness by monitoring the activities of others and potential infringements on their portfolio (see for example Blind et al., 2009). The codification and validation processes may be lengthy and imply an investment by the firm, a fact that may hamper the efficiency and effectiveness of formal knowledge protection methods for smaller firms with limited resources (Mansfield, 1986; Byma and Leiponen, 2006). As a consequence, the propensity to use formal knowledge protection methods varies greatly between industries and is closely related to the engagement in R&D activities (Brouwer and Kleinknecht, 1999). As shown by Arundel and Kabla (1998), different sectors attribute different values to patents. Pharmaceutical, chemical, and machinery firms are most active in patenting.

In other sectors, formal protection mechanisms have a residual importance when compared with strategic ones (Encaoua et al., 2006; Amara, Landrya and Traoré, 2008). Strategic knowledge protection strategies do not require dedicated investments nor knowledge codification or disclosure which makes them attractive to smaller or low-tech firms (Byma and Leiponen, 2006). These knowledge protection methods make use of organizational processes to prevent knowledge spillovers or to mitigate the negative consequences of such spillovers through organizational processes (Harabi, 1995). These strategies add extra barriers to knowledge transfers to competitors (Szulanski, 1996). Knowledge protected with secrecy or complex design can only be fully exploited once it is combined with additional expertise. Unique production or marketing operations may also provide efficient knowledge protection (Teece, 1986), specially when applied to process innovations which are embedded in a production system and have been found to be less frequently patented than product innovations (Harabi, 1995; Byma and Leiponen, 2006). Lead time or first mover advantages help to mitigate the consequences of spillovers, by establishing competitive advantages before competitors can react (Lieberman and Montgomery, 1988). Strategic knowledge protection capabilities require expertise in designing organizational rules and processes that determine who has access to certain parts of knowledge, restrict its usage and monitor the compliance with these rules (Liebeskind, 1997). However, the potential of strategic knowledge protection capabilities is limited as important parts of the valuable knowledge are simply visible in the final product (Ndofor and Levitas, 2004). Furthermore, personnel mobility negates the effectiveness of secrecy (Arrow, 1962). Table 2 summarizes the discussion based on the literature mentioned above.

Table 2: Comparison of formal and strategic knowledge protection capabilities

Knowledge protection strategy	Formal	Strategic
Major forms	Patents, copyrights, trademarks, industrial design	Secrecy, lead time, complex design, complementarities with production or marketing
Basis of knowledge protection	Law	Prevention of spillovers
Process	Formal application to official agency	Organization
Costs of protection	Substantial time and resource commitments	Flexible element of organizational design
Embodiment of protection	Tangible	Intangible
Type of suitable knowledge	Easy to codify, large group of potential users, low costs/high risks of imitation, product innovations	All forms of knowledge
Limitations to effectiveness	Knowledge disclosure enables “inventing around”	Knowledge embodied in products on the markets, personnel turnover

Formal knowledge protection methods (such as patents) provide a tangible output of the knowledge created by firms (Harabi, 1995). They signal the quality of the R&D activities developed by firms and stakeholders can more easily evaluate the scientific performance of firms. This may result in government R&D subsidies, tax credits, bank loans or engagements from private equity investors. Consequently, it is expected that formal knowledge protection methods imply a growth of the financial resources available to new R&D projects. Strategic methods do not provide any tangible signal to stakeholders about the quality of the knowledge produced by firms. This signalling effect of formal knowledge protection capabilities exists in both high- and low-tech environments. We therefore derive the basic hypothesis:

> Hypothesis 1: Formal knowledge protection capabilities have a greater impact on the firm's investment into knowledge creation than strategic knowledge protection methods in high and low-tech environments.

