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COOPERATING WITH UNIVERSITIES AND R&D ORGANIZATIONS: MAINSTREAM PRACTICE OR PECULIARITY?

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COOPERATING WITH UNIVERSITIES AND R&D ORGANIZATIONS: MAINSTREAM PRACTICE OR PECULIARITY?

This paper develops an integrated framework to examine the determinants of industry-science cooperation in the general process of developing innovation. Based on the literature review and using firm-level data on innovation strategies of 805 manufacturing enterprises in Russia we investigate what are the incentives to firms (1) to cooperate with universities and R&D organizations and (2) to choose a particular mode of interaction that ranges from purchasing S&T services to a full scale original R&D aimed at creating new-to-market innovation. We suggest that a broad range of intramural and external determinants, including competition regime, absorptive capacity, technological opportunities, appropriability conditions, public support, as well as barriers to the practical application of R&D results influence the firm's decision on cooperation with knowledge producers. The findings indicate that the scale of industry-science linkages in Russian manufacturing is limited and generally hampered by low propensity of business to the R&D-based innovation strategies.

Keywords: Science-industry cooperation; Innovation strategy; Firm-level; Manufacturing; Russia

JEL Codes: D22; D83; L2; O31

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1 Introduction

One of the most efficient instruments to gain access to new knowledge at the firm level is the implementation of cooperative strategies. Networks have long been recognized as playing an important role in innovation (e.g. Powell and Grodal, 2005). The increasing complexity of knowledge processes and the speed of information dissemination, which are the backbone of innovation activities, lead innovative companies to search for capabilities and collaborative learning beyond their boundaries.

The importance of engaging external knowledge sources was formally emphasized in the central conceptual models (e.g. the chain-link model of innovation (Kline and Rosenberg, 1986) and reflected in the internationally recognized statistical measurement frameworks (Oslo Manual, 2005). These theoretical considerations were fully supported by the emerging base of empirical evidence that has greatly improved our understanding of different patterns of cooperative innovation strategies. However, few researchers focused on empirical analysis of the determinants for the joint innovation strategies, fully taking into account the heterogeneity of motivations for different configurations of collaborative networks.

There are different patterns of cooperative innovation strategies: cooperation within the supply chain, with market actors, knowledge producers, government bodies and consulting firms. Still cooperation with universities and R&D organizations holds a unique position among all types of cooperation. Such interactions can create benefits for all parties involved and for society as a whole. Businesses may benefit from the access to complementary technological knowledge, additional equipment and facilities, skilled workers, public funding and initiatives, while typical motivations for scientific institutions include the additional research funding, access to empirical data and new research problems, reputation enhancement and training opportunity. The relationships between industry and science are not linear and unidirectional but rather interactive and collaborative, as it is not only traditional knowledge producers are relevant to firms but also firms are a critical source of knowledge for universities and R&D organisations (Carvalho de Mello et al., 2016).

The exploitation and commercialization of public research results is an intermediate objective that contributes to better attaining the broader goals of both science and innovation policies and economic and social policies (OECD, 2016). Firstly, the diffusion of public research results stimulates private sector innovation and new technologies development, as innovation in firms increasingly relies on the science base generated at R&D organizations and universities. Secondly, by transforming R&D results obtained by universities into new products and services, knowledge transfer may contribute to addressing more efficiently global and grand societal challenges (including demographic growth, increasing scarcity of natural resources, climate change and other). With large public investment in research and mounting budgetary pressures, governments should improve the efficiency of these investments, specifically by strengthening and fostering science-industry linkages.

The role of the state is not limited to financial support of knowledge transfer from university (or R&D organization) to industry. It's also about providing incentives and developing the necessary infrastructure, addressing the interests of all stakeholders, ensuring coordination and an effective legal and regulatory framework. At the same time, there is a constant adaptation of policy instruments to changing external conditions, such as digitalization and globalization (including emergence of global networks, private-driven digital platforms and online communities).

The study of the goals and forms of cooperation between industry and science and the determinants of cooperative relationships effectiveness remains of current interest for economists, as well as in management practice in terms of providing STI policy evidence-based recommendations. The aim of this paper is to contribute to a better understanding of the extent and quality of industry-science linkages in Russian manufacturing. More specifically, we want to investigate the drivers and barriers for innovative companies (1) to cooperate with knowledge producers and (2) to adopt new technologies developed by R&D organizations and universities (application of R&D results and technologies as opposed to purchasing S&T services or the lack of cooperation with knowledge providers).

2 Theoretical considerations and empirical evidence

2. 1 Innovation cooperation between industry and science

Universities, public and private R&D organizations remain key producers and providers of knowledge, which has an essential contribution to the economic competitiveness and social welfare (Cohen et al., 2002; Mansfield, 1998; OECD, 2016). They fill in a specific niche in undertaking long-term basic research, ensuring access to international knowledge networks and conducting applied research and experimental development.

The diversity of knowledge types forms the basis for science-industry cooperation, which may be initiated both by firms (such as contract research) and scientific institutions (such as spinouts) (Perkmann and Walsh, 2007). Knowledge is commonly categorized as either tacit (embodied in people) or explicit (i.e. codified), which ensures sufficient level of confidence between the parties (Schartinger et al. 2002). Types of knowledge vary according to the nature of research: basic or applied, multidisciplinary or mono-disciplinary (Brennenraedts et al., 2006).

Industry has different motivations for collaborating with knowledge producers. Public research is an essential input in innovation process of firms, especially in the initial stage characterized by low innovation demand (Jensen et al., 2003). New scientific and technological knowledge (not always oriented towards industrial application) may contribute to the "blue sky" (explanatory) research in search of new technology and research oriented on technical problems solution (De Faria et al., 2010; Lee, 2000), development of new products new to the market and advanced technologies (Kaufmann and Tödtling, 2001; Veugelers and Cassiman, 2005).

Access to financial and in-kind resources is another motivating factor behind cooperation between industry and science. Often, companies become initiators of innovation projects and invest considerable effort and money for the success. Benefits for stakeholders are associated with an access to various tangible assets (for example, equipment, laboratories, material) and to additional funding (Tartari and Breschi, 2012). The support of industry-science collaboration, especially practically oriented and aimed at solving general economic and social problems, is reflected in public promotion programs in many countries (Bruneel et al., 2010; OECD, 2016).

