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External Knowledge, R&D, and Innovation: Mapping the Market for Technology Across European Industries

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ABSTRACT: A well-functioning market for technology, or ideas, is an important determinant for the type, scope, and distribution of innovation activities. We use a panel of 20 industries across 24 European countries to study the key determinants driving the market for technology. We explore whether the expenditures on external knowledge depends on the sectoral pattern of innovation and an industry's distance to the global technological frontier. Disseminating knowledge and technology within the industry, bringing it closer to the global technological frontier, tends to reduce the expenditures for external knowledge except in supplier-dominated industries. We also find important complementarity effects in the market for external knowledge. Industries with high R&D spending, with increasingly large firms, and with large investments in machinery and software foster growth of the market for technology. Our findings suggest tailoring innovation policies to help expand both the size of the market for technology and the use of these markets in specific industries.

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WORKING PAPERS

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Contents

INTRODUCTION

The market for technology, covering the exchange of external knowledge, for example, through licenses, is a crucial instrument for many firms searching for and acquiring external knowledge for their innovation processes (Arora *et al.*, 2001; Arora *et al.*, 2010; Arora *et al.*, 2012; Grimpe *et al.*, 2016). In this market, also referred to as the market for ideas (Gans *et al.*, 2003, 2010; Agrawal *et al.*, 2015), knowledge is traded at a certain price, for example, by transferring the intellectual property (IP) or granting licenses. Research suggests that the market for technology can be an important institution for allowing vertical specialization and improving the allocative efficiency of innovation activities (Monk, 2009). In other words, such markets determine which firms produce new technologies and which ones commercialize them (Arora *et al.*, 2001; Agrawal *et al.*, 2015). At the same time, studies also highlight that markets for technology are underdeveloped or inefficient (Gans *et al.*, 2008; Gans *et al.*, 2010; Kani and Motohashi, 2012), suggesting mostly imperfections in the market design or the unwillingness of suppliers to offer technologies (Agrawal *et al.*, 2015).

Despite the previous work, we still have little comprehensive insights into the factors that drive the size of the market for technology as well as structural forces that shape the demand in this market (Arora *et al.*, 2010). This study seeks to address these shortcomings and identifies heterogeneities in the demand in the market for technology. The previous literature on markets for technology is almost exclusively focused on the supply side issues. However, heterogeneities on the demand side deserve attention given the distinct sectoral patterns of technical change (Pavitt, 1984) as well as substantial evidence that industries differ widely as to how firms in those industries value the acquisition of technologies in this market (e.g., Grimpe *et al.*, 2016). An empirical investigation is warranted to uncover heterogeneity across industries and countries, exploring existing theory while enabling further theorizing that takes heterogeneity into account.

We seek to explain the realized market demand for technology— expenditures on external knowledge—by examining key industry level drivers.[1] We proxy the realized demand by the expenditures on external knowledge since it is not possible to disentangle the price and quantity of the technology traded on the market. More specifically, we explore if internal R&D spending and realized demand for machinery or software in an industry act as a substitute or complement to the realized demand for external knowledge at the industry level. The former indicates direct interactions with an industry's knowledge production (via internal R&D) while the latter can provide insights into indirect non-R&D effects in which the market for technology is interconnected with the procurement of physical or digital assets, i.e., machinery or software. We also examine the sectoral patterns of technical change, describing the nature of the innovation activities in a specific industry (Pavitt, 1984), an industry's average firm size, and the distance of the industry in a country to the global technological frontier (Kumar *et al.*, 2002; Mahmood *et al.*, 2005). Pavitt's (1984) taxonomy of industries into supplier dominated[2], scale intensive[3], specialized supplier[4], and science-based industries[5] (described below) explicitly discusses the division of innovative labor. Moreover, the division of innovative labor has been characterized by knowledge and technology flows across countries (e.g., Belderbos *et al.*, 2020), which suggests that an industry's position vis-à-vis the global technological frontier is an important determinant of realized demand.

[1] The presence of many potential buyers and suppliers in the market for technology allows the market to match them efficiently (Roth, 2007; Gans *et al.*, 2010). Otherwise, it fails (Agrawal *et al.*, 2015).

[2] For example, manufacturing of textiles or paper.

[3] Manufacturers of chemicals or the automobile industry.

[4] Manufacturers of machinery or electrical equipment.

[5] Pharmaceuticals or electronics.

Uncovering structural heterogeneity in the market for technology requires a research design that can systematically and consistently cover these markets across countries and industries. We use the industry-level data from the Community Innovation Survey (CIS) across 20 different industries in 24 European countries over an eight-year period and estimate correlations rather than causal associations. With this qualification in mind, we find that internal R&D spending and realized demand for machinery and software are complementary to expenditures on external knowledge in the market for technology at the industry level, suggesting that these investments may have positive spillovers on innovation activities. Technological distance of the industry to the global frontier has a heterogeneous effect across different types of industries. Scale intensive and specialized supplier industries that are comparatively more distant from the global technological frontier increase the realized demand in the market for technology, whereas supplier-dominated industries do so when they are closer to the frontier. The global technological distance does not seem to matter for science-based industries. Moreover, larger firms in an industry create more demand in the market for technology. All in all, we find that buying knowledge in the market for technology is an integral part of sectoral innovation patterns in some industries, depending on the technological distance, while industry characteristics such as internal R&D and firm size are important in driving the realized demand for technology.

These empirical insights contribute to the literature on markets for technology in at least three ways. First, we identify structural features of the industries that propel or constrain demand in the market for technology (Monk, 2009; Arora *et al.*, 2010). While firms may have individual motives for trading technologies (Atuahene-Gima *et al.*, 1993), the aggregation to the industry level, reducing idiosyncratic factors, may prove useful since decision makers are similarly affected by industry specific environments, which can be influenced by government policy (Pavitt, 1984; Teece, 1986). Using industry-level data, we show that the realized demand for technology depends on sectoral innovation patterns, key industry characteristics, and technological leadership positions of countries in specific industries. Complementarities with internal R&D and expenditures on machinery and software are especially important for external knowledge acquisition.