However, we argue that the effects of formal and strategic protection mechanisms differ in high- and low-tech environments with regard to knowledge exploitation for two primary reasons. First, innovation in low-tech industries is typically incremental and often times process oriented. Opportunities for formal knowledge protection are therefore limited. Granting institutions such as patent offices demand a certain degree of newness (innovative step) to grant a patent (see for example Encaoua et al., 2006). This innovative step is typically more difficult to attain in low tech environments. Secondly, formal protection mechanisms may not be as effective in low-tech environments. Formal protection instruments provide efficient protection from imitation through competitors. However, one of their major features is that they require a certain amount of knowledge disclosure in the protection application itself. This enables competitors to "invent around" the formal protection (Mansfield, 1986), i.e. they may not directly imitate the product but provide substitutes with different technologies but aimed at similar customers and uses. We argue that this threat from substation in knowledge exploitation is more elevated in low-tech environments compared to the threat from imitation. We suggest that the limited degree of novelty in low-technology innovation leads to an increased availability of technological alternative which favour substitution in competition and make strategic knowledge protection capabilities more effective in knowledge exploitation than formal ones. We propose:

> Hypothesis 2a: In countries with less technological opportunities, strategic knowledge protection capabilities enable firms to exploit their knowledge more successfully than formal knowledge protection capabilities.
>
> Hypothesis 2b: In countries with more technological opportunities, formal knowledge protection capabilities enable firms to exploit their knowledge more successfully than strategic knowledge protection capabilities.

3 Empirical study

3.1 Data

The quantitative analysis of our hypotheses requires the comparison of at least two different host country environments with different characteristics. We test our hypotheses through a harmonized survey for Portugal and Germany. Both countries are part of the European Union and use the single European currency Euro. Hence, they are comparable countries with regard to basic economic infrastructure. However, important differences remain, making the comparison between both countries a good fit for our research framework. Table 3 summarizes main indicators of economic performance and science/technology in both countries. Germany's economy is large and technology-intensive, while Portugal's economy is smaller in size and less R&D intensive. Differences in subsidiary behavior may also arise from the effectiveness of legal mechanisms for knowledge protection at the national level. They are a major element of a country's appropriability regime of "environmental factors […] that govern an innovator's ability to capture the profits generated by an innovation" (Teece, 1986, p. 287). Several authors have suggested indices on the degree of patent protection across countries (e.g. Rapp and Rozek, 1990). Ginarte and Park (1997) construct an index for 110 countries based on a country's patent laws extent of coverage, membership in international patent agreements, provisions for loss of protection, enforcement mechanisms and duration of protection. In previous years Portugal has lagged behind Germany based on this patent rights index (Portugal reaches 1.98 out of a maximum of 5 in 1990 compared to Germany's 3.71). However, a more recent update of the index by Park (2008) shows that this gap has largely been closed (4.38 to 4.5 in 2005). Hence, differences in legal appropriability rights regimes are not expected to influence the results.

Table 3: Selected economic and technology indicators for Portugal and Germany (2006)

	Portugal	Germany
GDP at current market prices (EUR 1 000 Mio.)	147	2 247
GDP per capita at current market prices (PPS) (EU-25 = 100)	71.4	109.8
Human resources in science and technology (employees with an S&T occupation, % of total employment)	18.6	36.9
Gross domestic expenditure on R&D (% of GDP)	0.8	2.5
Patent applications to the European Patent Office (number of applications per million inhabitants)	4.8	297.4
Index of patent rights (5 = highest patent right protection) (Park, 2008)	4.38	4.50

Source: Eurostat (2007): Europe in figures - Eurostat Yearbook 2006-07. Most recent year available reported.

We use data from the Community Innovation Survey III (CIS III), which was undertaken by the member states of the European Union in 2001. The survey collects data on the innovation activities of firms in each country from both the manufacturing and the service sector. The questionnaire and the methodology are based on the Oslo Manual (OECD, 1997) and harmonized across countries, allowing for comparisons between different countries. Some minor differences exist nonetheless, as countries are allowed to add questions to their questionnaire and to cover firms that are smaller than the threshold (ten employees) or belong to industries outside the core sector coverage of the CIS. National data privacy protection laws restrict the access to the national CIS micro-datasets. Legal obligations and confidentiality agreements prevent us from merging both samples. We will therefore analyze harmonized samples separately.