Moreover, cooperation between industry and science facilitates learning opportunities for all stakeholders, which, in turn, indirectly contributes to the process of creating original creative ideas (Schmidt et al., 2007). Conducting joint R&D, developing joint innovation trajectories, staff exchange programs including staff hiring and training are essential means of implementation (Kim et al., 2005; Schmidt et al., 2007). High mobility of human resources across sectors contributes to the mutual enrichment of ideas and the reduction of mismatches between skills in demand and skills acquired.

Nevertheless, due to the differences in the norms and rules that regulate the interactions between industry and science and the significant information asymmetry between partners, strong industry-science linkages are not frequent. Companies often face a number of bottlenecks in appropriating the acquired knowledge for private goals. This is linked to the divergence of objectives between industry and science (Bruneel et al., 2010; Fiaz, Naiding, 2012). Knowledge producers are concerned with research and education, while the basic direction of firm activity is capturing valuable knowledge, which may be leveraged to create a competitive advantage.

The contradictory relationship between industry and science is characterized by the readiness and willingness of scientists to disclose publicly obtained scientific results and the desire of firms to conceal timely access to information. The maturity of a national innovation system also has a decisive influence on the scale and quality of interactions between industry and science. In countries with "immature" innovation systems, for example in case of developing countries, institutions (such as education and financial systems, public and private R&D organizations, universities) are weak and have serious flaws (Fischer et al., 2017; Rapini et al., 2009). This may negatively affect the intensity and effectiveness of university-industry interactions.

2.2 The diverse nature of knowledge transfer from research institutions to industry

Universities and R&D organizations are key actors in innovation ecosystems and contribute in multiple ways as they engage in basic and applied research, provide training and education, facilitate skill development, and promote innovation through interactions and collaboration with industry.

Channels of knowledge transfer between the two sectors include collaborative research and academic consultancy, labor mobility and informal knowledge sharing. A number of factors determine the form of interaction, including the kind of knowledge transferred, the direction of knowledge flows, characteristics of knowledge senders and receivers (such as their size, research orientation, sector of activity, geographical proximity to each other), an alleged intensity and duration of relations. Not surprisingly, policy and framework conditions, setting external incentives and barriers, are also key characteristics of knowledge and technology transfer (Kortzfleisch et al., 2015).

There are different forms of science-industry interactions. Perkmann and Walsch (2007) distinguish between "research partnerships" and "research services" based on the concept of finalization, i.e. the degree to which scientific knowledge is consistent with the goals of private companies ready for practical application. Research services (e.g. contract research, academic consulting) are performed by science institutions under control of industrial clients and at their expense, have clear objectives and deliverables. Research partnerships (e.g. sponsored research), by contrast, generate intellectual outputs that are high of academic relevance, but inappropriate for business goals. The reason is that industry often focuses on inventions that generate revenue quickly while S&T results obtained by universities and research institutions have usually more long-run economic benefits.

Schartinger et al. (2002) argue, that in addition to "contract research" and "joint research" (covering both collaborative R&D and co-publications) there are two more forms of interactions between industry and science – "personnel mobility" (staff exchange and joint supervision of students) and "training and lectures" (training of employees and lecturing by industry staff, cooperation in education). This classification reflects different company strategies, which aims at providing research efficiency, accessing S&T opportunities and meeting demand for knowledge at various stages of innovation process. Differences in the intensity of face-to-face interactions, knowledge characteristics and the direction of knowledge flows predetermine the choice of interaction pattern.

According to Bekkers and Bodas Freites (2008), there are four typical ways of knowledge transfer between the two sectors: codified output, collaborative and contracted research, personnel exchange and informal contacts. They represent the variety of forms of knowledge transfer by sectoral effects, basic knowledge characteristics, academic disciplines, characteristics of organizations and individuals involved. The authors analyzed the differences in transfer channels importance for industrial and university R&D performers by controlling for 23 different types of knowledge transmission from universities to companies. Finally, they identified six groups (similar level of importance within each cluster): scientific output, informal contacts and students; labor mobility; collaborative and contract research; contacts via alumni or professional organizations; specific organized activities, and patents and licensing.

Arza (2010) proposes a conceptual framework that classifies forms of interactions between industry and science according to the incentives for cooperation. The author differentiates between economic (related to the research commercialization and obtaining of extra funds) and intellectual ("learning in the context of application") benefits for research institutions and between passive (aims to address current challenges) and proactive (contributing to innovation activities) strategies of companies. Potential benefits define the form of interaction and channels of industry-science knowledge transfer.

"Service" relations are characterized by passive strategies of firms and economic strategies of research institutions when they provide services (such as consulting, monitoring and testing) for money. Scientists' focus on intellectual values contributes to "traditional" way of getting benefits – publication of research results in scientific journals, conferencing and networking, labor and research mobility. This form of knowledge relations does not require personal contact between participants. Engaging in innovation activities encourage firms to take part in the knowledge generation process, therefore, the knowledge flow becomes "bi-directional". In this case, collaborative R&D projects and networking are the most widespread forms of cooperation. The riskiest form of interaction is "commercial" (including intellectual property transactions and spin-offs), when research institutions are interested in the commercialization of science and research, and proactive innovation strategies of firms. Competing interests of the involved actors may cause unethical behavior and consequently poor quality of research.

According to Tödtling, Lehner and Kaufmann (2009), there are two basic dimensions of knowledge: formalization (i.e. degree of commercialization) and dynamism. Taking that approach, four different forms of science-industry cooperation are developed. "Market relations" are traded relations and include transfer of explicit pieces of knowledge (e.g. patents, machinery) from science to industry in exchange for money. Static relations with a transmission of untraded knowledge represent "knowledge externalities and spillovers" often resulted from informal face-to-face contacts and staff mobility. Dynamic relationship between R&D organizations and businesses supports collective learning practiced in form of "cooperation" (i.e. formal agreements) or "informal networks" largely based on social capital and trust. Geographic proximity of actors (on local, regional level) facilitates their innovation activities and knowledge transfer, because informal interactions and personal contacts between research staff and industry researchers are a necessary condition for the effective exchange of scientific (often tacit) knowledge.

