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DISCUSSION PAPER

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Markets for Technology in Europe – Mapping Demand and its Drivers

MARKETS FOR TECHNOLOGY IN EUROPE –

MAPPING DEMAND AND ITS DRIVERS

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ABSTRACT

Functioning markets for technology are an important determinant for the type, scope and distribution of innovation activities in an economy. However, markets for technology are often underdeveloped or inefficient. Existing theory attributes such imperfections to the supply side or differences in market designs. We know comparatively little, though, about the structural forces that shape the demand side of markets for technology. In this study, we reason that demand depends on the sectoral pattern of innovation and the distance of a country's industry to the global technological frontier. We explore these dimensions based on longitudinal industry-level data from the Community Innovation Survey. We find that the demand on markets for technology is particularly driven by science-based industries and to a lesser degree by scale-intensive industries. Demand decreases, though, the closer industries are to the technological frontier. These findings highlight sector specific opportunities and constraints for policies promoting markets for technology.

Keywords: markets for technology, demand side, patterns of innovation, sectoral studies

JEL: L10, O32, O34

INTRODUCTION

Markets for technology are a crucial instrument for many firms searching for and acquiring external knowledge for their innovation processes (Arora, Fosfuri, and Gambardella, 2001; Arora and Gambardella, 2010; Arora and Nandkumar, 2012; Grimpe and Sofka, 2016). On these markets, also referred to as markets for ideas (Gans and Stern, 2003, 2010; Agrawal, Cockburn, and Zhang, 2015), disembodied knowledge is traded at a certain price, for example by trading the intellectual property (IP) itself or granting licenses. Prior research suggests that markets for technology can be important institutions for allowing vertical specialization and improving the allocative efficiency of innovation activities in a country. In other words, such markets determine which firms produce new technologies and which ones commercialize them (Arora *et al.*, 2001; Agrawal *et al.*, 2015). However, several studies highlight that markets for technology are underdeveloped or inefficient (Gans, Hsu, and Stern, 2008; Gans and Stern, 2010; Kani and Motohashi, 2012), pointing mostly to imperfections in the market design or the unwillingness of suppliers to offer technologies (Agrawal *et al.*, 2015). However, we have little comprehensive insights into the demand side of markets for technology as well as on the structural forces that shape the demand on such markets (Arora and Gambardella, 2010).

This study seeks to address these shortcomings and identifies heterogeneities in the demand on markets for technology. Extant literature on markets for technology seems to build on the implicit, yet important assumption that demand is ubiquitously available and homogenously distributed across countries and industries. This strong assumption is surprising, given the distinct sectoral patterns of technical change (Pavitt, 1984) as well as evidence that industries differ widely in the degree to which firms in those industries find the acquisition of technologies on markets useful and beneficial (e.g., Grimpe and Sofka, 2016).

Our study is designed to provide an account of the realized demand on markets for technology in Europe by industry, i.e. the investments that firms have made on those markets in technology. A well-developed demand side is an important prerequisite of "market thickness", i.e. the presence of sufficient potential buyers and suppliers to allow the market to match them efficiently (Roth, 2007; Gans and Stern, 2010). A lack of market thickness has been shown to be one of the main reasons why markets for technology fail (Agrawal *et al.*, 2015). Subsequently, we seek to explain the demand side of the market by decomposing the demand at the industry level along two dimensions: the sectoral patterns of technical change, describing the nature of the innovation activities in a specific industry (Pavitt, 1984), as well as how technologically intensive and advanced an industry in a country is vis-à-vis the technological frontier (Kumar and Russell, 2002; Mahmood and Rufin, 2005).

Given the shortage of empirical priors, we conduct an exploratory study that utilizes the unique data opportunity provided by the Community Innovation Survey (CIS) to study the demand on markets for technology for 20 different industries in 15 European countries over a seven-year period. We find the size of markets for technology to vary greatly between industries and countries in Europe, indicating that such markets are in fact very heterogeneous. Moreover, we show that the demand is significantly associated with the pattern of innovation firms in an industry follow and with the distance of an industry to the global technological frontier. In that sense, demand on markets is driven by science-based industries and to a lesser degree by scale-intensive industries in a country. Moreover, industries that are comparatively more distant from the technological frontier create demand on markets for technology. Taken together, we find that buying knowledge on markets for technology is an integral part of sectoral innovation patterns of some industries (science-based, scale-intensive) but not others and that the demand on markets for technologies is constrained by technological sophistication of the industries reducing its usefulness relative to internal R&D.

Our study contributes to extant research on markets for technology in at least three ways. First, we respond to calls in the literature and identify structural features of industries that propel or constrain demand on markets for technology (Arora and Gambardella, 2010). We reason that demand on markets for technology depends on sectoral innovation patterns and technological leadership positions of countries in specific industries. Delineating these factors enables future studies to (a) approximate the demand side of markets for technology at the industry level in a country and (b) separate demand side mechanisms from the supply side. We demonstrate the usefulness of this approach by providing a systematic account of the demand side of markets for technology in Europe for the period from 2008 to 2014, differentiated by industry. While prior research contains numerous estimations of the (worldwide) size of the market for technology, evidence remains patchy. Arora and Gambardella (2010), for example, argue that the world market size has increased substantially between 1995 and 2002 in terms of transaction value, reaching about USD 100 billion. Robbins (2006) estimates the total income from licensing in the United States in 2002 to be about USD 50 billion. These estimates, however, typically do not disaggregate the market size per industry or they are only focused on single industries like pharmaceuticals. As a result, the mapping we provide in this study allows tailoring innovation policies intended to expanding the overall size and utilization of markets for technology to specific industries.

Second, our research advances literature that analyses the consequences of industry differences in patterns of innovation activities and technological leadership by extending it to consequences for sectoral markets for technology. While this stream of literature takes into account that innovation in an industry can depend on knowledge production by other firms or sectors (e.g., Pavitt, 1984; Castellacci, 2008), we know little about whether this interaction between firms can be accomplished via markets, arguably the most efficient form of economic interaction. In that regard, more developed markets for technology offer considerable cost advantages and the flexibility associated with market transactions which may outweigh the advantages of other, more collaborative and relational forms of external knowledge acquisition (e.g., Laursen and Salter, 2006). Moreover, the notion that the demand on markets for technology depends on an industry's leadership status highlights that industries benefit unevenly from market development because markets may simply not offer access to the most cutting-edge research but rather to a considerable amount of "shelf-warmer technologies" (Grimpe, 2006) that may not advance innovation in leading industries (Grimpe and Sofka, 2016).

Third, our analysis provides an empirical platform that other studies can use to quantify the size of markets for technology in various industries and countries. Based on publicly available data from the CIS, we calculate aggregate firm expenditures on markets for technology in 20 different industries, 15 European countries and over seven years. The data complement prior efforts in the literature that have focused on measures such as the supply of university patents (e.g., Arora and Nandkumar, 2012), or narrowly focused on industries with high patent propensity (e.g., Gambardella, Giuri, and Luzzi, 2007). Hence, our research addresses not only the general shortage of data on these particular market transactions but can trigger future research on a variety of related topics, such as the interaction of markets for technology with firm strategies and particularly those directed at opening up the innovation process (Grimpe and Sofka, 2016).

THEORETICAL FRAMEWORK

We provide a structured review of extant literature on the demand side of markets for technology in three steps. First, we review central theoretical mechanisms determining the size of markets for technology in general and afterwards for the demand side in particular. Subsequently, we introduce the theories that we will use to uncover sectoral patterns of demand on markets for technologies, i.e. sectoral patterns of technological change, and technological leadership of industries.

The size of markets for technology

The size of markets for technologies depends on the presence of supply, demand as well as the efficiency of market mechanisms. Extant literature on market design (Roth, 2007; Gans and Stern, 2010) suggests three features that are associated with efficient market operations: market thickness (referring to sufficient opportunities for suppliers and buyers to trade), lack of congestion (referring to a transaction speed that is slow enough to allow participants to seek alternatives but fast enough to ensure market clearing), and market safety (referring to the absence of incentives for misrepresentation or strategic action). While congestion and safety are mostly design features at the market level, thickness relates most directly to supply and demand on markets for technology.