The Portuguese questionnaire is mainly a translation of the harmonized Eurostat questionnaire, but includes some additional questions. Nevertheless, and owing to the experience of CIS II, a more comprehensive design of the questionnaire was developed with several notes and examples to make it easier for the respondent to understand the questions. The German sample is stratified by region (East Germany and West Germany) in addition to size and industry to account for the effects of economic restructuring in East Germany.

To make the results of the surveys and our econometric analysis in the two countries comparable, all variables were constructed in the same way based on the harmonized survey questionnaire. Additionally, firms with fewer than ten employees were omitted from the German dataset and the NACE categories included in the German survey were brought in line with those covered in Portugal. Since most of the questions in the survey have to be answered only by innovative firms, i.e. firms that introduced at least one product or process innovation between 1998 and 2000 or had ongoing or abandoned innovation activities, we restricted our sample to this group of firms.

The CIS captures a larger variety of innovation activities rather than just R&D expenditures, e.g. personnel skills and training. Innovative output includes the introduction of innovative production processes and organizational changes. It contains also a wealth of information about the organization of innovation processes, including sources of knowledge, the reasons for innovating and the perceived strength of various knowledge protection mechanisms. For a detailed description of the survey see Peters (2008).

Heads of R&D departments or innovation management are asked directly if and how they are able to generate innovations. This leads to the production of direct measures for innovation processes and outputs which can complement traditional measures of innovation activity such as patents (Kaiser, 2002; Laursen and Salter, 2006). Moreover, CIS surveys are subject to extensive pre-testing and piloting in various countries, industries and firms with regard to interpretability, reliability and validity (Laursen and Salter, 2006). This multinational application of CIS surveys adds extra layers of quality management and assurance.

The industry coverage of both samples is representative for each country respectively. To ensure that results can be generalized we complement both datasets with official statistics for overall business R&D expenditures and foreign direct investment at the industry level. This additional information is intended to reflect that some industries may be more technologically advanced than others and/or may have received more attention from foreign investors. For Germany R&D data is derived from the OECD ANBERD database, for Portugal it is provided by the Portuguese statistical office and calculated in accordance with OECD procedures.

3.2 Variables

Dependent variables

Since we want investigate the dual effects of firms' knowledge protection capabilities on their resource portfolio, our dependent variables measure the investment into new knowledge production through R&D activities and their success in exploiting it. The share of turnover invested in intramural R&D and the share of turnover due to new or improved products to market allow inquiring how firms invest into the creation of new resources and exploit existing ones.

Independent variables

We conduct explorative principal component factor analyses on firm's usage of seven knowledge protection mechanisms which are directly derived from Laursen and Salter (2005): Patenting, design patterns, trademarks, copyrights, secrecy, lead time and complex design. Table 4 provides full details on factor loadings, scale reliability and sampling adequacy. All indicators point towards a meaningful application of factor analyses.

In both countries lead-time, complex design and secrecy form one factor of knowledge protection capabilities. We will refer to them as strategic knowledge protection capabilities. In Portugal the remaining formal mechanisms, patenting, design patterns, trademarks and copyrights, form a separate factor (formal knowledge protection). Interestingly, these protection mechanisms are split up into two factors in Germany. One contains patenting and design patterns while the other one contains copyrights and trademarks. Hence, we find an early indication of differences in the structure of knowledge protection capabilities in high- and low-tech environments. We score all factors to retain scales that will be used in all subsequent estimations. The coefficient of the formal knowledge protection capabilities variables should be positive and significant in the knowledge creation estimations to support hypothesis 1. The coefficient of the strategic knowledge protection capabilities variables should be positive and significant for both countries in the knowledge creation estimations to support hypothesis 1 and should be positive and significant in the knowledge exploitation estimation for Germany to support hypothesis 2b. To support hypothesis 2a, the coefficient of the strategic knowledge protection capabilities variable should be positive and significant in the exploitation estimation for Portugal.