Brennenraedts et al. (2006) distinguished ten different categories of knowledge interactions between industry and science: publications, conferences and workshops, mobility, informal contacts, cooperation in R&D, sharing of facilities, cooperation in education, contract research and advisement, IPR (e.g.co-patents, copyright), and spin-offs. Building on Cohen's et al. (2002) taxonomy, they established a more detailed classification that comprises 40 possible ways of knowledge transfer. The authors argue that a current stage of innovation cycle and general features of the national innovation system affect the choice of knowledge transfer mechanisms.

More recently, some new mechanisms for the transfer, exploitation and commercialization of public research results have emerged, including public-private partnerships, open science initiatives (student-based start-ups) and entrepreneurial channels (financing and mobility schemes) (OECD, 2016).

Generally, the heterogeneity of business-goals and strategies causes the diversity of channels of science-industry interactions. Fischer et al. (2017) using the data for Brazil distinguish between R&D-oriented partnerships and training, consulting, technical forms of cooperation. R&D intensive interactions often represent strategic partnership, fully or partly funded by industry, and can range from small-scale projects to strategic partnerships with multiple stakeholders. R&D-oriented collaborative projects often lead to technology adoption. Science-industry linkages oriented to consultancy, training and other non-R&D activities are mostly of an operational nature (Rapini et al., 2009).

Hence, knowledge and technology created by universities and research organizations reach markets through many channels, which vary across industries and scientific disciplines, in accordance with the characteristics of companies and research institutions. General structural features of countries (such as urban context, institutional capacity); intellectual property rights policies; policies that facilitate labor mobility and other policy and framework conditions also determine the opportunities for science-industry knowledge transfer.

2.3 Empirical studies on cooperation with knowledge producers

In recent years, a number of empirical studies have explored the determinants of science-industry linkages. The literature discusses a wide range of factors related to the industry and firm characteristics, firm’s absorptive capacity, market structure, technological and appropriability conditions, availability and scope of the government support measures. The summary of results, with a special focus on cooperation with knowledge producers is presented in Table 1.

Most of the studies in European countries find a positive relation between the firm size and the probability to be engaged in cooperation with knowledge producers (Dachs et al., 2008; Mohnen and Hoareau, 2003 and other). Moreover, Arranz and Fdez. de Arroyabe (2008) and Badillo and Moreno (2016) in the case of Spain and Miotti and Sachwald (2003) in the case of France find that companies belonging to the same corporate groups and those who received public support more likely perform R&D cooperative projects with public research institutions. Similarly, Dachs et al. (2008) and Veugelers and Cassiman (2005) find that access to public financial support has a positive impact on the probability of cooperation with universities.

As works by Eom and Lee (2010) and Veugelers and Cassiman (2005) have indicated, risk and cost sharing are other firms' rationales for interacting with universities and R&D organizations. Nevertheless, other researchers demonstrated that obstacles such as high economic risks and excessive innovation costs have no significant (Arranz and Fdez. de Arroyabe, 2008) or negative effect (Badillo and Moreno, 2016; Miotti and Sachwald, 2003) on the probability of cooperation with public research institutions.

Table 1. Empirical studies on cooperation with knowledge producers

Authors	Sample characteristics	Cooperation partner	Methodology	Determinants of cooperation
Arranz and Fdez. de Arroyabe (2008)	1 652 firms, CIS2, Spain, 1997	Public research institutions	Logit regression	high-, mid-high- and mid-low-tech (+); low-tech (○); size (○); group (+); permanent R&D (○); external R&D (+); high cost (-); lack of market and technology (○); public funding (+)
Badillo and Moreno (2016)	7 362 firms, PITEC, Spain, 2006-2008	Public research institutions	Multivariate probit	industrial sector (-); size (+); group (+); incoming spillovers (+); R&D intensity (+); high cost (○); high risk (-); lack of qualified personnel (○); legal protection (○); public funding (+)
Dachs, Ebersberger and Pyka (2008)	1 046 and 453 firms, CIS3, Finland and Austria, respectively, 1995	Universities and research organizations	Multivariate logit	industry (○); size (+); group (○); competitors as information source (○); economic and internal hampering factors (○); export (○); continuous R&D (+); basicness of R&D (+); vertical spillovers (+); horizontal spillovers (-); innovative efforts (+); product or process innovation (+); internal knowledge flow (+); formal and strategic appropriability mechanisms (+)
Eom and Lee (2010)	538 firms, KIS, Korea, 2002	Universities and government research institutes	Probit	size (○); group (○); R&D intensity (○); importance of IPR (+); high cost (+); high risk (+); public funding (+)
Miotti and Sachwald (2003)	4 215 firms, CIS2, France, 1994-1996	Public research institutions	Logit regression	high-tech (-); mid-high-tech (○); size (+); group (-); market share (○); lack of market information (+); lack of technological information (○); permanent R&D (+);external sources close to scientific research (+); high risk (○); high cost (-); public funding (+)
Mohnen and Hoareau (2003)	9 191 firms, CIS2, France, Germany, Ireland and Spain, 1994-1996	Knowledge sourcing from universities or government labs	Ordered probit	size (+); belonging to a group (○); growth in employment (○); recent merger (○); non R&D expenditures/ sales (○); patents applied for R&D/sales (+); being a radical innovator (+); public support (+)

Table 2. continued

Authors	Sample characteristics	Cooperation partner	Methodology	Determinants of cooperation
Bayona Sáez, Marco and Arribas (2002)	747 firms, Survey on Technological Innovation in Business, Spain, 1996	Universities and research centers	Logit regression	industry (○); size (+); foreign (+); systemic R&D (+); objectives of innovation: substitution (○), quality (○), domestic market share (-), productive flexibility (-); adaptation of a new business orientation (+); sources of ideas: research centers (+), customers (-), suppliers (-)
Srholec (2014)	11 142 firms, CIS, The Czech Republic, 1999-2001, 2008-2010	(1) private labs, (2) government labs, (3) universities	Multivariate probit	size (+), age (○); continuous R&D (+); (1) belonging to a group (+); lagged cooperation with suppliers and private labs (+); (2) lagged cooperation with suppliers, private labs, competitors, government labs and universities (+); (3) lagged cooperation with universities (+); (2,3) group (○); lagged cooperation with customers (○)
Veugelers and Cassiman (2005)	325 firms, CIS1, Belgium, 1993	Universities	Instrumental probit	size (+), foreign (-); high risk (-); high cost (+); cooperation with universities at industry level (+); vertical cooperation (+); appropriability mechanisms: legal and strategic (○); public funding (+)