Market thickness implies that knowledge exchange does not depend on the presence of a specific buyer and supplier, so that the value of the knowledge is determined indirectly by the market interaction. Buyers and suppliers reveal their preference prices for a particular technology, and the market mechanism determines the equilibrium price at which buyers and suppliers cannot find a better offer. Efficient markets allow for allocative efficiency (Arora and Gambardella, 2010). However, many market transactions do not emerge in such clear-cut form. They can be embedded, e.g. in alliance agreements (Arora et al., 2001), or reduce the search costs borne by buyers and suppliers of knowledge by providing more limited services, such as brokerage, auctioning, or online presentation (Yanagisawa and Guellec, 2009; Dushnitsky and Klueter, 2011). At the same time, the types of knowledge that can be traded on markets for technology are limited, as the knowledge must typically be fully developed, codified, and ready to use.

Markets allow knowledge producers to sell the knowledge itself instead of developing complementary assets in, for example, distribution, manufacturing, or servicing for the purpose of commercializing that knowledge on the product market (Lamoreaux and Sokoloff, 2001; Gans and Stern, 2003). Conversely, firms that possess complementary assets do not need to invest in the development of new technologies because they can simply buy them on the market for technology (Arora and Nandkumar, 2012).

Industries differ in how thick their markets for technology are. Important determinants of market thickness are the nature of the knowledge that is tradable and the institutional rules, especially rules on intellectual property rights (IPR), which govern potential market transactions. First, knowledge traded on markets needs to be codified. Although, in principle, all knowledge can be codified, the costs of doing so can be excessive (Conti, Gambardella, and Novelli, 2013). If the costs are too high, the knowledge will not be codified and therefore not offered on the market for technology. Second, appropriability regimes are determined by the legal and technological conditions in an industry (Teece, 1986). As appropriability hazards increase, fewer knowledge producers will be willing to offer knowledge on a market for technology (Gans *et al.*, 2008). Arundel and Kabla (1998) estimate that roughly one-third of all inventions are patented. They find that this patent propensity ranges from 15 percent in iron and steel production to 74 percent in pharmaceuticals. Hence, there is a remarkable share of knowledge that is either kept secret (e.g., Hall *et al.*, 2014) or that does not qualify for patenting based on the formal criteria of the patent office or inventors' expectations of benefits. The low levels of patented knowledge combined with significant inter-industry differences consequently affect the functioning of markets for technology.

Market thickness has been found to be a particularly important factor in the early stages of licensing agreements, i.e. when sellers and buyers compare multiple potential partners and their knowledge (Agrawal *et al.*, 2015). Hence, thicker markets for technology provide richer and broader opportunities for licensing. They provide strong incentives for knowledge producers to offer their knowledge proactively (Felin and Zenger, 2014). What is more, the market mechanism requires that the knowledge be offered in codified form and largely ready to use, i.e. not requiring further interaction with the knowledge producer (Conti *et al.*, 2013). These features reduce absorption costs.

The nature of demand on markets for technology

Many industries in which competitive advantage is based on technology experience a high pace of technological change so that a pure recourse on internal resources is often too costly and time consuming even for advanced firms (e.g., Motohashi, 2008). Markets for technology are an option to supplement the internal knowledge base and to widen the strategic opportunities of the buyer (Arque-Castells and Spulber, 2018). The use of internal and external knowledge sources offers additional opportunities for recombination, improving innovation performance (Rosenkopf and Nerkar, 2001). Combinations from external and internal knowledge sources include idiosyncratic elements which delay the imitation of innovations by competitors (Kogut and Zander, 1992).

Firms can obtain external knowledge through relational or transactional mechanisms (Grimpe and Sofka, 2016). Relational mechanisms include – among other channels – R&D collaborations (e.g., Fitjar and Rodríguez-Pose, 2013), consortia (e.g., Branstetter and Sakakibara, 2002) and consulting (e.g., Grimpe and Hussinger, 2013). Transactional modes include R&D outsourcing (e.g., Grimpe and Kaiser, 2010), mergers and acquisitions (e.g., Ahuja and Katila, 2001) and in particular the purchase of external knowledge in the form of patents and licensing agreements on markets for technology (e.g., Ceccagnoli and Jiang, 2013). Relational and transactional modes of external knowledge sourcing are not mutually exclusive but may overlap, for example in technology alliances (Grimpe and Sofka, 2016).

External knowledge sourcing does not occur in isolation but is strongly linked to the capabilities and assets of the firm receiving the knowledge. A large body of research stresses the importance of absorptive capacity, which is defined as the capability to evaluate, assimilate and transform external knowledge to commercial ends and typically a by-product of internal R&D efforts (Cohen and Levinthal, 1990). Since the applicability and the commercial value of new technologies are often not obvious ex-ante, pursuing R&D in-house helps to learn about technological problems via trial and error (Cohen and Levinthal, 1990). A strong expertise in technological issues thereby helps the potential buyer to separate useful from useless technology (Ceccagnoli and Jiang, 2013). In that sense, existing research has shown that internal and external R&D are complements rather than substitutes (Cassiman and Veugelers, 2006; Ceccagnoli, Higgins, and Palermo, 2014). Taken together, we conclude that the demand on market for technology emerges from expectations of firms that (a) knowledge on markets for technologies can be effectively and efficiently acquired and absorbed as well as (b) advances a firm's innovation performance relative to internal R&D efforts.

Drivers of demand on markets for technology

We reason that the considerations of firms to buy knowledge on markets for technology are to a substantial degree determined by their industry. More specifically, we delineate two industry aspects that are likely to determine the demand of firms in a specific industry: the general pattern of innovation that an industry follows, and the industry's distance to the technological frontier.

Sectoral patterns of innovation

We start the discussion of structural features determining sectoral differences in the demand on markets for technology with differences in the nature of technological change and innovation across industries. Knowledge is cumulative in nature and emerges in sector specific trajectories resulting in a knowledge base of an industry that largely differs in means of knowledge creation, the sources of new knowledge as well as in the predominant strategies of appropriation (Pavitt, 1984; Castellacci, 2008). This knowledge base – or technological regime – shapes and constrains what is technologically and economically feasible and what not (de Jong and Marsili, 2006; Pavitt, 1998). In his seminal work, Pavitt (1984) differentiates between four groups of industries: *science-based industries, specialized suppliers, scale-intensive industries* and *supplier-dominated industries*. Within these categories, science-based industries are the technologically most advanced while supplier-dominated industries are the technologically least advanced groups. We briefly introduce all four groups.

Science-based industries use a complex knowledge base, and technology is produced to a considerable extent through internal R&D (Pavitt, 1984). The firms are typically large, and collaboration with universities or research labs is common. Due to the advanced internal R&D capabilities and the collaboration with scientific partners, inventions in science-based industries have a high degree of novelty, are technological in nature and can consequently often be protected with patents (Pavitt, 1984). Examples of science-based industries are the pharmaceuticals or electronics industries.

Specialized suppliers are typically smaller firms, which produce advanced machinery that is purchased by firms from other sectors (Pavitt, 1984). The latter use products from specialized suppliers to increase the efficiency of their own production processes. Specialized suppliers strongly rely on engineering and design capabilities as well as on the knowledge of users (Castellacci, 2008). Leading mechanisms of appropriation are design, know-how, tacit user knowledge and patents (Pavitt, 1984). Typical industries are manufacturers of machinery and electrical equipment.

Scale-intensive industries are strongly linked to specialized suppliers (Pavitt, 1984). Firms in these industries rely on a complex knowledge base, which is rooted in operative efficiency rather than in scientific principles (Castellacci, 2008). The exploitative use of external technology is connected with a large plant and market size (Pavitt, 1984). Typical industries are manufacturers of chemicals, rubber and plastic products, consumer durables and the automobile industry.

Finally, supplier-dominated industries have some internal R&D capabilities but mainly source disembodied technology from suppliers to save on costs (Pavitt, 1984). Central means of appropriation are non-technical and comprise trademarks, aesthetics, design and marketing activities. Representative industries include the manufacturing of leather, textiles and paper as well as agriculture.