Second, our research advances literature that analyzes the effects of industry differences in patterns of innovation activities and technological leadership by extending it to sectoral markets for technology. While this stream of literature takes into account that innovation in an industry depends on knowledge production by other firms or sectors (e.g., Pavitt, 1984; Castellacci, 2008), we know little about whether this interaction among firms can be accomplished via markets, arguably the most efficient form of economic interaction. 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 *et al.*, 2006).[6]

Third, our analysis provides an empirical exploration into the market for technology in various industries and countries in Europe. 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 the transaction value, reaching about $100 billion. Robbins (2006) estimates the total income from licensing in the United States in 2002 to be about $50 billion. These estimates, however, typically do not disaggregate the market size per industry or they are only focused on single industries like pharmaceuticals. We calculate aggregate firm expenditures in the market for technology in 20 different industries across 24 European countries over eight years. The data

[6] Moreover, the notion that the demand in the market 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, encourage "shelf-warmer technologies" (Grimpe, 2006) that may not advance innovation in the leading industries (Grimpe *et al.*, 2016).

complement prior efforts in the literature that have concentrated on measures such as the supply of university patents (e.g., Arora *et al.*, 2012), or narrowly focused on industries with high patent propensity (e.g., Gambardella *et al.*, 2007).[7] To our knowledge, the paper not only uses the broader data across European industries but also explores key determinants of the realized demand in the market for technology.

Theory Review: Market Size and the Nature of Demand

We provide a structured review of the literature on the drivers of markets for technology in two steps. First, we review central theoretical mechanisms determining the size of the market for technology and the nature of the demand. Second, we introduce theory to uncover sectoral patterns of realized demand in the market for technologies, i.e. sectoral patterns of technological change, and technological leadership of industries. The theoretical discussion motivates the empirical analysis in the next section.

A. The Size of the Market for Technology

The size of the market for technology depends on the presence of supply of and demand for technologies as well as the efficiency of market mechanisms. Obviously, the extent to which firms can acquire technology in the market, that is, the realized demand, depends on which technologies are being made available through suppliers such as universities, research institutes, and other firms. The previous literature on market design (Roth, 2007; Gans *et al.*, 2010) indicates 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, market thickness directly relates to supply of and demand for technologies.[8] Thicker markets exhibit greater supply of and demand for technologies.

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 *et al.*, 2001; Gans *et al.*, 2003). Conversely, firms that possess complementary assets do not need to invest in the development of new technologies because they can simply buy them in the market for technology (Arora *et al.*, 2012).

The market thickness in the markets for technology differs across industries. The important determinants of market thickness are the nature of the knowledge that is tradable and the institutional rules, especially rules on

[7] Our research addresses not only the general shortage of data in these particular market transactions but can potentially pave the way for future research on a variety of related topics such as the interaction of markets for technology with firm strategies, particularly those directed at opening up the innovation process (Grimpe *et al.*, 2016).

[8] Market thickness implies that the 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 market interactions. 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 *et al.*, 2010). However, many market transactions do not emerge in such a clear-cut form. They can be embedded, for instance, in alliance agreements (Arora *et al.*, 2001), or they reduce merely search costs by providing limited services such as brokerage, auctioning, or online presentation (Yanagisawa *et al.*, 2009; Dushnitsky *et al.*, 2011).

IP protection, which govern potential market transactions. First, knowledge traded in the markets needs to be codified, that is, documented, for example, in a patent that can be used for a licensing contract. Although, in principle, all knowledge can be codified, the costs of doing so can be excessive (Conti *et al.*, 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 that determine the extent to which firms can capture the returns to their innovations are driven by the legal and technological conditions in an industry (Teece, 1986). As misappropriation risks increase, fewer knowledge producers are willing to offer knowledge in the market for technology (Gans *et al.*, 2008). The low levels of patented knowledge combined with significant inter-industry differences consequently affect the functioning of markets for technology.[9]

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 *et al.*, 2014). Moreover, the market mechanism requires that the knowledge is largely ready to use, i.e. not requiring further interaction with the knowledge producer (Conti *et al.*, 2013).

B. The Nature of Realized Demand in the Market for Technology

In many industries in which competitive advantage is based on rapidly changing technologies, the sole reliance on internal resources is often overly costly and time consuming even for technologically advanced firms (Motohashi, 2008). The market for technology is an option to supplement the internal knowledge base and to widen the strategic opportunities of buyers (Arque-Castells *et al.*, 2018). The use of internal and external knowledge sources offers additional opportunities for recombination, that is, the purposeful combination of knowledge elements to generate innovation, which can improve innovation performance (Rosenkopf *et al.*, 2001).[10] Combinations from external and internal knowledge sources include idiosyncratic elements that delay the imitation of innovations by competitors (Kogut *et al.*, 1992).

External knowledge sourcing does not occur in isolation but is strongly linked to the capabilities and assets of firms 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, typically a by-product of internal R&D efforts, to commercial ends (Cohen *et al.*, 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 *et al.*, 2013). In that sense, existing research has shown that internal and external R&D are complements rather than substitutes (Cassiman *et al.*, 2006; Ceccagnoli *et al.*, 2014).

[9] 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 substantial 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.

[10] Firms can obtain external knowledge through relational or transactional mechanisms (Grimpe *et al.*, 2016). Relational mechanisms include – among other channels – R&D collaborations (e.g., Fitjar *et al.*, 2013), consortia (e.g., Branstetter *et al.*, 2002), and consulting (e.g., Grimpe *et al.*, 2013). Transactional modes include R&D outsourcing (e.g., Grimpe *et al.*, 2010), mergers and acquisitions (e.g., Ahuja *et al.*, 2001), and the purchase of external knowledge in the form of patents, non-patented knowledge, and licensing agreements on markets for technology (e.g., Ceccagnoli *et al.*, 2013). Relational and transactional modes of external knowledge sourcing are not mutually exclusive but may overlap, for example, in technology alliances (Grimpe *et al.*, 2016).

All in all, we conclude that the realized demand for technology emerges from expectations of prospective buyers in an industry about (a) the knowledge on markets for technologies that can be effectively and efficiently acquired and absorbed and (b) the prospective contribution of the acquired knowledge to a firm's innovation performance relative to internal R&D efforts.