Source: National Research University Higher School of Economics

One of the most controversial topics in the studies of industry-science interactions is the role of technological intensity of industries. Obviously, both innovative activities and cooperative behavior vary significantly across sectors, i.e. manufacturing and service industries, from country to country. In a sample of Spanish firms Arranz and Fdez. de Arroyabe (2008) find that high-technology companies are more likely to have cooperative agreements with public institutions, while in a sample of France Miotti and Sachwald (2003) find an opposite effect. The estimation results of Dachs et al. (2008), Bayona Sáez et al. (2002) show that the probability of cooperation with universities and R&D organizations does not depend on the industry sector at all.

Appropriability conditions are positively related to cooperation strategies with universities and research organizations. Confidence in a steady return on implemented innovations is provided through effective intellectual property protection mechanisms, otherwise the probability of free-riding problem related to innovation investments increases (Belderbos et al., 2004). Dachs et al. (2008) and Eom and Lee (2013) find that companies that use formal (including patents, trademarks, registered designs) and strategic (such as secrecy, complexity, lead time, confidentiality agreements) methods to protect valuable inventions are more likely to interact with knowledge producers.

The decision on cooperation with universities and research institutions also largely depends on the firm's 'absorptive capacity' – the ability to "identify, assimilate and exploit knowledge from the external environment" (Cohen & Levinthal, 1990). Proxies that have been used to capture absorptive capacity in recent empirical studies include intramural R&D expenditures, -intensities and –continuity, organizational structure and practices (Schmidt, 2010). Most of empirical evidence suggests that firms with higher absorptive capacity are more likely to be engaged in cooperation with knowledge producers (Badillo and Moreno, 2016; Bayona Sáez et al., 2002; Srcholec, 2014).

In recent years, more and more studies have focused on studying the roles of universities and research institutions and their research on productivity, innovation performance and entrepreneurship, but the results are contradictory. Table 2 provides a summary of empirical studies that address the contribution of science-industry interactions to the innovation output.

Table 2. Science-industry interactions and firm performance: summary of empirical studies

Authors	Sample characteristics	Methodology	Key findings
Arvanitis et al. (2008)	588 firms, Sweden, 2005	Probit and Tobit regressions	*Logarithm of the sales share of new products:* human capital intensity (+); intensity of physical capital (+); size (+); high- and low-tech industries (+); traditional services (+); research utilization (+); education activities (+) *Logarithm of the sales share of significantly modified products:* size (+); high-tech industries (+); utilization of research (+); education activities (+)
Aschoff and Schmidt (2008)	699 firms, MIP (CIS4), Germany, 2004	Tobit regression	*Reduction of average costs:* R&D cooperation (+); innovation intensity (+); squared innovation intensity (-); size (+); 6-15 competitors (+) *Improved products / new to the firm:* innovation intensity (+); squared innovation intensity (-); continuous R&D (+); size (+); age (-) *New to the market:* continuous R&D (+); high quality employees (+); 6-15 competitors (-)
Belderbos et al. (2004)	2056 and 1360 firms, CIS, Denmark, 1996 and 1998	-	*Growth labor productivity:* R&D cooperation (with competitors and suppliers) (+); incoming spillovers (university spillovers) (+); innovation intensity (+); foreign multinational (+); domestic group (+); productivity (-) *Growth innovative sales productivity:* R&D cooperation (cooperation with competitors and universities) (+); incoming spillovers (customer and university spillovers) (+); size; foreign multinational (+); cost-push innovation (-); demand-pull innovation (+); productivity (-)
Eom and Lee (2010)	538 firms, KIS, Korea, 2002	Probit regression	*Innovation probability:* cooperation with universities (+) *Firm performance:* cooperation with universities and PRIs (○) *Patents – new product innovation:* cooperation with universities and PRIs (+)

Table 2. continued

Authors	Sample characteristics	Methodology	Key findings
Howells, Ramlogan and Cheng (2012)	338 firms, IRIN, UK, 2008	Logit regression	*Innovation probability:* university collaboration (+); formal and informal links (+); size (+) Firms rate universities very low as information sources and potential partners, but their actual use and impact on firms (not necessarily equating with value and appreciation) is much higher
Kaufmann and Tödtling (2001)	318 firms, REGIS-survey, 1996	Logit regression	*Innovativeness* (products new to the market/ new to the firm): importance of customer and supplier firms (+), importance of universities (+); region dummies (+)
Lööf and Broström (2008)	2071 firms, CIS3, Sweden, 2001	19 matching adjustment estimators	*Innovation sales and Patent application:* cooperation with universities (large manufacturing firms) (+); cooperation with universities (service firms) (○)
Maietta (2015)	1531 firms, Italy, 4 waves 1995-2006	Multivariate probit	*Product innovation:* R&D cooperation with universities and/or public labs (+); R&D collaboration with private firms (+); R&D intensity (+); skilled employees (+); co-op firm dummy (-); subsidies (+); small size (-); distance (-) *Process innovation:* R&D cooperation with universities and/or public labs (+); R&D collaboration with private firms (+); R&D intensity (+); sales through distribution chain (+); subsidies (+)
Robin and Schubert (2013)	France and Germany, CIS4, 2004 and 2008	Tobit regression	*Product innovation intensity:* log size (-); squared log size (+); obstacles to innovation due to demand (-); industry dummies (-); cooperation with public research (+) *Process innovation intensity:* obstacles to innovation due to competition (+); openness of the company (+); low-tech (-); knowledge intensive services (-); cooperation with other organizations (no public research) (+)
Vega-Jurado et al. (2010)	3 257 firms, Spain, 2004 and 2007	Multinomial logit	*Products new to the firm:* in-house R&D (+); high- and mid-high-tech (+); size (+); high skill (+); export orientation (+) *Products new to the market:* cooperation with clients (+); outsourcing R&D to other firms (+); in-house R&D (+); purchase of equipment (+); high- and mid-high-tech (+); export orientation (+)

Source: National Research University Higher School of Economics

Arvanitis et al. (2008) and Lööf and Broström (2008) find for Swedish innovative companies that innovation activity of industrial enterprises is higher among industrial enterprises actively involved in research cooperation with universities. The rapid growth in sales of new products confirms the positive impact of collaborative research with knowledge producers on industry innovation. Similar results have been achieved by Aschoff and Schmidt (2008) and Belderbos et al. (2004), investigating the effect of R&D cooperation with research institutions on the innovation output of firms using data from Germany and Denmark, respectively. In contrast, evidence contradicting the importance of joint research projects between private firms and public researchers for product innovation is reported by Miotti and Sachwald (2003) and Vega-Jurado et al. (2010) and for process innovation by Robin and Schubert (2013).