While highly influential, Pavitt's taxonomy makes no explicit reference to the importance of markets for technology in the respective groups. Nevertheless, it holds two implications for the study of demand on markets for technology. First, the taxonomy suggests that there is a division of innovative labor (Castellacci, 2008), i.e. some industries tend to be knowledge producers while others tend to be users of knowledge generated externally. Second, the appropriation mechanisms differ significantly between the sectors (Pavitt, 1984). Science-based industries and specialized suppliers are technologically advanced and rely strongly on formal protection of their intellectual property, while the use particularly of patents is less pronounced in scale-intensive and supplier-dominated industries. However, the codification of knowledge and the protection through patents are generally regarded as a prerequisite for trading technology on markets (Arora *et al.*, 2001). Hence, both implications are likely to influence the demand on markets for technology. In that sense, we expect science-based industries to exhibit strong demand on markets for technology. Firms in science-based industries typically possess the absorptive capacity required to assess the relevance of technologies that can be found on markets and therefore identify those technologies that are most promising or complementary to their own knowledge base. At the same time, patents are of high importance in science-based industries, which facilitates the exchange of knowledge and technology.

Specialized suppliers can be assumed to be technologically advanced enough to assess the value of external technology. Then again, specialized suppliers are often small in size. Smaller size may indicate a lack of downstream capabilities for production and marketing, which decreases the incentives to purchase external technology. Smaller size may however also hint at resource constraints in general which in turn motivates firms to source technology externally instead of engaging in costly internal R&D efforts.

Firms in scale-intensive industries are typically technologically less advanced which makes the evaluation of disembodied technology more difficult due to lacking absorptive capacity. Yet, the linkages to specialized suppliers and the reliance on a complex knowledge base suggest that firms in these industries procure to some extent knowledge on markets for technology.

Finally, firms in supplier-dominated industries tend to lack substantive technological capabilities, while a large share of the returns from innovation is appropriated by non-technological intellectual property rights. For that reason, we expect the demand on markets for technology to be the smallest of all four industry groups.

Technological leadership of industries

Another important dimension separating industries with regard to their demand on markets for technology is how closely they operate to the global technological frontier of the industry. The concept of the technological frontier takes industries or firms in a region or worldwide in an order based on their level of technological progressiveness (Mahmood and Rufin, 2005; Kumar and Russell, 2002). The technological frontier is a hypothetical construct that defines the optimum of what is technologically feasible at any given point in time (McCain, 1977). Industries in various countries differ in how close their innovation activities are to what is globally possible. Industries at the technological frontier are forced to keep pace with technological progress and can hardly rely on established knowledge stocks traded on markets for technology (Mahmood and Rufin, 2005). Their competitive advantage is anchored in yet unknown re-combinations of diverse knowledge. Grimpe and Sofka (2016) argue that lagging industries are comparatively more likely to benefit from mature technologies on markets for technology. Lagging industries rely on "off the shelf" technologies and efficient implementation instead of creating a new technology (Arora *et al.*, 2001). Pursuing strategies of imitation and reliance on sophisticated technologies from highly specialized sellers allows industries with a higher distance to the technological frontier to save on costs and to foster growth (Mahmood and Rufin, 2005).

As a result, firms in leading industries typically acquire external knowledge through relational rather than transactional mechanisms because the degree of novelty of knowledge traded on markets for technology tends to be lower (Grimpe and Sofka, 2016). Moreover, knowledge traded on markets for technology is of comparatively lower complexity (Caviggioli *et al.*, 2017). In fact, firms with advanced internal R&D capacities have been shown to internalize the development of new technologies instead of purchasing technology on markets (Atuahene-Gima and Patterson, 1993). Taken together, we expect that demand on markets for technologies increases with the distance of the industry from the global technological frontier. Put differently, globally lagging industries are particularly likely to source technologies on markets for technology.

Given the complex nature by which sectoral innovation patterns and technological leadership of an industry determine jointly the demand on markets for technology in an industry, we conduct an explorative empirical study.

DATA AND METHODS

Data

The empirical part of this paper is based on data from multiple sources. The foundation of the dataset consists of industry-level data from the EU Community Innovation Survey (CIS), which is a widely used survey instrument to measure the innovativeness and innovative behavior of firms within the EU member states and some neighboring countries (e.g., Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Grimpe and Sofka, 2016). Relevant parts of the survey include separate questions on types of innovation, expenditures for internal and external R&D and expenditures for external knowledge. This feature makes CIS particularly useful for the purpose of our study since it enables us to track demand on markets for technology for a wide variety of industries and countries as well as separate from other R&D investments.

CIS is a bi-annual survey, and we utilize the survey waves carried out in 2008, 2010, 2012 and 2014.[1] In each survey year, the responses of the participants refer to the three-year period prior to (and including) the survey year. CIS has been found to provide high quality data since heads of R&D departments and innovation managers are asked directly about important aspects of innovativeness in their firms (Sofka and Grimpe, 2010). Several steps of preparation and quality assurance like extensive pre-testing and piloting in various contexts ensure a high quality of the data with regard to representativeness, interpretability, reliability and validity (Laursen and Salter, 2006). Response accuracy is increased by the provision of detailed definitions and examples of the underlying concepts.

[1] The CIS introduced a new structure in the disseminated tables for the survey carried out in 2016. To facilitate comparability, we restricted our sample to the four survey years mentioned.

Harmonized survey results aggregated at the industry level are publicly released by Eurostat to provide information on the innovativeness of the EU, its member states and their industries. However, data are not uniformly available for all EU member states and years due to individual contracts between the participating countries and Eurostat about the provision of data. Our analysis is therefore focused on 15 European countries with complete data records for the period under study, i.e. Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Netherlands, Norway, Poland, Slovak Republic and Spain. In sum, we end up with 1249 observations on the industry level by country and year. The industry level data from the CIS are augmented with country-level data from the European Innovation Scoreboard, the Global Competitiveness Index of the World Economic Forum, and OECD statistics.

Variables

Dependent variable

The CIS questionnaire contains detailed questions on the different types of expenditures for innovation activities, including expenditures for internal R&D and external knowledge. To measure the demand on markets for technology, i.e. our dependent variable, we use data from the question regarding the expenditures for "other external knowledge". This variable captures mainly licensing expenditures and expenditures for the acquisition of patents from other parties. The variable does not include expenditures for external R&D in general or for external knowledge embodied in machinery, equipment, or software. Since the variable is highly skewed, we use its natural logarithm in all estimations. It is important to note that the dependent variable captures only the realized demand on markets for technology on the industry level and not the "deals not done" (Agrawal *et al.*, 2015).

Explanatory variables

Our first explanatory variable is the pattern of innovation that an industry commonly follows (Pavitt, 1984; Castellacci, 2008). To identify the industries that belong to specific patterns of innovation, we follow the approach of Bonaccorsi et al. (2013) who map NACE industry codes onto Pavitt's taxonomy. More specifically, we create four dummy variables measuring the sectoral patterns of innovation as follows. The NACE (Rev. 2) codes 10-12, 19, 20, 22-25, 29 and 30 are classified as scale-intensive industries; NACE 27, 28 and 33 as specialized suppliers; NACE 21 and 26 as science-based industries; all other NACE codes cover supplier-dominated industries.

Our second explanatory variable is an industry's distance to the technological frontier. We follow prior research which argues that relative R&D expenditures can proxy for an industry's position vis-à-vis the technological frontier (e.g., Chung and Alcácer, 2002; Grimpe and Sofka, 2016). To measure distance to the frontier, we first determine the (hypothetical) technological frontier by comparing the R&D intensity (internal R&D expenditures divided by sales) of a specific industry between the countries in our sample. The country-industry with the highest value for internal R&D intensity serves as the technological frontier.[2] Subsequently, we subtract the value for internal R&D for each country-industry from the identified technological frontier. The resulting value measures the distance to the technological frontier, with increasing values indicating higher distance to the technological frontier.

As a consistency check, we follow Salomon and Jin (2008) and calculate the distance to the technological frontier by normalizing the country-industry's R&D expenditure by the

[2] The maximum value of the R&D intensity in our sample does not necessarily correspond to the global technological frontier. However, we use this measurement since our sample contains a number of technologically highly advanced countries in Europe and since our focus of analysis is on markets for technology in Europe and not worldwide.

country's GDP and subtract from this the average R&D/GDP of all other countries. Increasing values of the variable indicate relative technological leadership (i.e. decreasing distance to the technological frontier).