Table 4: Factor loadings after varimax rotation

Variable	***Germany***			***Portugal***	
	Factor 1 Strategic	Factor 2 Patents/ design pattern	Factor 3 Trademarks/ copyrights	Factor 1 Strategic	Factor 2 Formal
Patenting	0.21	0.82	-0.10	0.00	0.80
Design Patterns	0.08	0.74	0.31	0.11	0.77
Trademarks	-0.01	0.44	0.66	0.13	0.70
Copyrights	0.21	-0.06	0.83	0.36	0.41
Secrecy	0.79	0.23	-0.03	0.86	0.03
Complex Design	0.76	-0.07	0.30	0.81	0.04
Lead Time	0.70	0.28	0.15	0.81	0.16
Cronbach's alpha scale reliability coefficient		0.71		0.70	
Kaiser-Meyer-Olkin measure of sampling adequacy		0.73		0.73	

Control variables

We include a set of independent variables in order to control for several firms characteristics. We add dummy variables indicating whether the survey firm is part of a multinational group with headquarters abroad and indicating whether a firm is part of a group with domestic headquarters ("domestic group"). In addition, we control for a firm's degree of internationalization through the share of their turnover that comes from exports. We also control for basic firm features like size (number of employees), level of education of the workforce (share of employees with college education) and regional differences (location in economically challenged East Germany). We also add four industry dummies (medium high-tech manufacturing, high-tech manufacturing, distributive services and knowledge-intensive services). Low-tech manufacturing will serve as the comparison group. Appendix A shows the detailed industry classification.

The moderating effect of the degree of host country environment technological development may not exclusively stem from the country level. Instead, important differences among industries within a given host country may exist. We follow Salomon and Byungchae (2008) and construct an index (RDI) for industry technological leadership based on OECD ANBERD data. The index is calculated through the subtraction of the R&D intensity of an industry in the country under consideration (Portugal or Germany) from the average industry R&D intensity of all other OECD countries. Positive values can be interpreted as relative technological leadership in an industry and negative values indicate a lagging status. We calculate the RDI index separately for Portugal and Germany using values from 1998 (the beginning of our observation period). The formula for the RDI index is:

$$RDI_{jt}^{h} = \frac{R_{jt}^{h}}{GDP_{t}^{h}} - \left[\sum_{k=1}^{n} \left(\frac{R_{kjt}}{GDP_{kt}} \right) \right] \times \frac{1}{n}$$

RDI_{jt}^{h}: R&D index of country h for the jth industry in year t

R_{jt}^{h}: R&D expenditure of country h in the jth industry in year t

GDP_{t}^{h}: GDP of country h in year t

GDP_{kt}: GDP of country k in year t

n: number of OECD countries (excluding country h)

3.3 Method and Model

The two dependent variables under analysis are corner solution outcomes. More precisely, the two variables are continuous and take on the value zero with positive probability. So, the Tobit model is the most adequate model to address our research questions.

The inclusion of R&D intensity amongst the determinants of productivity raises a possible endogeneity problem as this variable is potentially correlated with the error term in the knowledge exploitation equation. In this context, using a Tobit specification does not guarantee the consistency of the estimators. The solution adopted was to implement an instrumental variable approach. The success of this estimation depends on finding effective instruments that lead to the correct identification of all model parameters. The instruments chosen were two dummy variables that indicate if firms receive government funding for R&D activities and if the R&D activities developed by the firms are continuous. These variables are correlated to the R&D intensity even after partialing out all the explanatory variables, and there is no apparent reason to be correlated with unobserved heterogeneity in the exploitation equation.

Therefore, we estimate instrument variable tobit models in both countries. This allows us to investigate the effects of knowledge protection capabilities on R&D investments and market success with new products in separate equations but estimated simultaneously.

Exploitation = f (knowled. protection scales; control variables; R&D intensity)

R&D intensity = f (knowled. protection scales; control variables; instruments)

3.4 Descriptive statistics

Table 5 presents descriptive statistics for the Portuguese and German sample. Major features are outlined briefly in this section. There are some interesting similarities but also differences between the two samples.