Eom and Lee (2010) and Howells et al. (2012) evaluate whether cooperation with knowledge producers increases the probability to innovate. They find a strong positive effect of university-industry collaborative projects on the probability of innovations, even though companies do not consider then as valuable sources of information.

Maietta (2015) and Robin and Schubert (2013) measure firm innovativeness as the number of product and process innovations. Maietta (2015) using data sample of Italian firms finds that cooperation with universities and/or public laboratories positively influences the probability of successful innovation, regardless of its type. Other factors enhancing firm innovativeness include high R&D intensity, inter-firm research cooperation and government subsidies. Robin and Schubert (2013) evaluated the impact of cooperation with PRIs on success in innovation: the cases of France and Germany. There is a significant positive effect of cooperation with PRIs on product innovation, while the general 'openness' of enterprise influences success in innovation and cooperation ties with other organizations (not with research institutions).

All innovation contain a degree of novelty, nevertheless, they have different degrees of novelty depending on whether they are new to the firm, new to the market or new to the world. Aschoff and Schmidt (2008) and Kaufmann and Tödtling (2001) show that innovativeness is enhanced by the close cooperation with knowledge producers and continuous R&D. A higher intensity of innovation and an increase in the number of employees also contribute to the creation of new products. In contrast, Vega-Jurado et al. (2010) reports a contradictory evidence about the importance of cooperation with scientific agents and R&D outsourcing for innovation (whether new to the firm or new to the market). Firm size, technological intensity of the industrial sector, in-house R&D capabilities and export orientation are the key determinants of innovation performance of companies.

The relatively few studies are trying to investigate empirically what are the determinants of forms and channels of science-industry interaction. Nevertheless, forms and channels of interaction largely determine the 'quality' of cooperation (i.e. adoption of technologies and/or application of scientific findings obtained by universities and R&D organizations) and, consequently, effects on the firm innovation performance.

3 Data and method

The following results are based on the data from a specialized survey entitled "Monitoring of Innovation Activities of the Innovation Process Actors"[1] conducted in 2014 by the Institute for Statistical Studies and the Economics of Knowledge (ISSEK) of the National Research University Higher School of Economics (NRU HSE) and covering manufacturing and service companies located in Russia. Questions relate to innovation practices over the period 2011-2013.

The survey of the innovation activities performed by the enterprises in manufacturing and service sectors adapts international standards on statistical measures of innovation as well as

[1] https://www.hse.ru/en/monitoring/innproc/

techniques from the long-running (since 2001) European project – European Manufacturing Survey (organized by the Consortium of 16 research centers and universities in EU and beyond and coordinated by Fraunhofer ISI, Germany[1]). It expands the established framework by adding a number of specialized modules that provide the harmonized methodology for the Community Innovation Survey (CIS), but also serve as a basis for the assessment of respondents' participation in the official innovation surveys.

The sample includes 1324 companies. Of these, 1206 (91%) are manufacturing enterprises and 118 (9%) belong to the service sector. Data is weighted by population characteristics derived from the Federal State Statistics Service (Rosstat) that include information on the number of enterprises in each industry sector and size group.

In this paper, we look at the subset of the innovation-active manufacturing firms that replied positively to a question regarding the implementation any type of innovation during the last three years ("Which of the following types of innovations have been successfully implemented in your company in the period from 2011 to 2013?"). The sample of 805 innovative manufacturing companies are representative of cooperation patterns in Russian manufacturing sector.

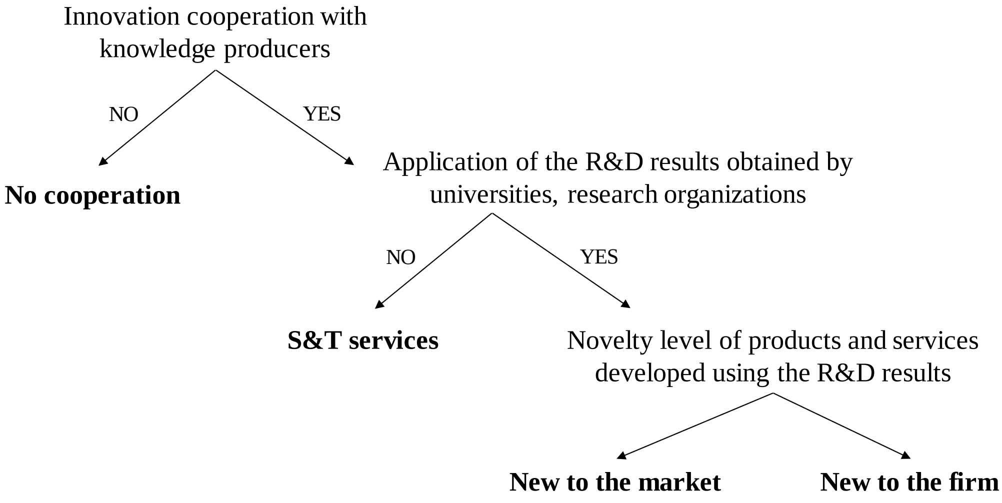
This paper addresses two questions: what increases the firms' propensity to cooperate with knowledge producers (i.e. universities and R&D organizations) and what determines the form (and channels) of science-industry interactions.