Control variables

We use several control variables at the industry and the country level that could potentially influence the degree to which industries demand technology on markets. First, we use the industry R&D intensity, defined as industry R&D expenditure over industry sales, as a proxy for the industry's absorptive capacity (e.g., Laursen and Salter, 2006). To account for a potential nonlinearity of the relationship, we also include a squared term of the industry R&D intensity. Next, we include the total number of employees in an industry as a proxy for the overall size and economic importance of an industry in a country. We also include the average firm size defined as the total number of employees over the number of firms in an industry in order to measure industry structure. Since transactions on markets for technology oftentimes occur in connection with relational search (Grimpe and Sofka, 2016), we include the share of firms in an industry that reports to have any external collaborative activities.[3]

On the country level, we control for the strength of the national innovation system by including the gross domestic expenditures on R&D (GERD) as a share of GDP (Sofka and Grimpe, 2010). GERD covers the total R&D expenditures in a country by domestic and foreign actors like firms, research institutes and universities. As consistency checks, we use a variable that proxies for the available supply on markets for technology by measuring the number of PCT patent applications per billion Euro GDP. Moreover, we use a variable that

[3] Missing values in the variables for industry in-house R&D expenditures (19.3 % missing), turnover (10.6 %), number of total enterprises (9.2 %) and number of employees (9.8 %) were replaced by the variables' mean value calculated over all survey years. To control for a potential non-response bias we calculated dummy variables which indicate if values were replaced or not. Since the imputation dummies are highly correlated with each other, we include only one of them in our empirical models.

measures the strength of IP protection which has been referred to as an important factor determining why deals are done or not (Gans *et al.*, 2008). For this purpose, we use a survey-based measure collected by the World Economic Forum as part of the Global Competitiveness Index indicating, on a scale from 1 to 7, the perceived strength of the protection of IP in a certain country. Both consistency check variables are highly correlated with the country GERD and thus can only enter the regressions separately. Finally, our regressions include country and year dummy variables to control for remaining differences on the country level as well as for time effects.

Empirical approach

We begin our results section by providing a mapping of the development of markets for technology in Europe. Next, we show descriptive statistics of all variables under study. Finally, we conduct pooled OLS regressions including country and time fixed effects.

RESULTS

Mapping markets for technology

Before we proceed to explaining drivers of demand on markets for technology, we provide descriptive evidence on the development of markets for technology in Europe. The aggregate statistics indicate expenditures on markets for technology of 5.2 billion Euro in 2008, 3.6 billion Euro in 2010, 2.8 billion Euro in 2012 and 3.0 billion Euro in 2014.[4] Moreover, we find the demand on markets for technology to vary markedly between industries and countries. Figure 1 shows the total expenditures for external knowledge in billion Euro within the four industry groups from Pavitt's taxonomy over time. It turns out that the group of scale-inten-

[4] The countries in our sample cover about 73% of the total population in the EU member states in each survey year. The total market size in the EU can therefore be assumed about 30% larger.

sive industries exhibits the highest overall expenditures, followed by science-based industries, specialized suppliers and supplier-dominated industries. While this is certainly driven by the number of industries that compose a particular group, it shows the difference in importance of markets for technology among the four groups. Table 1 summarizes the expenditures for external technology by year, industry group and country.

[Insert Table 1 about here]

With the exception of specialized suppliers, we find decreases in the expenditures during the period from 2008 to 2014, i.e. expenditures are almost cut in half. This suggests that markets for technology are volatile and that demand can be adjusted flexibly. Both supplier-dominated industries and science-based industries experience decreasing expenditures during the entire period, while scale-intensive industries and specialized suppliers experience stable expenditures or even increasing expenditures in 2014. The decrease is potentially connected to the economic and financial crises during this time period that has considerably impacted firm R&D expenditures and, apparently, also the demand on markets for technology (Teplykh, 2017; Spescha and Woerter, 2018).

[Insert Figure 1 about here]

A slightly different picture emerges regarding expenditures for external knowledge relative to in-house R&D expenditures (Figure 2). Whereas the decline over time is observed for all industry groups (with the exception of specialized suppliers), markets for technology are frequently used opportunities especially in the technologically least advanced subgroups (supplier-dominated industries and scale-intensive industries).

[Insert Figure 2 about here]

Focusing on country differences, Figure 3 shows the total expenditures within the four largest European economies in our sample over time versus the remaining countries. German firms appear to be the most active on markets for technology, followed by France, Spain and Italy.

Again, we observe a decline in demand in the four countries from 2008 to 2014 with the exception of France, which exhibits a strong increase from 2012 to 2014.

[Insert Figure 3 about here]

Figure 4 allows a deeper insight into patterns of external knowledge purchasing within the smaller countries over time. Expenditures for external knowledge are cumulated and normalized with the respective GDP of the country at time t. For the largest economies (Germany, France, Spain and Italy) the pattern of declining expenditures is confirmed. In most of the smaller economies, the expenditures are roughly stable. However, we see some notable exceptions. For the Czech Republic and Norway, we observe an increasing share of expenditures over time. Hungary and the Slovak Republic show a sharp decrease from 2008-2010 and subsequently a strong increase of normalized expenditures until 2014.

[Insert Figure 4 about here]

Descriptive results

Next, we turn to presenting descriptive statistics for all variables used in the regression models. Table 2 shows the summary statistics for the dependent and explanatory variables. We find that most industries in our sample are scale-intensive (44%), followed by supplier-dominated (35%), specialized supplier (13%), and science-based industries (8%). The mean distance to the technological frontier, i.e. the difference between a focal industry's R&D intensity and the maximum R&D intensity of an industry in the sample, is 2.38%, but we also observe rather high variation in our data. Regarding our control variables, we find the average R&D intensity to be 1.13%, again with considerable variation in the data. The data also reveal that industries differ largely in the number of employees (min. 87, max. 1,035,370) and the average firm size (min. 17.4, max. 3675.75). On average, the share of firms in an industry engaged in any type of innovation collaboration is 19%, and countries spend 1.74% of their GDP on R&D.

[Insert Table 2 about here]

Table 3 contains the pairwise correlation coefficients of the explanatory variables. We find no indication for collinearity as evidenced by the rather low correlation coefficients.

[Insert Table 3 about here]

Regression results

Table 4 shows the OLS regression results of the main models for the expenditures for external knowledge (in log.). Model 1 includes the control variables only. The relationship between the control variables and the expenditures for external knowledge turn out to be largely consistent across all model specifications. We find an inverse U-shaped relationship between R&D intensity and the demand for external knowledge, indicating that higher R&D is initially associated with higher demand, likely because it provides absorptive capacity and allows the integration of external knowledge. After a certain threshold, though, industries are technologically sophisticated and demand for external knowledge decreases. Presumably, the market does not offer much useful, i.e. sufficiently novel, knowledge. Moreover, we find that larger industry size and larger average firm size are positively associated with the demand for external knowledge. On the one hand, this indicates that larger industries with many firms contribute to market thickness since there are more transaction partners available. On the other hand, markets for technology seem to be more useful for larger firms compared to smaller firms. Next, we find that industries in which more firms are also engaged in innovation collaboration exhibit higher demand on markets for technology. This underlines the notion that markets for technology are oftentimes used in connection with more relational forms of knowledge acquisition, such as collaborative R&D (Grimpe and Sofka, 2016). Lastly, Model 1 also demonstrates that more technologically advanced countries as measured by a country's total R&D expenditures (GERD) over GDP have more demand on markets for technology.

Model 2 contains the three dummy variables for the industry groups from Pavitt's taxonomy, with supplier-dominated industries being the reference category. As expected, we find science-based industries to be strongly positively associated with demand for external knowledge. The coefficient turns out to be much larger than for the other industry groups. Scale-intensive and specialized supplier industries also have a significant positive but comparatively smaller relationship with demand. In relative terms, supplier-dominated industries, the reference group in our estimations, show significantly lower demand on markets for technology.

Model 3 includes the control variables and the variable measuring the distance to the technological frontier, which we find to be positively and significantly associated with the demand for external knowledge. This finding indicates that industries spend more on external knowledge when they are increasingly distant to the technological frontier. This confirms our expectations that technologically sophisticated industries have comparatively less to gain from acquiring knowledge on markets for technology.

Model 4 includes both the dummies for sectoral innovation patterns and the distance measure. We find the results to be consistent with the exception of the coefficient for specialized suppliers, which turns out to be no longer statistically significant.