C. Drivers of the Realized Demand for Technology

We contend that the considerations of firms to buy knowledge in the market for technology are to a substantial degree shaped by the product market and technological environments in an industry. We emphasize two industry features that are likely to determine the realized demand in a specific industry: the industry, or sectoral, patterns of innovation, and the industry's distance to the technological frontier.

We start by exploring differences in technological change and innovation across industries. Knowledge is cumulative in nature and produces a knowledge base in an industry that largely differs in the means of knowledge creation, the sources of new knowledge, and 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 (de Jong *et al.*, 2006; Pavitt, 1998). In his 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.

Science-based industries use a complex knowledge base, and technology is produced to a considerable extent through internal R&D (Pavitt, 1984). Firms in these industries are typically large, and the 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 often be protected through patents (Pavitt, 1984). Examples of science-based industries are the pharmaceutical or electronics industries.

Specialized suppliers are typically smaller firms, which produce advanced machinery for 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). Dominant mechanisms of appropriability are not just patenting but also superior designs and know-how as well as access to tacit user knowledge (Pavitt, 1984). Typical specialized supplier industries are manufacturers of machinery and electrical equipment.

Scale-intensive industries are strongly linked to specialized suppliers (Pavitt, 1984). Firms in scale-intensive industries rely on complex knowledge, which is rooted in operative efficiency rather than in scientific principles (Castellacci, 2008). The exploitative use of external technology benefits from economies of scale or scope, i.e. serving substantial product markets or relying on large plants (Pavitt, 1984). Typical scale-intensive industries are manufacturers of chemicals, rubber and plastic products, and consumer durables, and the automobile industry.

Finally, supplier-dominated industries have some internal R&D capabilities but mainly source disembodied technology from suppliers for cost reasons (Pavitt, 1984). The central means of appropriation are trademarks, aesthetic differentiation, design and marketing activities. Representative supplier-dominated industries include the manufacturing of leather, textiles and paper, and agriculture.

Pavitt's (1984) taxonomy suggests that there is a division of innovative labor across industries (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 among 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 of patents is less common in scale-intensive and supplier-dominated industries. The codification of knowledge and the protection through patents are generally regarded as a prerequisite for trading technology on markets (Arora *et al.*, 2001). Both factors are likely to positively influence the realized market demand for technology. In addition, an industry's technological advancement and reliance on complex knowledge may also create incentives to procure knowledge in the market for technology.

In addition to industry patterns of innovation, another important dimension in the realized demand for technology is how closely an industry operates to the industry's technological frontier.[11] Industries at the technological frontier are forced to keep pace with technological progress and can hardly rely on established knowledge traded in the market for technology (Mahmood *et al.*, 2005). Their competitive advantage is anchored in yet unknown re-combinations of diverse knowledge.[12] Grimpe and Sofka (2016) argue that lagging industries, that is, those that are farther away from the technological frontier, are comparatively more likely to benefit from mature technologies in the market for technology. Lagging industries rely on "off the shelf" technologies and efficient implementation instead of creating a new technology (Arora et al., 2001). Compared with technology leaders, laggards can rely on imitation and purchases of technologies that makes their technological development efficient and predictable but rarely novel (Mahmood *et al.*, 2005). Globally lagging industries are particularly likely to source technologies in the market for technology.

Data and Methods

A. Data

We use the 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 *et al.*, 2006; Laursen *et al.*, 2006; Grimpe *et al.*, 2016). Since Pavitt's taxonomy only covers manufacturing industries, we restrict our analysis to manufacturing industries (NACE Rev. 2 codes 10-33). The survey includes 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

[11] The concept of a technological frontier suggests that industries or firms in a region or worldwide are sorted according to their level of technological advancement (Mahmood *et al.*, 2005; Kumar *et al.*, 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 (Belderbos *et al.*, 2020).

[12] Firms in leading industries typically acquire external knowledge through relational rather than transactional mechanisms because the degree of novelty of knowledge traded in the market for technology tends to be lower (Grimpe *et al.*, 2016). Moreover, knowledge traded is of comparatively lower complexity (Caviggioli *et al.*, 2017). In fact, firms with advanced internal R&D capabilities have been shown to internalize the development of new technologies instead of purchasing technology on markets (Atuahene-Gima *et al.*, 1993).

purpose of our study since it enables us to track realized demand in the market for technology separately from other R&D investments for a wide variety of industries and countries.

As CIS is a bi-annual survey, we use the survey waves in 2008, 2010, 2012 and 2014.[13] 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).[14] 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.[15] The collected data are extrapolated with the appropriate weighting scheme for obtaining the population totals.

Our analysis uses data from 24 European countries.[16] These are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, and Spain. Data on some industries in some countries and years are missing, and our final dataset has 1584 observations on the industry level by country and year. The industry level data from the CIS are complemented with country-level data from the European Innovation Scoreboard, the Global Competitiveness Index of the World Economic Forum, and OECD statistics.

As a caveat, the data used capture a specific view on the “true” size of the market for technology in Europe. 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 realized 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 in the market for technology comprises only realized demand. Prior literature, however, emphasizes that a considerable part of technology deals remains unrealized due to market imperfections. Fourth, not all firms in a specific industry necessarily follow the typical pattern of technological change. Fifth, we capture an equilibrium outcome in the market for technology. Movements in the market might be driven by supply or demand considerations. While we cannot make claims on causality, investments in internal R&D and equipment are generally precursors for the development of innovation capabilities in firms, which might enable firms to become buyers on the market for technology. Sixth, knowledge acquisition might also come in the form of hiring new R&D personnel. The data do not allow us to isolate this mechanism or compare it to expenditures.

B. Variables

To measure the realized demand in the market for technology, i.e. our dependent variable, we use data from the question regarding the expenditures for “other external knowledge.” The CIS questionnaire clarifies that

[13] 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.

[14] 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 *et al.*, 2006). Response accuracy is increased by the provision of detailed definitions and examples of the underlying concepts.