The average share of sales with market novelties is similar in both countries (11-12%) but the R&D intensity is higher in Germany (3%) than in Portugal (1%). The average German firm is larger (302 employees) than the average Portuguese one (220 employees). 13% of firms in the Portuguese sample are subsidiaries of foreign firms, compared to 10% in Germany. The share of firms that are part of a group with domestic headquarters is higher in Germany (32%) than in Portugal (27%). However, firms in both countries generate on average the same share of sales from exports (22%). The share of employees with higher education is twice as high in Germany (24%) as in Portugal (12%).

Some of these differences can be explained by country specific industry compositions. The majority of Portuguese firms operate in low (35%) or medium tech manufacturing sectors (31%). In comparison, low tech manufacturing in Germany accounts for only 13% of the sample and the largest shares stem from medium tech manufacturing (48%) and knowledge intensive service sectors (23%). In addition to the differences on the industry composition of the two economies, the R&D intensity of industries is also dissimilar in Portugal and Germany. On average, Portuguese industries have a lagging status when compared with OECD countries industries (-0.37), while Germany industries, on average, have a relative technological leadership in the OECD context (0.21).

In conclusion, the descriptive part of our analysis highlights major differences between Portugal and Germany in innovation activities and knowledge protection strategies. However, these could be due to other factors like firm size or industry composition. As a result, a multivariate analysis is warranted. We inspect the correlation-matrix of all independent variables as well as variance inflation factors and condition numbers. They indicate no significant level of multicollinearity within our datasets.

Table 5: Descriptive statistics - Dataset

Variable	*Portugal*		*Germany*	
	Mean	*SD*	*Mean*	*SD*
Share of Sales with Market Novelties	0.12	0.21	0.11	0.17
R&D Intensity	0.01	0.03	0.03	0.06
Industry R&D Index 1998	-0.37	0.52	0.21	0.57
Firm Group with Foreign HQ (d)	0.13	0.34	0.10	0.31
Domestic Group (d)	0.27	0.44	0.32	0.47
Exports as a Share of Sales (ratio)	0.22	0.32	0.22	0.25
No. of Employees (log)	220.06	623.56	302.43	646.35
Share of Empl. w/ College Educ. (ratio)	0.12	0.16	0.24	0.24
Location East Germany (d)			0.35	0.48
Medium Tech Manufacturing (d)	0.31	0.46	0.48	0.50
High Tech Manufacturing (d)	0.05	0.22	0.09	0.29
Distributive Services (d)	0.14	0.34	0.10	0.29
Knowledge Intensive Services (d)	0.17	0.37	0.23	0.42
Government Funding for R&D (d)	0.35	0.48	0.40	0.49
Continuous R&D Activities (d)	0.25	0.43	0.57	0.50
No of observations	755		889	

4 Results

Table 6 presents the results of the instrumental variable estimations for the R&D intensity and knowledge exploitation for Germany and Portugal. We estimate separate, identical models for Portugal and Germany because legal restrictions and confidentiality agreements prevent us from merging both datasets. Both instrument variable tobit estimations perform well with individually as well as collectively significant instrument variables (government funding for R&D as well as continuous R&D activities). The instruments can be considered as strong with F-values above 10. What is more, we conduct tests on over-identifying restrictions which are not supported by any conventionally applied standard of significance.

Table 6: Estimation results of two-step tobit with endogenous regressors for Portugal and Germany (marginal effects)

	Germany		Portugal	
	R&D exp. as share of sales	Share of sales w/ new to market products	R&D exp. as share of sales	Share of sales w/ new to market products
Strategic knowledge protection (scale)	0.00**	0.03***	0.12	0.06***
	(0.00)	(0.01)	(0.09)	(0.01)
Patents/design pattern knowledge protection (scale)	0.01***	0.05***		
	(0.00)	(0.01)		
Trademarks/copyrights knowledge protection (scale)	0.00	0.02**		
	(0.00)	(0.01)		
Formal knowledge protection (scale)			0.01	0.04***