In addition, we create interaction terms between the industry groups and the measure for the distance to the technological frontier. Due to collinearity concerns, they cannot all enter the model at the same time. Model 5 shows the interaction between technological distance and scale-intensive industries to have a positive and significant association with the demand for external knowledge. Scale-intensive industries tend to have lower technological capabilities. In combination with increasing distance to the technological frontier, these industries turn out to spend more on external knowledge, which is what can be expected to occur. Model 6 includes the interaction of technological distance and specialized supplier industries, which shows up as not significant. Model 7 shows the interaction of technological distance and science-based industries which turns out to be negatively and significantly associated with the demand for external knowledge. This finding indicates that industries with higher technological capabilities tend to demand less on markets for technology with increasing distance to the technological frontier. The strong relationship between technological distance and market demand is in that sense attenuated for science-based industries.

[Insert Table 4 about here]

Robustness checks

Table 5 shows several robustness checks of our results when we use different measures for some of our explanatory variables. Model 1 includes the alternative measure for the distance to the technological frontier based on Salomon and Jin (2008). The coefficient turns out to be negative and significant. Since higher values of the variable indicate relative technological leadership, the negative coefficient is in line with the measure for technological distance used in the main models. Models 2 and 3 include the alternative measures for the country GERD/GDP, namely the normalized PCT patent applications of a country and the IPR protection index. While we find a consistent positive and significant relationship for the former variable, the index turns out to be unrelated to the demand for external knowledge. Overall, these findings provide confidence in our main model results.

[Insert Table 5 about here]

DISCUSSION

Markets for technology are important institutions that facilitate vertical specialization and a division of labor in innovation, thereby increasing the allocative efficiency of innovation activities in a country (Arora *et al.*, 2001; Arora and Gambardella, 2010; Arora and Nandkumar, 2012). Despite their importance, our understanding of the development of such markets is surprisingly coarse. We know relatively little about what drives firms in certain industries to engage with the market for technology as customers. Our study is designed to delineate drivers of demand on markets for technology and map their presence across multiple countries and industries in Europe.

The analysis of 15 European countries over the period from 2008 to 2014 shows that the market size in those countries is substantial (5.2 billion Euro in 2008) but also volatile (2.8 billion Euro in 2012 and 3.0 billion Euro in 2014). Interestingly, we find that demand on markets for technology is pro-cyclical similar to other innovation inputs (Spescha and Woerter, 2018) and affected by the economic crisis in Europe after 2008. Economic downturns are accompanied by increased uncertainty within the business environment and declining demand increases the relative price of the innovative input. With the outcomes of innovation inputs typically becoming visible only with a 2-3 year time lag (Hall, Mairesse, and Mohnen, 2009), firms rely stronger on the exploitation of internal knowledge and capabilities rather than the exploration of something new (Teplykh, 2017). We find this logic to hold also in the context of demand for external knowledge on markets for technology. In that sense, our findings do not support the view that expenditures for external knowledge are not subject to cyclical fluctuations because in-licensing is an opportunity to utilize new technology at comparatively lower risk (López-García, Montero, and Moral-Benito, 2013).

Our results also show that the importance of the market for technology varies considerably among industries. We follow Pavitt (1984) and Castellacci (2008) with regard to the identification of sectoral patterns of innovation and show that markets for technology play a markedly different role in these patterns. We find firms in supplier-dominated industries to be considerably less likely to generate demand for external knowledge on markets for technology compared to other industry groups. In fact, firms in science-based industries are most likely to demand external knowledge, followed by firms in scale-intensive industries (positive results for specialized supplier industries are not consistently significant). This result is in line with prior literature given the ability of science-based industries to codify knowledge and the high propensity to protect inventions through patents (Arora *et al.*, 2001; Arora and Gambardella, 2010). Thus, a higher propensity to patent implies thicker markets for technology in science-based industries, which allows for higher allocative efficiency (Gans and Stern, 2010). Moreover, our results support the view that scale-intensive industries are important recipients of externally produced technology (Pavitt, 1984).

Next, we address the degree to which an industry in a country is positioned vis-à-vis the technological frontier (Kumar and Russell, 2002; Mahmood and Rufin, 2005). Apparently, industries at the technological frontier cannot rely on readily developed knowledge to keep pace with technological progress (Mahmood and Rufin, 2005). Indeed, we find striking evidence that industries spend more money on markets for technology the further away they are from the technological frontier. In that sense, markets for technology provide a means to catch up, at least to some extent, with the technological frontier. Our results also show that the extent to which lagging industries rely on external knowledge is not equally pronounced in the four industry groups. While firms in scale-intensive industries demand more external knowledge on markets when the industry is further away from the technological frontier, firms in science-based industries demand less when the industry is further away from the frontier. Apparently, when competitive advantage is based on innovative technologies, as for firms in science-based industries, using the market for technology is not a viable strategy. This finding underlines the heterogeneous response of firms within a certain pattern of innovation to being behind the technological frontier.

In sum, we contribute to extant literature in three ways. First, we identify structural features of industries that propel or constrain demand on markets for technology (Arora and Gambardella, 2010). We alleviate the strong and oftentimes implicit assumption in existing literature that demand on markets for technology is uniformly available. Instead, we identify two factors, sectoral innovation patterns and technological leadership of an industry that determine demand on markets for technology. We trace these industry differences back to how efficiently firms in an industry can acquire and absorb knowledge from markets for technology and how much value this particular knowledge creates when compared and combined with their internal R&D investments. Hence, we provide mechanisms, which other studies can use to (a) explore other sources of heterogeneity of demand on markets for technology and (b) avoid biased results in studies ignoring such heterogeneities. We demonstrate this heterogeneity by providing a systematic account of the demand side of markets for technology in Europe for the period from 2008 to 2014, differentiated by industry.

Second, we advance literature that analyses the consequences of industry differences in patterns of innovation activities and technological leadership by extending it to consequences for sectoral markets for technology. Prior literature has largely acknowledged that firms in certain sectors are more likely to rely on knowledge produced by others (e.g., Pavitt, 1984; Castellacci, 2008) but it does not consider the instruments by which firms can interact with knowledge producers in other firms or industries. Our focus on markets for technology is particularly relevant for studying sectoral innovation patterns since markets are arguably the most efficient mechanism to govern such interactions. Markets for technology offer considerable cost advantages and the flexibility associated with market transactions which can outweigh the advantages of other, more collaborative and relational forms of external knowledge acquisition (e.g., Laursen and Salter, 2006). In sum, we extend the literature on sectoral innovation patterns by highlighting how buying knowledge on markets for technology is an integral part of innovation in science-based industries and to a lesser degree in scale-intensive ones. Moreover, we show that the demand on markets for technology depends on the industry's leadership status which highlights that industries benefit unevenly from developed markets because markets may simply not offer access to the most cutting-edge research but rather to a considerable amount of "shelf-warmer technologies" (Grimpe, 2006).

Third, our analysis provides an empirical platform that other studies can use to quantify the size of markets for technology in various industries and countries based on publicly available data from the CIS. Our data constitute a unique measure of the demand side which complements prior efforts in the literature that have focused on measures such as the supply of university patents (e.g., Arora and Nandkumar, 2012), or narrowly focused on industries with high patent propensity (e.g., Gambardella *et al.*, 2007). Hence, our research addresses not only the general shortage of data on these particular market transactions but can trigger future research on a variety of related topics, such as the interaction of markets for technology with firm strategies and particularly those directed at opening up the innovation process (Grimpe and Sofka, 2016).

Our findings have immediate relevance for policy making on markets for technology. Our mapping of demand on markets for technology allows tailoring innovation policies intended to expanding the overall size and utilization of markets for technology to specific industries. In that sense, science, technology and innovation (STI) policy needs to acknowledge that markets for technology are considerably driven by industry-related factors, such as the pattern of innovation and the technological sophistication, rather than by country-level factors. Consequently, policies should be sector-specific and take into account that the potentials for markets for technologies reach their limits when the technological sophistication of industries in certain countries increases.

CONCLUSION

While we provide comprehensive evidence on the development of markets for technology in Europe, our research is not free from limitations, which – at the same time – offer promising avenues for future research. Our data captures a specific view on the "true" size of the market for technology in Europe for several reasons. First, the coverage of the data is incomplete due to individual agreements between the EU member countries and Eurostat. Second, the questionnaire structure does not allow drawing any conclusions on the demand for external knowledge on the European market by foreign firms, which are not part of the sampled population of firms in the EU member states. Third, our measure for the demand of markets for technology comprises only realized demand. Prior literature, however, emphasizes that a considerable part of technology deals remains unrealized due to market imperfections.