[15] Any cross-country dataset raises the question as to how comparable the data, which the different statistical offices in the EU member states collect, are. CIS surveys follow the Oslo Manual that provides a harmonized framework for data collection (OECD, 2005). Moreover, together with the national statistical offices, Eurostat has implemented several measures that seek to ensure the comparability of the obtained data across countries (Eurostat, 2009).

[16] 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.

these expenditures include those for the “purchase or licensing of patents and non-patented inventions, know-how, and other types of knowledge from other enterprises or organisations.” The variable does not include expenditures for external R&D in general or for external knowledge embodied in machinery, equipment, or software. It is the extrapolated sum of the expenditures for such external knowledge by country, industry, and year. The dependent variable captures only the realized demand, rather than the “deals not done,” in the market for technology at the industry level (Agrawal *et al.*, 2015).[17,18]

The explanatory variables included in the analysis include key industry characteristics such as sectoral patterns of innovation, technological distance, and internal R&D expenditures. We separate external R&D expenditures from internal R&D because external R&D services are provided from outside parties and unlikely to constitute technological capabilities or absorptive capacities inside the firm. Further, we would have liked to consider the cumulative effect of internal R&D investments, but the time structure of the data is not well suited for calculating R&D stocks.

To identify the industries that belong to specific patterns of innovation (Pavitt, 1984; Castellacci, 2008), we follow the approach of Bonaccorsi *et al.* (2013), who map NACE industry codes onto Pavitt’s taxonomy. We create four dummy variables measuring the sectoral patterns of innovation. 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; and all other NACE codes cover supplier-dominated industries (Appendix Table 1).

To measure an industry’s distance to the global technological frontier, we follow the previous literature and use relative R&D expenditures as a proxy for an industry’s position vis-à-vis the technological frontier (e.g., Chung *et al.*, 2002; Grimpe *et al.*, 2016; Belderbos *et al.*, 2020).[19] To measure distance to the frontier, we follow Salomon *et al.* (2008) and calculate the distance to the technological frontier by normalizing the country-industry’s internal R&D expenditure by the country’s GDP and subtract the average of all other countries’ R&D to GDP ratios. Increasing values of the variable indicate relative technological leadership (i.e. decreasing distance to the technological frontier). This measure allows us to stay consistent with prior research but may be sensitive to the size of the industry in a country. Hence, we use also an alternative measure: The difference between the R&D intensity (internal R&D expenditures divided by sales) of a specific industry in a country from the corresponding technological frontier, computed as the highest value of the R&D intensity in an industry across all the countries in the sample.[20] Increasing values indicate a larger distance to the technological frontier.

We explore the importance of R&D and spending on equipment and software and examine whether they are complements or substitutes to the realized demand for technology in the market. We use the industry R&D

[17] Our measure of demand reflects the equilibrium outcome of realized demand and supply. With the cross-country data, we are unable to control for the actual supply of technologies in the market.

[18] A limitation of the measure used is that it does not provide information on the country of the licensor or seller of the technology. It is therefore impossible to isolate, for example, the purchase and licensing from abroad or non-European parties. However, the previous literature provides strong evidence for the localization of knowledge spillovers and the importance of proximity to enable the transfer of knowledge (e.g., Jaffe *et al.*, 1993; Audretsch *et al.*, 1996), suggesting that national or intra-European activity constitutes the bulk of transactions. Moreover, the measure does not account for the actual number of transactions, and it is possible that the observed value could be due to a limited number of large transactions.

[19] An advantage of this relative variable is that it allows the measurement of leading/lagging industries relative to the frontier independently from industries’ overall R&D intensities, which are likely to capture other mechanisms such as absorptive capacity and can be used as a control variable in our model.

[20] 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, not worldwide.

intensity, defined as industry's internal R&D expenditures over sales, as a measure of input innovation as well as a proxy for the industry's absorptive capacity (e.g., Laursen *et al.*, 2006). Given that the data are at the industry level, we cannot exclude the possibility that expenditures for external knowledge and internal R&D are substitutes at the firm-level when production functions substantially diverge among firms. Our reasoning on complementarity effects at the firm level requires the assumption of a homogeneous production function. To account for a potential nonlinearity of the relationship, we also include a squared term of the industry's R&D intensity. We also include industry's spending on machinery equipment and software, which is important to account for in the industry's investment in innovation.

We further use several control variables at the industry and the country level that could potentially influence the degree to which industries demand technology in the market. We include the average firm size defined as the total number of employees over the number of firms in an industry in order to measure an industry's structure (in logarithm). Since transactions in the market for technology generally occur in connection with relational search, that is, collaborations in innovation projects (Grimpe *et al.*, 2016), we include the share of firms that have any external collaborative activities. In addition, we also test whether other collaborative activities are relevant in the market demand for technology.

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 *et al.*, 2010). GERD covers the total R&D expenditures in a country by domestic and foreign actors like firms, research institutes, and universities. Alternatively, we use a a proxy for the output of the national innovation system by measuring the number of PCT patent applications per GDP (in billion euros). Moreover, we use a variable that 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). The variable is 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. Lastly, our regressions include country, industry, and year dummy variables, or fixed effects, to control for time-invariant heterogeneity and common time effects.

C. Empirical Approach

Since the dependent variable, spending in the market for technology, has a substantial amount of zeros (about 10 percent of the sample size), we account for the problem of zeros using an iterated OLS (iOLS) technique that is shown to have better properties than the pseudo-Poisson maximum likelihood estimator (Bellego, Benatia, and Pape, 2022). For comparison, we include the estimation with logarithm of spending as well, that is, discarding the zeros. The popular fix of *ln(1+x)* is not a good approximation since the dependent variable is not substantially below one. We use robust standard errors in the regressions.[21] The estimated relationships, however, are not necessarily causal because of the endogeneity of key explanatory variables.