	Germany		Portugal	
	R&D exp. as share of sales	Share of sales w/ new to market products	R&D exp. as share of sales	Share of sales w/ new to market products
			(0.09)	(0.01)
Industry R&D index 1998	0.00	-0.02	-0.12	-0.06
	(0.00)	(0.02)	(0.21)	(0.04)
Firm group with foreign HQ (d)	-0.01**	0.01	-0.55*	0.12**
	(0.01)	(0.03)	(0.29)	(0.05)
Domestic group (d)	-0.01*	0.02	0.10	0.06
	(0.00)	(0.02)	(0.22)	(0.04)
Exports as a share of sales (ratio)	0.01	0.03	0.80***	0.02
	(0.01)	(0.04)	(0.30)	(0.05)
No of employees (log)	-0.01***	-0.03***	-0.37***	0.01
	(0.00)	(0.01)	(0.08)	(0.01)
Share of empl. with college educ. (ratio)	0.05***	-0.05	2.69***	-0.20
	(0.01)	(0.06)	(0.73)	(0.14)
Location in East Germany (d)	0.00	-0.04*		
	(0.00)	(0.02)		
Medium tech manufacturing (d)	0.00	0.00	-0.07	0.02
	(0.01)	(0.03)	(0.24)	(0.04)
High tech manufacturing (d)	0.03***	-0.03	1.55***	-0.20**
	(0.01)	(0.05)	(0.49)	(0.09)
Distributive services (d)	0.00	0.01	0.01	0.02
	(0.01)	(0.04)	(0.29)	(0.05)
Knowledge intensive services (d)	0.02***	-0.02	0.30	0.07
	(0.01)	(0.04)	(0.35)	(0.06)
Government funding for R&D (d)	0.02***		0.43**	
	(0.00)		(0.19)	
Continuous R&D activities (d)	0.02***		1.57***	
	(0.00)		(0.22)	
R&D exp. as share of sales (instrum.)		1.59***		0.06***
		(0.58)		(0.02)
Constant	0.03***	0.15***	1.22***	-0.14**
	(0.01)	(0.05)	(0.36)	(0.06)
Adjusted R2	0.30		0.17	
N	889		755	
Wald chi2	114.86		69.32	
P-value	0.00		0.00	

* significant at 10%; ** significant at 5%; *** significant at 1%;
(d) Dummy variable.

We find partial support hypothesis 1 in Germany. Firms with the capabilities to apply for patent and design pattern protection invest more into new knowledge protection through R&D. However, strategic knowledge protection capabilities have only a slightly smaller positive effect. Additional Wald-tests reveal that the difference is only significant at the 86% significance level. Protection strategies focusing on reproduction monopolies (copyrights, trademarks), though, have no impact on R&D investment decisions. Most strikingly, though, is the absence of any significant effect of knowledge protection capabilities in Portugal.

The effects of knowledge protection capabilities in Portugal are limited to the exploitation stage resulting in sales with market novelties. Both formal and strategic protection capabilities have a positive and significant effect with the latter being larger as suggested by hypothesis

2a. This difference is significant based on additional Wald-tests. Conversely, patenting and design pattern protection have the strongest, positive effect on sales with market novelties in Germany. It is significantly stronger than from trademarks/copyright protection and equal to strategic protection. These findings provide partial support for hypothesis 2b.

Consistency and sensitivity checks

We conduct additional consistency check estimations taking into account that not all industries in Germany can be considered as high tech. Conversely, not all firms in Portugal operate in a low tech environment. Put simply, we ask: Do the differences in the technological environment stem from the country or industry level? To evaluate this question we include additional interaction effect variables to separate estimation models. More precisely, we interact our scales on knowledge protection capabilities with the industry's R&D index. The latter compares the R&D intensity of a country's industry (Portugal or Germany) with the average of all other OECD countries. Positive values indicate that a country's industry is close to the technological forefront while negative values provide a proxy for how far it is behind. Appendix B provides the detailed results of these consistency check models. The model does not provide any evidence for significant interaction effects. We conclude that the effects identified before stem primarily from the country environment and its technological status.