Future research should therefore broaden the basis on which the demand on markets for technology can be estimated. Moreover, there are probably additional important explanatory variables that could improve our understanding of what shapes market demand. Specifically, it would be interesting to contrast data on expenditures with data on revenues on markets for technology. This would enable an investigation of the relationships regarding the flow of disembodied technological knowledge between and across firms in different sectoral patterns (Pavitt, 1984).

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TABLES

Table 1: Expenditures for other external knowledge by year, industry-group and country (Source: own calculations based on Eurostat data)

	Expenditures in Euro per 1000 Euro sales				Expenditures as a share of in-house R&D			
	2008	2010	2012	2014	2008	2010	2012	2014
Supplier-dominated industries								
Austria	0.055	0.020	0.017	0.025	0.110	0.027	0.034	0.031
Belgium	0.030	0.044	0.019	0.020	0.037	0.072	0.032	0.044
Czech Republic	0.019	0.043	0.015	0.026	0.031	0.141	0.030	0.077
Estonia	0.019	0.043	0.007	0.009	0.186	0.179	0.049	0.051
Finland	0.098	0.106	0.031	0.018	0.180	0.187	0.059	0.036
France	0.022	0.040	0.042	0.014	0.034	0.034	0.045	0.016
Germany	0.075	0.054	0.038	0.039	0.121	0.065	0.043	0.045
Hungary	0.306	0.017	0.158	0.039	1.632	0.116	0.109	0.124
Italy	0.035	0.039	0.027	0.016	0.070	0.055	0.049	0.031
Latvia	0.008	0.006	0.000	0.004	0.191	0.233	0.009	0.045
Netherlands	0.014	0.021	0.006	0.014	0.039	0.053	0.019	0.041
Norway	0.035	0.021	0.024	0.036	0.054	0.035	0.031	0.046
Poland	0.008	0.008	0.006	0.006	0.090	0.087	0.047	0.050
Slovak Republic	0.025	0.008	0.002	0.064	0.148	0.020	0.009	1.238
Spain	0.007	0.001	0.003	0.011	0.019	0.003	0.008	0.021
Scale-intensive industries								
Austria	0.037	0.021	0.025	0.036	0.032	0.018	0.019	0.035
Belgium	0.016	0.038	0.029	0.005	0.028	0.072	0.054	0.010
Czech Republic	0.023	0.064	0.071	0.142	0.052	0.163	0.192	0.359
Estonia	0.018	0.036	0.030	0.009	0.064	0.045	0.019	0.021
Finland	0.048	0.031	0.018	0.017	0.056	0.030	0.017	0.021
France	0.093	0.047	0.017	0.045	0.059	0.032	0.011	0.032
Germany	0.089	0.071	0.061	0.043	0.055	0.035	0.033	0.021
Hungary	0.129	0.016	0.006	0.032	0.870	0.090	0.031	0.169
Italy	0.063	0.036	0.017	0.014	0.129	0.052	0.028	0.027
Latvia	0.004	0.019	0.008	0.007	0.138	0.486	0.299	0.104
Netherlands	0.013	0.031	0.004	0.009	0.021	0.034	0.004	0.013
Norway	0.008	0.018	0.016	0.053	0.012	0.029	0.021	0.072
Poland	0.009	0.025	0.008	0.008	0.075	0.139	0.062	0.041
Slovak Republic	0.121	0.025	0.050	0.084	1.638	0.148	0.408	0.411
Spain	0.117	0.114	0.084	0.070	0.317	0.234	0.191	0.174
Specialized suppliers								
Austria	0.067	0.078	0.039	0.074	0.016	0.015	0.009	0.015

	Expenditures in Euro per 1000 Euro sales				Expenditures as a share of in-house R&D			
	2008	2010	2012	2014	2008	2010	2012	2014
Belgium	0.032	0.043	0.052	0.086	0.012	0.016	0.021	0.037
Czech Republic	0.027	0.028	0.160	0.101	0.037	0.034	0.171	0.096
Estonia	0.004	0.030	0.015	0.005	0.010	0.076	0.026	0.010
Finland	0.039	0.054	0.013	0.024	0.014	0.018	0.004	0.008
France	0.061	0.042	0.006	0.161	0.032	0.028	0.003	0.072
Germany	0.066	0.056	0.038	0.046	0.026	0.016	0.011	0.013
Hungary	0.022	0.011	0.203	0.283	0.074	0.031	0.038	0.776
Italy	0.065	0.065	0.044	0.029	0.064	0.043	0.038	0.024
Latvia	0.004	0.000	0.114	0.005	0.133	0.007	0.840	0.040
Netherlands	0.021	0.025	0.012	0.019	0.007	0.007	0.003	0.005
Norway	0.008	0.012	0.026	0.088	0.006	0.011	0.021	0.059
Poland	0.066	0.038	0.063	0.041	0.190	0.076	0.130	0.084
Slovak Republic	0.066	0.079	0.008	1.115	0.157	0.183	0.014	2.304
Spain	0.003	0.006	0.003	0.009	0.004	0.006	0.002	0.008
Science-based industries								
Austria	0.068	0.053	1.281	0.305	0.006	0.005	0.092	0.034
Belgium	0.225	0.938	0.345	0.132	0.017	0.078	0.034	0.009
Czech Republic	0.086	0.220	0.029	0.052	0.133	0.354	0.046	0.058
Estonia	1.110	0.010	0.020	0.001	2.081	0.030	0.031	0.003
Finland	0.042	0.042	0.042	0.042	0.004	0.004	0.004	0.004
France	0.408	0.125	0.082	0.136	0.091	0.024	0.017	0.026
Germany	0.254	0.183	0.155	0.137	0.046	0.026	0.022	0.016
Hungary	0.054	0.036	0.035	0.115	0.054	0.038	0.018	0.080
Italy	0.138	0.130	0.091	0.093	0.041	0.036	0.052	0.029
Latvia	0.039	0.047	0.000	0.022	0.013	0.037	0.000	0.016
Netherlands	0.142	0.194	0.161	0.055	0.016	0.028	0.019	0.020
Norway	0.050	0.080	0.118	0.222	0.006	0.012	0.016	0.052
Poland	0.093	0.301	0.086	0.123	0.106	0.705	0.105	0.150
Slovak Republic	0.000	0.072	0.002	0.294	0.001	0.442	0.009	1.278
Spain	0.077	0.031	0.014	0.017	0.025	0.010	0.004	0.005

Table 2: Summary statistics (n=1249)

	Mean	St.Dev	min	max
Expenditures for other external knowledge (log.)	6.553	2.797	0	13.327
R&D as a share of sales	1.128	2.090	0	26.348
Number of employees	71958.84	116000	87	1035370
Average firm size	112.569	188.567	17.4	3675.75
Share of collaborating firms	0.185	0.150	0	1
GERD as a share of GDP	1.737	0.798	.462	3.726
Imputation dummy (d)	0.002	0.040	0	1
Supplier-dominated industries (d)	0.355	0.479	0	1
Scale-intensive industries(d)	0.440	0.497	0	1
Specialized supplier industries (d)	0.128	0.334	0	1
Science-based industries (d)	0.077	0.266	0	1
Distance to technological frontier	2.375	3.552	0	26.332

Table 3: Correlation coefficients (n=1249)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) R&D as a share of sales	1									
(2) Number of employees (log.)	0.014	1								
(3) Average firm size (log.)	0.311	0.027	1							
(4) Share of collaborating firms	0.488	-0.274	0.561	1						
(5) GERD as a share of GDP	0.197	0.043	0.101	0.328	1					
(6) Imputation dummy (d)	-0.002	0.008	0.032	0.019	-0.051	1				
(7) Supplier-dominated industries (d)	-0.221	-0.136	-0.441	-0.312	0.054	-0.030	1			
(8) Scale-intensive industries (d)	-0.095	0.121	0.304	0.134	-0.004	0.005	-0.658	1		
(9) Specialized supplier industries (d)	0.100	0.082	-0.007	-0.024	-0.019	-0.015	-0.284	-0.340	1	
(10) Science-based industries (d)	0.450	-0.084	0.233	0.341	-0.066	0.064	-0.214	-0.256	-0.111	1
(11) Distance to technological frontier	0.105	-0.108	0.357	0.220	-0.192	0.060	-0.306	-0.124	0.195	0.536