We consider three types of innovation cooperation between industry and science: cooperation with universities, with R&D organizations or with both knowledge producers simultaneously in order to maximize the amount of knowledge and skills received from multiple external sources. Since different types of innovation partnerships are complementary (Belderbos et al., 2004), there could be possible correlations between various cooperative strategies.

As already seen, there are different formal and informal channels of science-industry interactions. Focusing on innovation cooperation, we distinguish between four possible strategies of interaction: no cooperation, cooperation aimed at purchasing S&T services, implementing innovation based on the R&D of the knowledge producers — either new to the firm or new to the market (see Figure 1). The aim is to identify the factors that determine the decision of an innovative company to adopt the technologies developed by universities and R&D organizations as opposed to purchasing S&T service.

[1] http://www.isi.fraunhofer.de/isi-en/i/projekte/fems.php

Figure 1. Interaction strategies with knowledge producers



Source: National Research University Higher School of Economics

Given the central importance attached by the political bodies to building and supporting industry-science linkages, we investigate also possible obstacles to adopt the technologies. The respondents answered what they view as impediments to application of S&T results and successful technology transfer.

4 Science-industry relations in Russia

Russia is an interesting case, both in respect of the organizational structure of the R&D sector and ways to address challenges for sustainable S&T development posed by various global, macroeconomic and intra-industry changes.

There is a lack of diversity in types of organizations conducting R&D. The majority of public research in Russia is carried out by R&D organizations and not by universities, while in most European countries the situation is opposite (OECD, 2016) and universities (as well as public research bodies) ensure the competitiveness not only of fundamental research but also at the forefront of industrial innovation. In Russia, nearly 41% of all R&D is conducted by public research organizations that are legally independent from universities and businesses (HSE, 2017). These employ more than a half (59% in 2015) of total R&D personnel. Business sector and institutions of higher education contribute relatively minor proportions. During the past decade, the share of research produced by universities steadily increased (from 11% in 2005). Moreover, the higher education sector contributed 9.6% to total R&D expenditures in 2015 in comparison with 4.5% in 2000. This trend indicates the improving capacity of universities in the field of S&T, but most of the research activity is still carried out by scientific organizations.

It is essential that more than 60% of all organizations engaged in R&D are state-owned. It reflects the slow pace of structural reforms in Russian science and indicates that public research bodies have no need to seek sources of funding and develop their own innovative strategies. Knowledge diffusion and cooperation processes are hampered due to isolation of research organizations from universities and business enterprises.

Moreover, "complex of structural, resource, and institutional problems and imbalances" are important characteristics of the S&T and innovation sphere development (Gokhberg and

Kuznetsova, 2011, p. 27). The prevalence of state funding and limited scale of innovation activity in business sector are the main obstacles to promote effective science-industry linkages.

Firstly, financial flows are unstable and imbalanced. In 2015, gross domestic expenditure on R&D (GERD) accounted for 1.13% of GDP (HSE, 2017), compared to 1.05% in 2000 and 1.29% (maximum value) in 2003. By contrast, the ratio of R&D expenditure to GDP in the EU-engagement in 28 countries was 2.03% in 2015. By this measure, Russia lags behind many other countries. Whereas the budget funding of R&D activities has been on the rise in the recent years, the Russian R&D sector is still underfunded.

Secondly, this is aggravated by the passivity of business sector (Gokhberg and Kuznetsova, 2015), although the innovative companies, technology-driven start-ups and fast-growing SMEs are one of the key knowledge and technology producers. In Russia, the share of GERD funded by government still dominates (over 60%), while the contribution made by industry remains small (actually, it fells from 32.9% in 2000 to 26.5% in 2015). Meanwhile, in the EU-28 countries, the business enterprise sector is the main source of R&D funding (55.3% of total GERD in 2014), while government sector expenditures on R&D are less than a third. This indicates that Russian companies do not consider innovation as a strategic priority, while technology import is a common practice for them. In this case, it is questionable whether there is the need and desire for businesses to engage in collaborative scientific research activities with universities and research organizations.

The current funding model has its advantages and disadvantages. On the one hand, the state has the capacity to increase financial flows and investments for its priority areas, influence employee motivation, etc. at short notice. On the other hand, it cannot ensure the right choice of these priorities, efficient allocation of resources, sustained growth of R&D productivity and flexible respond to changes in internal and external environment. Moreover, the situation is compounded by a decline in budget revenues since 2015 due to the fall of oil prices, imposition if a sanctions regime and unpredictable geopolitical situation. Facing limited budgets, the choice of a policy mix always involves complex decisions on how to distribute available funding as effectively as possible.

The analysis of science-industry linkages in Russia should take into account all the features of the innovative activity and its institutional. Firstly, the innovation propensity of firms is very low. Poor framework conditions, various macroeconomic and intra-industry changes further complicate this issue. Secondly, there is a lack of contingency between the components of innovation systems, including the obsolete institutional structure of the public R&D sector and limited connections between industry and science.

The weighted data indicate that the majority (80.1%) of innovative manufacturing companies in Russia interact with several types of partners simultaneously; still there are few enterprises with an extensive partner network, which interact with counterparties from different sectors of the economy within a specific innovation project or line of business. The relatively high proportion of enterprises participating in rigid vertical cooperation (more than 70%) shows that businesses do not want to involve third parties in the innovation and production processes.

According to Table 3, the intensity of interaction with knowledge producers – with universities and R&D organizations – is relatively low (less than 30% for each group). More than a half (65.8%) do not cooperate with knowledge producers in innovation. For those who cooperate with the R&D sector in innovation activities, it a common practice to interact simultaneously with universities and research organizations (85%).

Table 3. Descriptive statistics for different channels of science-industry interactions

Variable	**Frequency (0)**	**Frequency (1)**
Cooperation with		
Universities	626 (77.8%)	179 (22.2%)
R&D organizations	587 (72.9%)	218 (27.1%)
Universities and R&D organizations	684 (85.0%)	121 (15.0%)
Universities and/or R&D organizations	530 (65.8%)	276 (34.2%)
Application of S&T results/ Adaptation of technologies developed by knowledge producers	141 (17.5%)	664 (82.5%)
Novelty level of products and services developed using the results obtained by knowledge producers		
New to the firm	732 (90.9%)	73 (9.1%)
New to the market	744 (92.4%)	61 (7.6%)

Note: Number of observations = 805

Source: National Research University Higher School of Economics

In case of cooperation, firms mostly focus on purchasing S&T services (17.5%) as opposed to adopting the technologies developed by research organizations and universities. Less than 10% of innovation-active companies establish R&D intensive interactions.