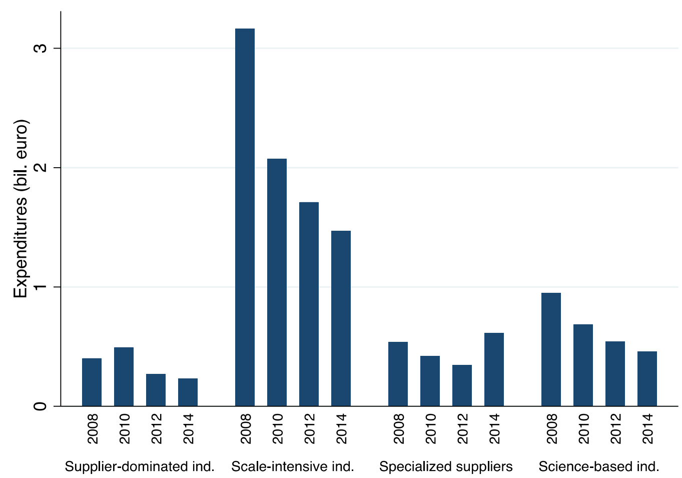
Results

A. Descriptive Statistics

[21] We also used country-clustered standard errors, and although standard errors are somewhat larger and the statistical significance is a bit weaker, the results generally hold.

The aggregate statistics indicate expenditures in the market for technology of 5.0 billion euros in 2008, 2.1 billion euros in 2010, 2.6 billion euros in 2012, and 2.6 billion euros in 2014.[22] Moreover, we find the demand in the market for technology to vary markedly among industries and countries. Figure 1 shows the total expenditures for external knowledge (bil. euro) within the four industry groups from Pavitt's taxonomy over time. Interestingly, the group of scale-intensive industries exhibits the highest overall expenditures, followed by science-based industries, specialized suppliers, and supplier-dominated industries. While this pattern is certainly driven by the number of industries that comprise each group, it shows the heterogeneity in the demand for technology among the four industry groups.

Figure 1. Total Expenditures in the Market for Technology by Industry Group



Except for specialized suppliers, we find a substantial decrease in the expenditures for external knowledge from 2008 to 2014, i.e. expenditures are almost cut in one-half. It could be driven by stagnant economic conditions in Europe after the financial crisis of 2008 (see also Figure 3), negatively affecting R&D spending and expenditures on external knowledge, or in the market for technology (Teplykh, 2017; Spescha *et al.*, 2018). In addition, on an industry level, this suggests that the market for technology is volatile and that demand may adjust relatively fast. Only specialized suppliers experienced increasing expenditures between 2008 and 2014.

A slightly different picture emerges regarding expenditures for external knowledge relative to internal R&D expenditures (Figure 2). While a decline from 2010 onward is observed for all industry groups (except for specialized suppliers), markets for technology are frequently used in the technologically least advanced subgroups (supplier-dominated industries and scale-intensive industries). Relative to the industries' own investment in R&D, demand for technology is more important in technologically less sophisticated industries, while technologically more sophisticated industries rely comparatively more on internal R&D.

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 in the market for technology, followed by France, Spain, and Italy. We observe a large decline in demand in the four countries, Germany, France, Spain, and Italy, between 2008 and 2010, which continued in all but France,

[22] These figures are based on all observations available, which – due to data restrictions by Eurostat – do not cover all EU countries, years, and industries. The figures therefore represent the lower bound of the size of the market for technology in Europe.

which exhibited a strong increase from 2012 to 2014. Among the smaller member states (not depicted in the figure), the Czech Republic, Hungary, the Slovak Republic, and Ireland have substantial demand for technology relative to GDP at different time periods, suggesting the one-time nature of acquisitions in the market for technology in these countries.

Figure 2. Total Expenditures in the Market for Technology by Industry Group (as a share of R&D)

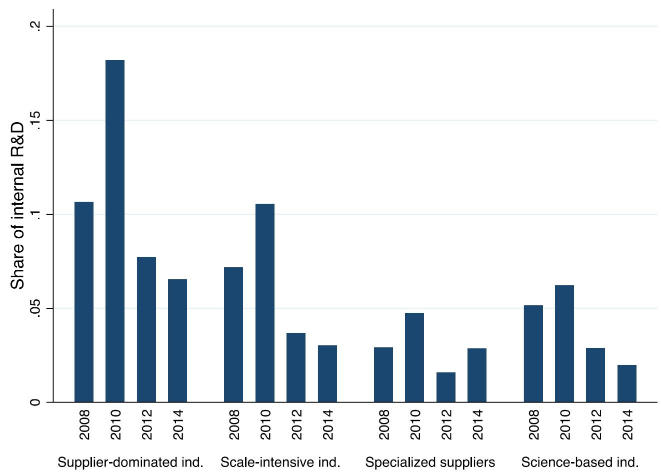
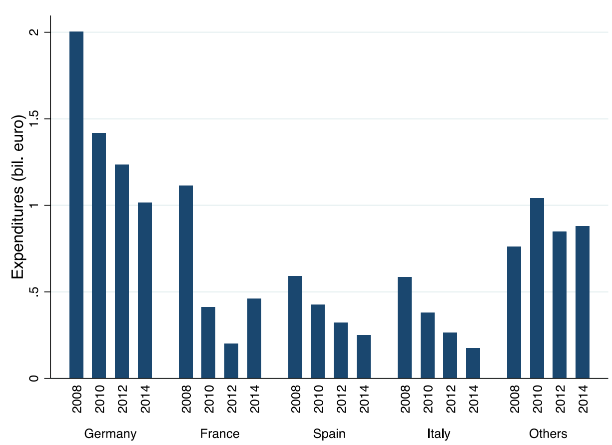


Figure 3. Total Expenditures in the Market for Technology by Country[23]



While the size of the market for technology fell rather sharply over the period from 2008 to 2014 in most countries and industry sectors, firms' expenditures for licenses and acquired patents constitute only a fraction

[23] The values for Germany are missing in 2010. They were imputed with the average values of the expenditures for external knowledge from the survey waves of 2008, 2012, and 2014.

of the expenditure on internal R&D. Table 1 shows the summary statistics for our key variables using the regression sample of 1584 country-industry observations. The dependent variable, expenditures on external knowledge as a share of sales, is about 0.06 percent on average with a relatively large variation. We find the average industry R&D intensity is about 1.1 percent, again with considerable variation in the data. Firms' internal R&D has quantitatively much higher importance than expenditures on external knowledge. Although we have witnessed a period of technological expansion for the past 20 years, expenditures for external knowledge are comparatively small and volatile, explaining at least part of the stark decline in expenditures shown above.