Table 4: OLS regressions for the demand on markets for technology – main models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
R&D as a share of sales	0.305***	0.195***	0.263***	0.220***	0.205***	0.221***	0.193***
	(0.050)	(0.056)	(0.051)	(0.057)	(0.057)	(0.057)	(0.059)
R&D as a share of sales (sq.)	-0.016***	-0.011***	-0.012***	-0.011***	-0.011***	-0.011***	-0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Number of employees (log.)	1.203***	1.182***	1.250***	1.217***	1.242***	1.219***	1.214***
	(0.050)	(0.051)	(0.050)	(0.052)	(0.052)	(0.053)	(0.052)
Average firm size (log.)	0.265***	0.195**	0.143	0.099	0.057	0.096	0.108
	(0.089)	(0.093)	(0.092)	(0.098)	(0.098)	(0.099)	(0.098)
Share of collaborating firms	2.095***	1.468***	1.886***	1.467***	1.566***	1.474***	1.440***
	(0.517)	(0.526)	(0.514)	(0.524)	(0.523)	(0.526)	(0.524)
GERD as a share of GDP	0.757**	0.765**	0.741**	0.757**	0.784**	0.757**	0.768**
	(0.350)	(0.346)	(0.346)	(0.345)	(0.344)	(0.345)	(0.345)
Imputation dummy (d)	4.142***	3.857***	3.968***	3.823***	3.946***	3.819***	3.972***
	(1.174)	(1.164)	(1.164)	(1.160)	(1.156)	(1.161)	(1.162)
Scale-intensive industries (d)		0.357***		0.343***	0.186	0.340***	0.339***
		(0.120)		(0.120)	(0.128)	(0.121)	(0.120)
Specialized suppliers (d)		0.350**		0.159	0.318*	0.176	0.149
		(0.160)		(0.172)	(0.178)	(0.194)	(0.172)
Science-based industries (d)		1.235***		0.792***	1.225***	0.766**	1.521***
		(0.236)		(0.279)	(0.306)	(0.310)	(0.490)
Distance to techn. frontier			0.075***	0.056***	0.012	0.059**	0.068***
			(0.015)	(0.019)	(0.023)	(0.024)	(0.020)
Distance * scale-intensive					0.114***		
					(0.034)		
Distance * specialized suppl.						-0.007	
						(0.035)	
Distance * science-based							-0.082*
							(0.045)
Constant	-8.348***	-7.793***	-8.319***	-7.801***	-7.949***	-7.815***	-7.811***
	(1.138)	(1.147)	(1.128)	(1.143)	(1.139)	(1.146)	(1.142)
Year dummies	included	included	included	included	included	included	included
Country dummies	included	included	included	included	included	included	included
R2	0.667	0.675	0.673	0.677	0.680	0.677	0.678
N	1249	1249	1249	1249	1249	1249	1249
F	102.160	93.730	100.830	91.270	89.240	88.050	88.390
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Coefficients are shown; standard errors in parentheses; (d) dummy variable; * p<0.10, ** p<0.05; *** p < 0.01. Country dummies and year dummies are each jointly significant

Table 5: OLS regressions on demand on markets for technology – robustness checks

	(1)	(2)	(3)
R&D as a share of sales	0.223***	0.216***	0.211***
	(0.059)	(0.057)	(0.057)
R&D as a share of sales (sq.)	-0.010***	-0.010***	-0.010***
	(0.003)	(0.003)	(0.003)
Number of employees (log.)	1.210***	1.221***	1.220***
	(0.053)	(0.052)	(0.052)
Average firm size (log.)	0.210**	0.107	0.100
	(0.094)	(0.098)	(0.098)
Share of collaborating enterprises	1.443***	1.429***	1.476***
	(0.530)	(0.524)	(0.526)
GERD as a percentage of GDP	0.712**		
	(0.347)		
PCT patent applications per billion GDP		0.700***	
		(0.228)	
Intellectual property protection index			-0.232
			(0.310)
Imputation dummy (d)	3.910***	3.854***	3.819***
	(1.165)	(1.158)	(1.162)
Scale-intensive industries (d)	0.326***	0.331***	0.337***
	(0.122)	(0.120)	(0.120)
Specialized suppliers (d)	0.332**	0.145	0.153
	(0.164)	(0.172)	(0.173)
Science-based industries (d)	1.167***	0.788***	0.791***
	(0.244)	(0.278)	(0.279)
Distance to technological frontier		0.057***	0.057***
		(0.019)	(0.019)
Alternative measure for distance to technological frontier	-0.187*		
	(0.109)		
Constant	-7.982***	-10.936***	-4.552**
	(1.162)	(1.806)	(1.882)
Year dummies	included	included	included
Country dummies	included	included	included
R2	0.675	0.678	0.676
N	1233	1249	1249
F	89.180	91.770	90.800
P-value	0.000	0.000	0.000

Coefficients are shown; standard errors in parentheses; (d) dummy variable; * p<0.10, ** p<0.05; *** p < 0.01. Country dummies and year dummies are each jointly significant

FIGURES

Figure 1: Total expenditures for external knowledge on markets for technology by industry group

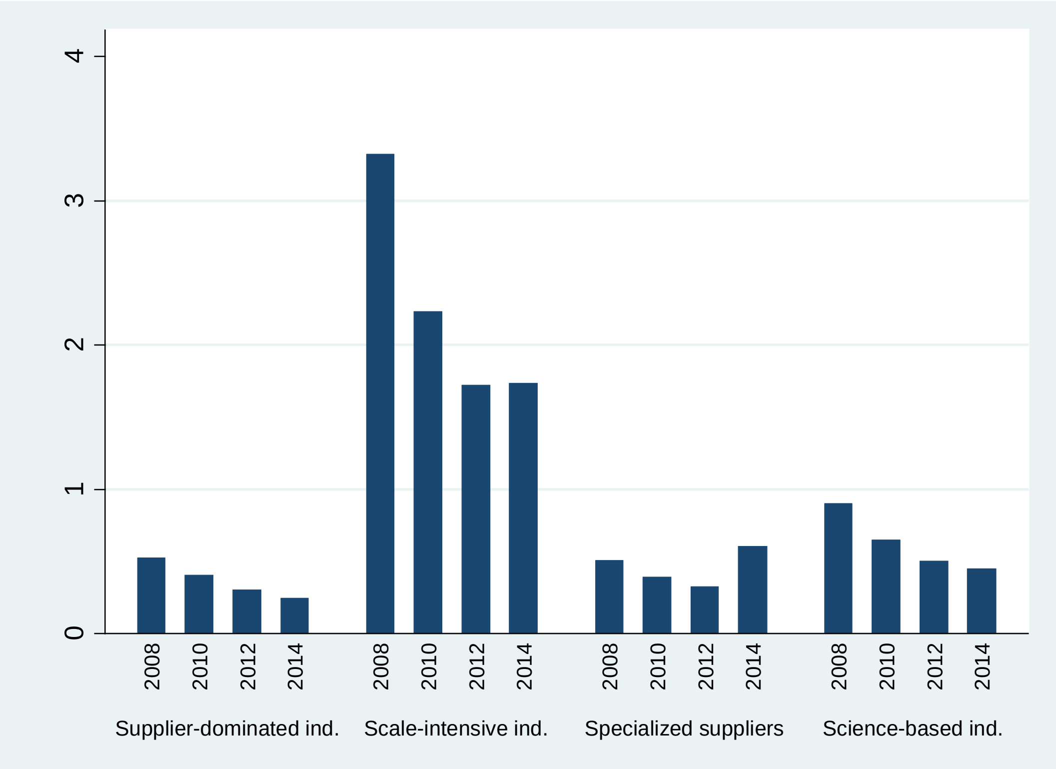


Figure 2: Total expenditures for external knowledge on markets for technology by industry group (normalized with in-house R&D expenditures)