According to the review of theoretical and empirical studies on cooperative strategies, potential determinants of cooperative behavior patterns could be grouped into six categories measures of firm and industry characteristics, competition and market structure, technological opportunities, absorptive capacity, appropriability conditions and public support, which might be operationalized by various indicators.

General characteristics. This group includes basic firm characteristics, such as size (e.g. represented as a logarithm of average number of employees), age, ownership structure (state or foreign) and profitability (e.g. operationalized by a return on sales). In order to control cross-sectoral differences, particularly the technological intensity of the industry, dummy variables (e.g. low-tech, medium low-tech, medium high-tech and high-tech) based on NACE Rev 1.1 should be included.

Level of competition. This group of variables is related to the level of competitive intensity in the market. Indicators include the number of competitors, e.g. less than two direct competitors – monopoly, 2-5 competitors – oligopoly, presence of numerous buyers and sellers – competitive; and markets considered by firms as high-potential for further development, e.g. local, regional, national and/ or foreign.

Technological opportunities are related to the firm innovativeness. Characteristics of firm's innovative behavior include innovation intensity (e.g. operationalized by a share of innovation expenditures in the total turnover), role of continuous R&D activities, types of innovations important for the commercial success of a firm – product and/ or process innovation, and the length of the innovation cycle. Companies evaluate the importance of the following types of innovation, whether they implement it or not.

Absorptive capacity. Variables in this group indicate the extent to which companies can "identify, assimilate and exploit knowledge from the external environment" (Cohen & Levinthal, 1990). Indicators to measure the level of absorptive capacity could include the proportion of high-qualified staff (e.g. with a high education qualification and/or doctor degree) and organizational culture representing company management's attitude towards (1) the involvement of external partners at various stages of development and implementation of innovation, (2) independent exchange of idea among the various units of the company and (3) the presence of developed standard procedures for interaction with external parties, especially with research institutions (regulatory framework, standards for assessing quality research, etc.).

Another important question is who makes a greater innovation effort – company itself or its cooperation partner. Company's own efforts, though vital, are insufficient and indicate the value of industry-science cooperation.

Appropriability conditions include formal and informal mechanisms using by firms to protect intellectual assets and innovation from imitation. Formal methods include patents, industry design and utility model, registration of trademarks and information units, while informal (strategic) mechanisms are confidentiality, secrecy, lead-time and registered access to knowledge.

Public support indicates various instruments of government support. We distinguish between (1) horizontal public support intended to reach a wider public (e.g. tax remissions and preferences, depreciation bonuses, subsidizing of interest rates on loans), (2) targeted public support (e.g. state grants, introduction of new technical regulations and standards) and (3) various networking measures (such as programs for creation and support of technology platforms and regional innovation clusters). Companies point out about both currently and previously (in the last five years) used support mechanisms.

Table 4 provides descriptive statistics for possible determinants of cooperative strategies operationalized by the indicators described above.

Table 4. Explanatory variables of cooperative strategies

Variable	Short description	Mean	S.D.
General characteristics			
Size	Log of the average number of employees (at least 10)	5.438	1.488
Age	At least 5 years old	0.055	0.227
Foreign ownership	Foreign stakeholders (at least 10%)	0.070	0.255
State ownership	State owners (at least 10%)	0.130	0.337
Return on sales: 0-5% More than 5%	Return on sales before tax	 0.302 0.463	 0.459 0.499
Industry: High-tech Medium high-tech Medium low-tech	Aggregations of manufacturing based on NACE Rev 1.1	 0.149 0.258 0.229	 0.356 0.438 0.420
Level of competition			
Market structure: Monopoly Oligopoly	 Less than 2 direct competitors 2-5 direct competitors	 0.196 0.308	 0.397 0.462
Markets for future development: Regional	High-potential markets for further development	0.244	0.429

National Foreign		0.475 0.191	0.500 0.394
Technological opportunities			
Innovation intensity: Low Medium High	Share of development and implementation costs in the total turnover	0.308 0.319 0.135	0.462 0.467 0.342
Continuous R&D	Critical to business success	0.747	0.435
Innovation: Product Process	Critical to business success	0.922 0.988	0.269 0.111
Length of innovation cycle: Product Process	Length of innovation cycle is more than 3-5 years	0.226 0.189	0.419 0.392

Table 4. continued

Variable	Short description	Mean	S.D.
Absorptive capacity			
Highly qualified staff	Share of graduated employees and employees with a Candidate of Sciences, Doctor of Sciences (or PhD) degree in the total staff number	33.520	23.588
External culture	Promotion of the external partners involvement in innovation process	0.424	0.494
Culture - standard procedures	Existence of standard procedures for external cooperation in R&D	0.386	0.487
Internal culture	Promotion of the internal (inter-firm) independent exchange of ideas	0.427	0.495
Own effort	Company makes greater innovation effort than cooperation partners	0.637	0.481
Appropriability conditions			
Formal	Formal methods of IP protection	0.611	0.488
Informal	Informal methods of IP protection	0.599	0.490
Public support			
Horizontal	Tax remissions and preferences, etc.	0.244	0.429
Targeted	State grants, etc.	0.271	0.445
Networking	Technology platforms, clusters, etc.	0.096	0.294