The data also reveal that industries differ substantially in the average firm size (min. 13, max. 3,676). On average, the share of firms in an industry engaged in any type of innovation collaboration is 18 percent, and countries spend 1.57 percent of their GDP on R&D.[24] Following the industry classification of Bonaccorsi et al. (2013), we find that most industries in the sample are scale-intensive (43 percent), followed by supplier-dominated industries (34 percent), specialized suppliers (15 percent), and science-based industries (8 percent). The distance to the technological frontier varies substantially across the data.

Table 1. Descriptive Statistics (a Sample of 1584 Observations)

Variable	Mean	Std. dev.	Min	Max
Expenditures on external knowledge as a share of sales (%)	0.06	0.31	0	10.5
R&D as a share of sales (%)	1.11	2.09	0	26.3
Average firm size (number of employees)	108	182	13	3676
Share of collaborating firms	0.18	0.15	0	1
GERD as percentage of GDP (%)	1.57	0.83	0.4	3.7
Expenditure on machinery/software as a share of sales (%)	0.99	1.53	0	28.5
Supplier-dominated industry share	0.34	0.47	0	1
Scale-intensive industry share	0.43	0.50	0	1
Specialized suppliers industry share	0.15	0.36	0	1
Science-based industry share	0.08	0.28	0	1
Distance to technological frontier	0.02	0.55	-0.9	8.7

B. Estimation Results

Table 2 shows the regression results for the expenditure on external knowledge. The first regression uses OLS and the logarithm of expenditures, essentially dropping the zero observations while other estimations use iterative OLS (iOLS), taking into account zeros in the dependent variable. The results for key variables like industry and country R&D are similar, but the average firm size becomes more relevant in the iOLS specification while the degree of firm innovation collaboration becomes less relevant (model 2 vs. model 1).

Across all specifications, there is an inverse U-shaped relationship between an industry's internal R&D intensity and its realized demand for external knowledge. Higher industry internal R&D intensity is initially associated with higher demand for technology, suggesting complementarity between internal R&D and expenditures on external knowledge and supporting the integration of external knowledge. After a certain threshold, however, industries are technologically sophisticated and realized demand for external knowledge decreases. In this

[24] The mean variance inflation factor of the variables is 1.62, well below commonly applied thresholds for multicollinearity (Belsley *et al.*, 1980).

case, the external market does not seem to offer much useful and sufficiently novel knowledge. However, since the turning point corresponds to an internal R&D intensity of above 20 percent, about 95 percent of observations in the pooled distribution is below this threshold, and in a more comprehensive specification (model 4), all observations are below the threshold (which is about 30 percent). The coefficient estimates of about 0.24 on internal R&D intensity and of -0.008 on its square (model 4) suggest that a one percentage point increase in internal R&D intensity is associated with about
0.23 percentage points increase in the demand for technology (evaluated at the average internal R&D intensity of about 1 percent). However, the impact of increasing internal R&D intensity at higher levels of R&D is progressively smaller. At internal R&D intensity of 10 percent, the effect is 0.16 percentage points, while at 20 percent, it is 0.08 percentage points.

Table 2. Realized Demand for Technology: Main Results

VARIABLES	iOLS	iOLS	iOLS	iOLS	iOLS	iOLS
R&D as a share of sales	0.252***	0.260***	0.211***	0.238***	0.178***	0.230***
	(0.059)	(0.058)	(0.058)	(0.060)	(0.061)	(0.062)
R&D as a share of sales squared	-0.008***	-0.009***	-0.007**	-0.008***	-0.005*	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Average firm size (log)	0.435***	0.357***	0.416***	0.355***	0.351**	0.388***
	(0.134)	(0.137)	(0.142)	(0.134)	(0.140)	(0.137)
GERD as percentage of GDP	0.916***	0.995***	0.956***	0.904***	1.022***	0.880***
	(0.332)	(0.318)	(0.329)	(0.329)	(0.354)	(0.333)
Expenditure on machinery/software as a share of sales	0.110**	0.136**	0.097*	0.081*	0.097*	0.121**
	(0.050)	(0.069)	(0.053)	(0.045)	(0.051)	(0.050)
Distance to tech frontier (based on R&D as a share of GDP)	-0.255***	-0.234***	-0.228***	-0.227***	-0.226***	-0.224***
	(0.075)	(0.075)	(0.070)	(0.069)	(0.069)	(0.070)
Share of collaborating firms with gove't and public research inst.		-1.244***				
		(0.465)				
Share of collaborating firms with universities			0.384			
			(0.650)			
Share of collaborating firms with suppliers				0.958*		
				(0.558)		
Share of collaborating firms with clients					1.331**	
					(0.588)	
Share of collaborating firms on innovation nationally						0.297
						(0.520)
Constant	-7.507***	-7.389***	-7.429***	-7.261***	-7.439***	-7.253***
	(1.061)	(1.048)	(1.048)	(1.049)	(1.095)	(1.058)
Year dummies	Included	Included	Included	Included	Included	Included
Country dummies	Included	Included	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included	Included	Included
N	1617	1383	1462	1563	1402	1530

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We find that the average firm size and a country's internal R&D intensity are positively associated with the demand for technology, but the share of firms collaborating on innovation is not statistically significant. Industries with large firms could support the market for technology as large firms are more willing to acquire knowledge both internally and externally than small firms.[25] In addition, more technologically advanced countries, as measured by a country's total R&D expenditures (GERD) over GDP (R&D intensity), have higher demand in the market for technology. This finding is specific for the GERD over GDP measure and does not extend to technological distance measured as the distance to the highest industry R&D intensity as a share of

[25] We do not find a statistically significant association with a larger industry size as measured by industry's number of employees.

sales.[26] Lastly, although markets for technology are often used in connection with more relational forms of knowledge acquisition such as collaborative R&D (Grimpe *et al.*, 2016), we do not find a significant statistical association of the degree of innovation collaboration of firms (but we explore the collaboration effect further below).