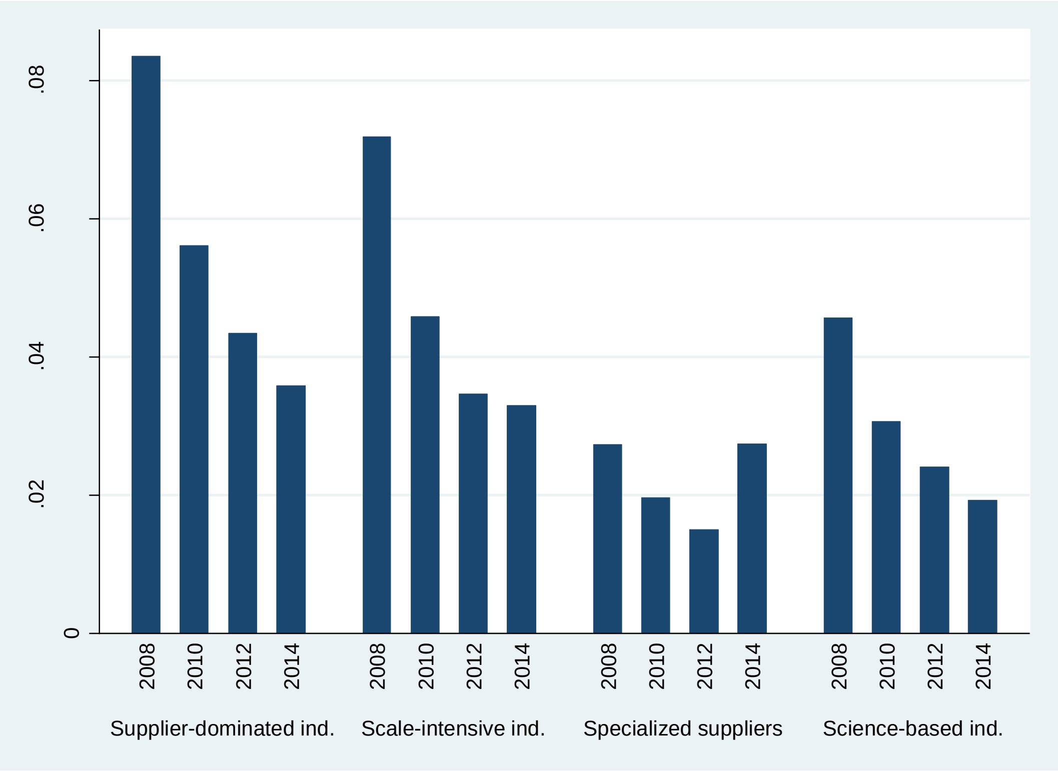
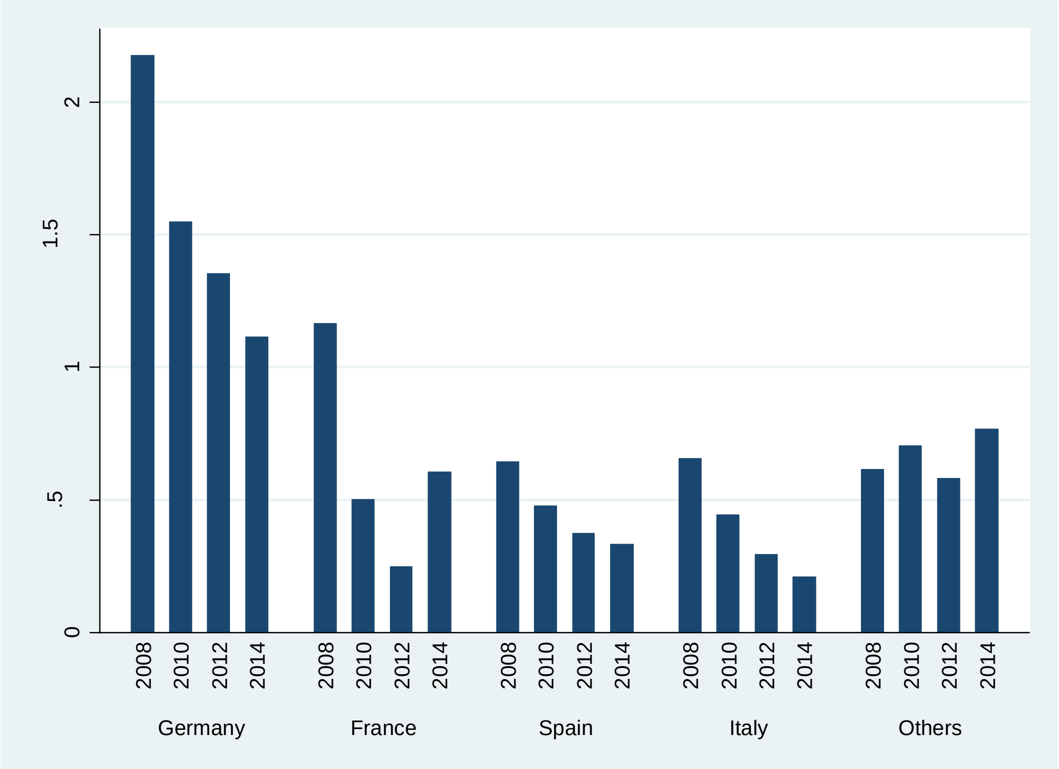
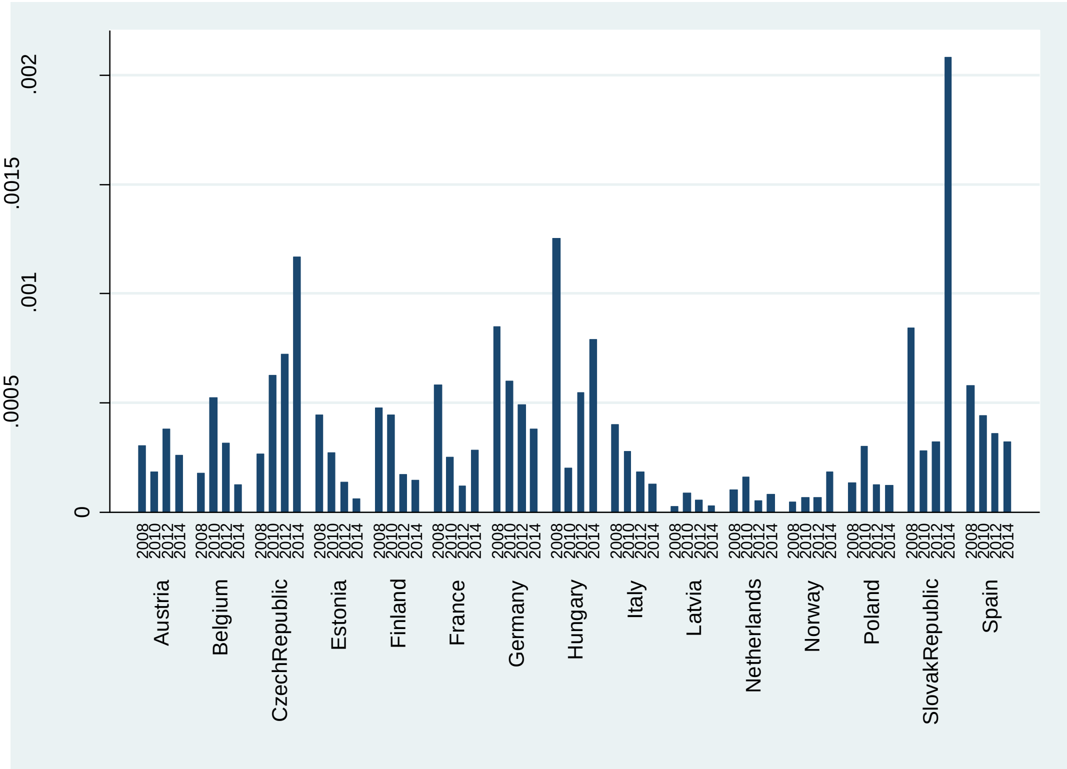


Figure 3: Total expenditures for external knowledge on markets for technology by country[5]



[5] The values for Germany could not be obtained from the survey in 2010. They were imputed with the average values from the survey waves in 2008, 2012 and 2014.

Figure 4: Expenditures for external knowledge on markets for technology (normalized with GDP)[6]



[6] The values for Germany could not be obtained from the survey in 2010. They were imputed with the average values from the survey waves in 2008, 2012 and 2014.

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