Note: Number of observations = 805

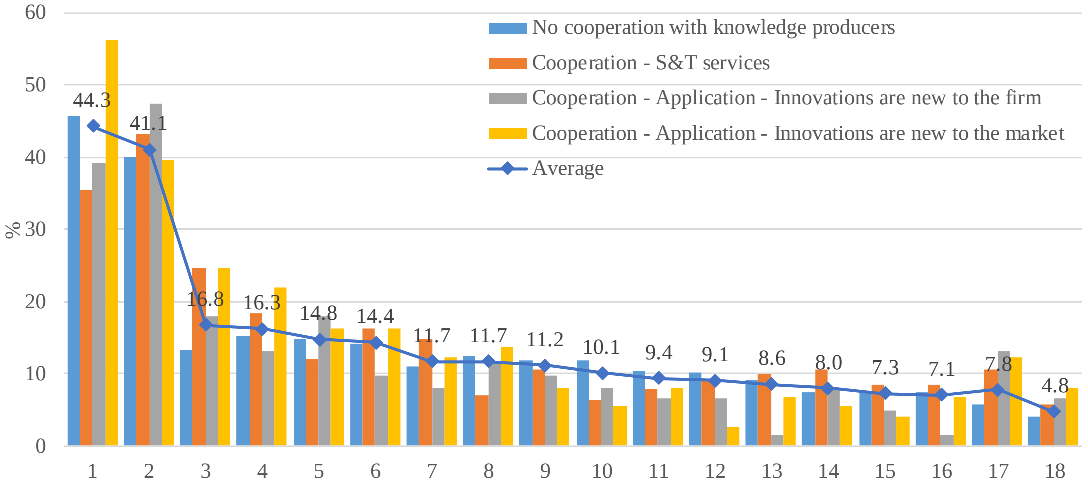
Source: National Research University Higher School of Economics

What are the main problems faced by innovation-active manufacturing enterprises when attempting to adopt technologies developed by domestic research institutions? As recognized by companies (see Figure 2), key constraints imply the lack of financial resources (44.3%) and high economic risks of new technologies adoption (41.1%). Firms focusing on the adoption of technologies developed by universities and R&D organizations, and the production of goods and services that are new for the market, more often complain about the lack of funding and higher competitiveness of foreign developments. High economic implementation risk and the shortage of qualified staff at business (such as engineers, technology specialists) are greatest for firms developing products and services that are new to the firm. Approximately 13% of companies preferring joint R&D-oriented activities come up against the problem of poor management at firm level.

The importance of each of the barriers varies considerably depending on the form of cooperation. In case of cooperation, companies focus on purchasing S&T services as opposed to adopting of new technologies in production, because besides financial constraints and high economic risks there is a problem of results not being sufficiently ready for practical implementation. Moreover, more than 16% of these companies refer to the low competitiveness of their technologies, as well as of goods and services compared to foreign ones.

Companies that decide not to cooperate with universities and R&D organizations in innovation note a poor innovation infrastructure as a barrier to the application of S&T results more often than those who cooperate.

Figure 2. Barriers to the application of scientific and technological results



1 Lack of financial resources
2 High economic risks of new technologies adoption
3 S&T results are not ready for practical introduction in innovation processes
4 Greater competitiveness of foreign technologies
5 Lack of qualified personnel (engineers, technologists)
6 Strong competition from imported goods and services
7 Technological risks related to the application of R&D results
8 Strong competition from other on domestic producers of goods and services
9 Other
10 Poor innovation infrastructure
12 Lack of information on new technologies in the company
13 Lack of cooperative ties with research organizations
14 Lack of qualified specialists to ensure the transfer of S&T results (economists, lawyers)
15 The disparity between the level of pilot research projects and the latest S&T achievements
16 Poor management in research organizations
17 Poor management in firms
18 General insufficient innovation legal and normative support
19 Legal and administrative barriers to the transfer and adoption of S&T results

Source: National Research University Higher School of Economics

5 Discussion and conclusion

This study explores the drivers that affect the contribution of the networking of companies and knowledge producers (i.e. universities and R&D organizations) into the general process of developing innovation. We present a literature review, the overall purpose of which is to discover incentives (i.e. potential determinants) and barriers to closer science-industry relations, forms of interaction and most important channels of knowledge transfer between academia and industry.

Pursuant to the detailed analysis of previous empirical studies on motives leading to innovation cooperation and factors affecting the choice of partners, we divide the determinants (i.e. explanatory variables) into six categories and develop a list of indicators to operationalize them. Groups include the following: general characteristics, level of competition, technological opportunities, absorptive capacity, appropriability conditions and public support. We give particular attention to the barriers faced by industries when attempting to adopt new technologies.

There are various channels of science-industry interactions, which differ substantially across scientific disciplines and industrial sectors. The opportunities for science-industry knowledge transfer are also affected by the characteristics of research institutions and industry, policy environment and specific features of national innovation systems. We distinguish between four possible strategies of science-industry interactions: no cooperation, cooperation aimed at purchasing research and advisory services (non-R&D oriented), implementing innovation based on the R&D of the knowledge producers — either new to the firm or new to the market.

The results confirm that the scale of industry-science linkages is generally determined by the overall propensity of business towards R&D-based innovation strategies. For the case of Russia, the general dominance of imitation and adoption of ready-made solutions hampers the overall demand on both in-house R&D and the research collaboration. Only 22.2% of innovative manufacturing companies maintain the on-going interaction with universities and 27.1% – with R&D organizations.

Other findings of interest include the results over the subject of interaction. In case of cooperation, less than 10% of innovation-active companies establish R&D intensive interactions and adopt the technologies developed by the Russian universities and research organizations. Meanwhile, partnerships aimed at purchasing S&T services (non-R&D oriented) are more widely spread.

Among the major constraints faced by companies when attempting to adopt technologies developed by universities and research organizations, firms most frequently mentioned lack of financial resources and economic uncertainty of innovation projects. Non-cooperators often complain about the insufficient innovation infrastructure. Enterprises that chose to adopt the developed technologies generally are more skilled with all the specific dimensions over the technology transfer and evaluate the R&D partner's performance higher.

In future work, the research will be strengthen by the econometric models estimation. Using the firm-level data on the Russian manufacturing enterprise, we will estimate a bivariate probit model to examine factors that influence the decision of manufacturing enterprises to cooperate with universities and R&D organizations in the process of creation and dissemination of innovations. A second phase of analysis will include an estimation of multinomial logit regression to investigate the determinants leading firms to choose a particular mode of interaction that ranges from purchasing S&T services to a full scale original R&D aimed at creating new-to-market innovation.

The findings will have a clear implication in terms of STI policy and for policies aiming to promote science-industry linkages, suggesting that determinants of cooperation with universities and with R&D organizations are heterogeneous. Especially important is also the assessment of the impact of public support measures (including various horizontal, networking and focused policy instruments) on the probability to cooperate and to adopt the technologies.

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