Control variables

We develop no a priori hypotheses on the control variables and the estimation results can be considered to be explorative in nature. Focusing on Germany, larger firms and those being part of a group (with domestic or foreign headquarters) have lower shares of R&D expenditures as a share of sales. The share of employees with college education increases this ratio. Firms in technologically intensive sectors, i.e. high tech manufacturing (e.g. medical devices) as well as knowledge intensive services (e.g. software) show also higher R&D intensities which is in line with the underlying industry classification. We identify a similar size effect with regards to the share of sales with market novelties. It is larger for smaller firms. Besides, we find a regional difference within Germany. The Eastern part suffering from comparatively higher economic stress following reunification has also significantly lower shares of sales with market novelties.

We find similarities and differences with regard to these control variable patterns when comparing the results for Portugal. The positive effect from skilled employees with college education and firms in high tech manufacturing on R&D expenditures as a share of sales is equally strong. Similarly, increasing firm size and being part of a multinational group with headquarters abroad lower the ratio between R&D expenditures and sales. Interestingly, internationally active firms (measured by the export share of sales) invest more in R&D. This provides some support for innovation based models of firm internationalization (for a recent review see for example Brennan and Garvey, 2009). Surprisingly, firms in high tech manufacturing in Portugal have lower shares of sales with market novelties. Instead firms being part of a multinational group with headquarters abroad have more sales with market novelties. The pattern for foreign firms with regard to lower R&D inputs but higher outputs may indicate a transfer of knowledge from within the multinational corporation (MNC) which enables the Portuguese subsidiary to exploit this knowledge in the domestic market (see for example Kuemmerle, 1999).

5 Conclusions

We conduct this study to provide additional insights into how firm's knowledge protection capabilities shape their decision on investments into knowledge production and their success in knowledge exploitation. Most studies in the field have narrowly focused on patent activity and high technology environments. We argue conceptually that the merits of formal and strategic knowledge protection capabilities will vary with regard to the technological environment they are applied. We benefit from the opportunity to test our hypotheses based on a harmonized innovation survey and more than 1,500 firm observations in both Germany and Portugal.

We find strong support for the notion of important differences in the structure and effect of knowledge protection capabilities in low and high tech environments. Most of the suggested relationships between R&D decisions and innovation success by existing literature are supported for Germany. This is not totally surprising as major parts of the literature have investigated similar high tech environments such as the USA or Switzerland. However, we find important differences when comparing these results with Portugal representing environments with fewer technological opportunities. 80% of all R&D expenditures are concentrated within the G7 most industrialized countries and this degree of concentration has hardly changed over the last decade (Kuemmerle, 1999; OECD, 2007). Hence, Portugal's situation may be representative for a lot of countries.

Investments in knowledge production seem to be primarily driven by knowledge protection capabilities in high tech environment. They are primarily a vehicle for exploiting knowledge in low tech environments. What is more, strategic knowledge protection capabilities are more efficient for exploiting knowledge in these environments compared to formal ones. Several implications can be drawn from these findings for both management and policy makers.

First, management decisions on R&D investments in low tech environments appear to be largely independent from eventual protection capabilities. Firms and economies may benefit from a more strategic and targeted allocation of their investment portfolios. Our findings on the status quo suggest that managers devise their protection strategies once the knowledge is already created. However, we suspect that the investments in R&D could generate more returns if the knowledge protection aspect would already be part of the initial decision making process on the R&D investment. Secondly, there appears to be a trend towards fostering formal intellectual property rights legal frameworks in an effort to spur innovation. Our findings indicate the low tech countries may benefit even more if they increase management expertise in strategic knowledge protection capabilities. These may include adding complex design elements to innovative products hampering reverse engineering or organizational designs facilitating secrecy through screening and monitoring practices. Developing and fostering these particular protection capabilities appears to be especially valuable as they provide a fit with the specific innovative patterns and mechanisms in low tech environments.

6 Future research

All studies face certain limitations which may provide fruitful pathways for future research. Our study benefits from a comparative design across two countries. Even deeper insights could be gained by longitudinal analyses. However, this may require significant investments into data generation and consistency management across borders. Besides, Portugal and Germany are economically and technologically different but share several common institutional and cultural underpinnings (such as a shared currency). It appears very worthwhile to compare our results with other cultural contexts or emerging economies. Finally, qualitative investigations may help to gain a more fine-grained understanding on how knowledge protection capabilities enter decisions on R&D investments within organizations.