Similar to the complementarity of the realized demand for external knowledge with internal R&D spending, there is also complementarity with expenditures on machinery and software with an elasticity estimate of about 0.1. Although the impact on average is about half as large as that of an R&D intensity, it is still rather important for the demand for technology. This finding suggests that spending on knowledge through various channels is complementary and reinforcing, potentially allowing firms and industries to obtain different kinds of knowledge and build on them.

The technological distance affects the realized demand for technology, driving an increase in demand in industries further away from the technological frontier except in supplier-dominated and science-based industries. With no differentiation among industry types, being closer to the technological frontier tends to reduce the realized demand for technology as external knowledge may be less relevant to the overall knowledge acquisition for industries at the technological frontier (model 4).[27] However, exploring the impact of technological distance by industry type (model 6), supplier-dominated industries that are closer to the technological frontier are associated with increased realized demand for external knowledge, and the effect is relatively large, almost three times as large as the effect of general R&D in the country (a 2.8 percentage point increase for each percentage point increase of industry R&D toward the frontier). Interestingly, the effect is essentially zero for science-based industries while it becomes negative, but small (about -0.5), for scale-intensive industries and specialized suppliers. It seems supplier-dominated industries, unlike other industries, acquire more external knowledge at the frontier suggesting multiple channels of knowledge acquisition. Other technologically sophisticated industries, in contrast, have comparatively less to gain from acquiring knowledge on the market for technology.

In an alternative specification (model 5), we omit industry effects to assess the differential impact of industry groups and technological distance on the demand for technology. The results are largely similar to the model with industry effects and the differential effects of the technological distance by industry types (model 6). The major difference is the larger elasticity of internal R&D spending, increasing from 0.24 to about 0.37. In addition, both specialized suppliers and science-based industries on average have higher demand for technology with the reference group of supplier-dominated industries demanding the least in the market for technology (model 5).

Lastly, we evaluate the impact of different types of collaboration on the realized demand for technology or external knowledge (Table 3). Any type of collaboration or collaboration on innovation nationally is statistically insignificant and perhaps not that material to the realized demand for technology. So is the effect of the collaboration with universities. In contrast, collaboration with public research institutes is negatively associated with the realized demand for technology as firms probably not require as much external knowledge once they collaborate with public research institutes. It seems this association is more pronounced unlike the association with university collaboration as the knowledge obtained may not necessarily be of an applied kind. Lastly, there

[26] Using alternative measures for the country GERD (as a share of GDP), namely, the normalized patent applications of a country and the intellectual property (IP) protection index, we find a positive, but statistically significant at the 10 percent level, association for the patents variable while the IP protection index turns out to be largely unrelated to the realized demand for external knowledge.

[27] The estimates are statistically insignificant in the regressions with an alternative measure of the technological distance based on R&D as a share of sales.

seems to be a positive strong association with the realized demand for technology for collaborating with suppliers and even more so with clients. This type of collaboration increases the realized demand for technology as collaboration with suppliers and clients may suggest that firms seek to spend more on external knowledge as a result of informational improvements or solving challenges in firms' relations with their suppliers and clients.

Table 3. Realized Demand for Technology: Different Types of Collaboration

VARIABLES	iOLS	iOLS	iOLS	iOLS	iOLS	iOLS
R&D as a share of sales	0.252***	0.260***	0.211***	0.238***	0.178***	0.230***
	(0.059)	(0.058)	(0.058)	(0.060)	(0.061)	(0.062)
R&D as a share of sales squared	-0.008***	-0.009***	-0.007**	-0.008***	-0.005*	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Average firm size (log)	0.435***	0.357***	0.416***	0.355***	0.351**	0.388***
	(0.134)	(0.137)	(0.142)	(0.134)	(0.140)	(0.137)
GERD as percentage of GDP	0.916***	0.995***	0.956***	0.904***	1.022***	0.880***
	(0.332)	(0.318)	(0.329)	(0.329)	(0.354)	(0.333)
Expenditure on machinery/software as a share of sales	0.110**	0.136**	0.097*	0.081*	0.097*	0.121**
	(0.050)	(0.069)	(0.053)	(0.045)	(0.051)	(0.050)
Distance to tech frontier (based on R&D as a share of GDP)	-0.255***	-0.234***	-0.228***	-0.227***	-0.226***	-0.224***
	(0.075)	(0.075)	(0.070)	(0.069)	(0.069)	(0.070)
Share of collaborating firms with gove't and public research inst.		-1.244***				
		(0.465)				
Share of collaborating firms with universities			0.384			
			(0.650)			
Share of collaborating firms with suppliers				0.958*		
				(0.558)		
Share of collaborating firms with clients					1.331**	
					(0.588)	
Share of collaborating firms on innovation nationally						0.297
						(0.520)
Constant	-7.507***	-7.389***	-7.429***	-7.261***	-7.439***	-7.253***
	(1.061)	(1.048)	(1.048)	(1.049)	(1.095)	(1.058)
Year dummies	Included	Included	Included	Included	Included	Included
Country dummies	Included	Included	Included	Included	Included	Included
Industry dummies	Included	Included	Included	Included	Included	Included
N	1617	1383	1462	1563	1402	1530

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Discussion

Our results show the importance of complementarities of acquiring knowledge. The realized demand for technology, or external knowledge, is strongly complementary with internal R&D spending and expenditures on machinery and software at the industry level (within industries), suggesting that the accumulation of knowledge happens through multiple channels and is built to produce desired outcomes. In fact, the external knowledge acquisition is further enhanced with the collaboration across suppliers and clients. Industries with larger firms have a higher realized demand for technology, and this realized demand is further supported by a larger country's R&D. Collaborating with universities does not seem to be relevant for the realized demand for technology, but the collaboration with public research institutes seems to be a substitute for acquiring external knowledge on the market.

The importance of the market for technology varies across an industry's position in the country vis-à-vis the industry's global technological frontier (Kumar *et al.*, 2002; Mahmood *et al.*, 2005). Industries at the technological frontier cannot rely on readily developed knowledge to keep pace with technological progress (Mahmood *et al.*, 2005). We find evidence that industries spend more money in the market for technology the further away they are from the technological frontier. Markets for technology provide a means to catch up, at least to some extent, with the technological frontier.