7 Appendices

Appendix A: Industry breakdown

Low-tech manufacturing	NACE 15-22, 36, 37
Medium-tech manufacturing	NACE 23, 24(excl.244), 25-29, 31, 34, 35(excl.353)
Hi-tech manufacturing	NACE 244, 30, 32, 33, 353
Low knowledge-intensive services	NACE 51, 60, 63
Knowledge-intensive services	NACE 61, 62, 64, 65, 66, 67, 72, 73, 74.2, 74.3

Appendix B: Estimation results of two-step tobit with endogenous regressors for Portugal and Germany with interaction effects between knowledge protection scales and the industry R&D index (marginal effects)

	Germany		Portugal	
	R&D exp. as share of sales	Share of sales w/ new to world products	R&D exp. as share of sales	Share of sales w/ new to world products
Strategic knowledge protection (scale)	0.00*	0.03**	0.03	0.07***
	(0.00)	(0.01)	(0.10)	(0.02)
Patents/design pattern knowledge protection (scale)	0.01***	0.04***		
	(0.00)	(0.01)		
Trademarks/copyrights knowledge protection (scale)	0.00	0.02**		
	(0.00)	(0.01)		
Formal knowledge protection (scale)			0.06	0.04**
			(0.11)	(0.02)
Industry R&D index 1998	0.00	-0.02	-0.12	-0.06*
	(0.00)	(0.02)	(0.21)	(0.04)
Firm group with foreign HQ (d)	-0.01**	0.01	-0.54*	0.11**
	(0.01)	(0.03)	(0.29)	(0.05)
Domestic group (d)	-0.01*	0.02	0.09	0.06
	(0.00)	(0.02)	(0.22)	(0.04)
Exports as a share of sales (ratio)	0.01	0.03	0.80***	0.02
	(0.01)	(0.04)	(0.30)	(0.05)
No of employees (log)	-0.01***	-0.03***	-0.37***	0.01
	(0.00)	(0.01)	(0.08)	(0.01)
Share of empl. with college educ. (ratio)	0.05***	-0.05	2.69***	-0.20
	(0.01)	(0.06)	(0.73)	(0.14)
Location in East Germany (d)	0.00	-0.04*		
	(0.00)	(0.02)		
Medium tech manufacturing (d)	0.00	0.01	-0.09	0.02
	(0.01)	(0.03)	(0.24)	(0.04)
High tech manufacturing (d)	0.03***	-0.03	1.53***	-0.19**
	(0.01)	(0.05)	(0.49)	(0.09)
Distributive services (d)	0.00	0.01	0.01	0.02
	(0.01)	(0.04)	(0.29)	(0.05)
Knowledge intensive services (d)	0.03***	-0.02	0.30	0.07
	(0.01)	(0.04)	(0.35)	(0.06)
Government funding for R&D (d)	0.02***		0.44**	

	Germany		Portugal	
	R&D exp. as share of sales	Share of sales w/ new to world products	R&D exp. as share of sales	Share of sales w/ new to world products
	(0.00)		(0.19)	
Continuous R&D activities (d)	0.03***		1.56***	
	(0.00)		(0.22)	
R&D intensity		1.61***		0.06***
		(0.58)		(0.02)
Interaction: RDI * Strategic	0.00	0.00	-0.25	0.02
	(0.00)	(0.02)	(0.16)	(0.03)
Interaction: RDI * Patents/design pattern	0.00	0.01		
	(0.00)	(0.02)		
Interaction: RDI * Trademarks/copyrights	0.00	0.01		
	(0.00)	(0.01)		
Interaction: RDI * Formal			0.14	0.01
			(0.15)	(0.02)
Constant	0.03***	0.15***	1.21***	-0.14**
	(0.01)	(0.05)	(0.36)	(0.06)
Adjusted R2	0.30		0.17	
N	889		755	
Wald chi2	115.10		69.66	
P-value	0.00		0.00	

* significant at 10%; ** significant at 5%; *** significant at 1%;
(d) Dummy variable.

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