However, the extent to which lagging industries rely on external knowledge is not equally pronounced in the four industry groups. Firms in specialized supplier industries exhibit more realized demand for external knowledge on markets when the industry is further away from the technological frontier and are on average have a higher realized demand in the market for technology, next to science-based industries. 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 when lagging behind the technological frontier although science-based industries are on average the largest consumers of external knowledge. The effect of the distance from the frontier in the scale-intensive industries is suggestive of firms catching up due to higher realized demand in the market for technology but is relatively small. Interestingly, in supplier-dominated industries, the effect is reversed, whereas industries closer to the frontier exhibit more realized demand for knowledge in the market for technology. This finding underlines the heterogeneous response of firms and industries within a certain pattern of innovation to the distance from the technological frontier.

Overall, firms in science-based industries are most likely to show high realized demand for external knowledge, followed by firms in specialized supplier and scale-intensive industries. This result is in line with prior literature given the ability of science-based industries to codify knowledge and the opportunities for patenting (Arora *et al.*, 2001; Arora *et al.*, 2010). A higher propensity to patent implies thicker markets for technology in science-based industries, which allows for higher allocative efficiency (Gans *et al.*, 2010). Moreover, the view that scale-intensive industries are distinct recipients of externally produced technology (Pavitt, 1984) is nuanced since these industries create significantly less realized demand in the market for technology than science-based and specialized supplier industries. Supplier-dominated industries exhibit even lower realized demand than other industries, whereas only those supplier-dominated industries closer to the technological frontier increase their realized demand substantially. Our results provide an important extension and qualification of Pavitt's taxonomy with respect to the importance of markets for technology in these sectors.

Conclusion

Markets for technology are important institutions that facilitate vertical specialization, a division of labor in innovation, and the allocative efficiency of innovation activities in a country (Arora *et al.*, 2001; Arora *et al.*, 2010; Arora *et al.*, 2012). The analysis of 24 European countries over the period from 2008 to 2014 shows that the market size in these countries is sizable (5.0 billion Euro in 2008) but also volatile (2.1 billion Euro in 2010 and 2.6 billion Euro in both 2012 and 2014). We find that the realized demand in markets for technology is procyclical similar to other innovation inputs (Spescha *et al.*, 2018) and was affected by the financial crisis in Europe after 2008. Economic downturns are accompanied by increased uncertainty within the business environment and declining realized demand reduces R&D investment. With the outcomes of innovation inputs typically becoming visible only with a 2-3 year lag (Hall *et al.*, 2009), firms rely comparatively more on the exploitation of internal knowledge and capabilities rather than the exploration of something new (Teplykh, 2017). This logic also holds in the context of realized demand for technology, or external knowledge. Our findings do not support the view that expenditures for external knowledge are countercyclical because in-licensing, i.e. acquiring a license, could be an opportunity to utilize new technology at comparatively lower risks (López-García *et al.*, 2013).

In brief, we identify structural features of industries that propel or constrain realized demand in markets for technology (Arora *et al.*, 2010). We relax the strong and usually implicit assumption in the existing literature that demand in markets for technology is uniform. Instead, we identify two factors, sectoral innovation patterns and technological leadership of an industry that are relevant for the realized demand in the market for technology. We provide mechanisms, which other studies can use to (a) explore other sources of heterogeneity of realized demand in the market for technology and (b) avoid biased results in studies ignoring such heterogeneities. We extend the literature on sectoral innovation patterns by highlighting how buying knowledge in the market for technology is an integral part of innovation in science-based industries and to a lesser degree in supplier-dominated and scale-intensive industries.

We show that the realized demand in the market for technology depends on the industry's leadership status. The effect of the distance from the technological frontier is heterogeneous across industry types. Moreover, it highlights that industries benefit unevenly from developed markets because markets may simply not offer access to the most cutting-edge research but provide "shelf-warmer technologies" (Grimpe, 2006).

Our findings have an important relevance for policymaking to foster the market for technology. Our mapping of the realized demand in the market for technology allows tailoring innovation policies intended to expand the overall size and utilization of markets for technology to specific industries. Science, technology, and innovation (STI) policy needs to acknowledge that markets for technology are largely driven by industry-related factors such as the pattern of innovation and the technological sophistication in combination with country-level factors. Consequently, policies should be sector-specific while also encourage R&D and other investments that are complementary to the expenditures on external knowledge acquisition.[28] These other investments become even more crucial as the technological sophistication of industries increases.

[28] Sector-specific policies may need to assess social benefits against fiscal costs as well as consider the implementation capacity to minimize resource misallocation (IMF 2024).

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Appendix

Table 1. NACE Codes and Pavitt's Taxonomy

NACE Manufacturing Industry Name	NACE Code	Pavitt's Taxonomy
D13: Textiles	13	Supplier-dominated
D14: Wearing apparel	14	Supplier-dominated
D15: Leather and related products, footwear	15	Supplier-dominated
D16: Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	16	Supplier-dominated
D17: Paper and paper products	17	Supplier-dominated
D18: Printing and reproduction of recorded media	18	Supplier-dominated
D31: Furniture	31	Supplier-dominated
D32: Other manufacturing	32	Supplier-dominated
D10: Food products	10	Scale-intensive
D11: Beverages	11	Scale-intensive
D12: Tobacco products	12	Scale-intensive
D19: Coke and refined petroleum products	19	Scale-intensive
D20: Chemicals and chemical products	20	Scale-intensive
D22: Rubber and plastic products	22	Scale-intensive
D23: Other non-metallic mineral products	23	Scale-intensive
D24: Basic metals	24	Scale-intensive
D25: Fabricated metal products, except machinery and equipment	25	Scale-intensive
D29: Motor vehicles, trailers and semi-trailers	29	Scale-intensive
D30: Other transport equipment	30	Scale-intensive
D27: Electrical equipment	27	Specialized suppliers
D28: Machinery and equipment n.e.c.	28	Specialized suppliers
D33: Repair and installation of machinery and equipment	33	Specialized suppliers
D21: Pharmaceuticals, medicinal chemical and botanical products	21	Science-based
D26: Computer, electronic and optical products	26	Science-based

PUBLICATIONS

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