Empirical Study of Industry-Science Linkages in the Russian Manufacturing Sector

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Abstract

Using the firm-level data on innovation strategies of 805 manufacturing enterprises in Russia, we reveal company profiles that prefer R&D and technology transfer-oriented interactions and also to S&T services that not directly imply R&D. We investigate a broad range of intramural and external determinants, including absorptive capacity, technological opportunities, competition regime, appropriability conditions, public support, as well as barriers to the practical application of R&D results. Findings provide partial support for the general theory, revealing that the likelihood of cooperation and technology adoption is higher for large and technologically advanced companies with higher absorptive capacity and effective intellectual property management mechanisms. Still the influence of various factors on the probability and subject of cooperation is heterogeneous.

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

1 Introduction

One of the most efficient instruments to gain access to new knowledge at the firm and organization level is the formation and implementation of cooperative strategies. The increased complexity of knowledge processes and increased speed of information dissemination, which are the backbone of innovation and new technologies, lead innovative companies to capabilities search and collaborative learning beyond their boundaries. There are different types of cooperative strategies (cooperation within the supply-chain, market actors, knowledge producers, consulting firms, public authorities) and companies choose cooperation partners according to the purposes, areas of operations and other internal and external factors.

External sourcing and cooperation are nowadays widespread, corresponding to an open innovation model (Chesbrough, 2003). Innovative companies are interested in complementary knowledge (both tacit and codified) which could be acquired rather through strong relationships such as cooperation (Tödling et al., 2009). An effective and well-thought-out cooperation strategy can contribute to shorter innovation cycles, cost and risk sharing, economies of scale and scope, competitive advantage, and facilitating market access.

Cooperation with knowledge producers (i.e. universities and R&D organizations) hold 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 exploitation and commercialization of public research results play also a key role in national S&T policies, because being a source of innovation public research can enhance the development of new technologies for economic and social purposes (OECD, 2016). Thus, in order to enhance the capabilities of innovation systems is essential to strengthen and foster science-industry linkages.

Science-industry cooperation has attached considerable attention both in the literature and in the policy discussions (Kaufmann, Tödtling, 2001; Lee, 2000; Perkmann and Walsh, 2007; Schartinger et al., 2002). Empirical studies specifically dealing with science-industry innovation cooperation suggest that interactions with knowledge producers may be valuable and useful (Amara and Landry, 2005; Aschoff and Schmidt, 2008; Belderbos et al., 2004; Lööf and Broström, 2008). Still, science-industry cooperation is not one of the most frequent and the gap between the knowledge produced and what is used in practice is large.

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 particularly, 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 research organizations and universities. Using a large-scale cross-industry sample of innovation-active manufacturing firms located in Russia, we estimate a bivariate probit model to investigate the factors that influence the likelihood to cooperate with universities and research organizations. Then, we estimate a multinomial logit model to determine what affects the subject of interaction, paying particular attention to barriers to adopting new technologies. We distinguish between four forms of interaction with knowledge producers for innovation activities: no cooperation, cooperation aimed at non-R&D activities (i.e. 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. This meets the internationally accepted definitions of R&D and classifications of its component activities (OECD, 2015).

We suggest that a number of factors influences the decision to cooperate and the choice of interaction pattern. Pursuant to the detailed analysis of previous empirical studies on motives leading to innovation cooperation and factors affecting the choice of partners (Abramovsky et al., 2009; Dachs et al. 2008; De Faria et al., 2010; Tether, 2002 and other), we divide the determinants (i.e. explanatory variables) into six groups. They include the following: general characteristics, level of competition, technological opportunities, absorptive capacity, appropriability conditions and public support. We give particular attention to the factors preventing the technology adoption and research results application.

The findings indicate that in the Russian case the scale of industry-science linkages is generally hampered by low propensity of business to the R&D-based innovation strategies (dominance of imitation and borrowing of ready-made solutions). However, companies that cooperate greatly value the contribution of universities and other public research institutions in innovation process. Results provide partial support for the general theory, revealing that the likelihood of cooperation and technology adoption is higher for large and technologically advanced companies with higher absorptive capacity and effective intellectual property management. Other factors (e.g. form of ownership, focus on global markets, government incentives, factors preventing the application of S&T results) have different impacts depending on the subject of interaction. This suggests that policy-making to support science-industry linkages should be selective. Moreover, we find that existing STI policy framework seems not to promote the development of new industry-science linkages, only supporting existing cooperation (e.g. in terms of length of contracts).

The remainder of the paper is organized as follows. Section 2 focuses on theoretical and empirical background and examines debates about the drivers, patterns and success factors of science-industry linkages. Section 3 discusses the research approach and describes the model and data specification. Section 4 presents and analyses the econometric analysis results. Sections 5 contains a discussion and a conclusion.

2 Theoretical considerations and empirical evidence

2.1. Innovation cooperation between industry and science

Networks have long been recognized as playing an important role in innovation process (e.g. Powell and Grodal, 2005). There are different patterns of cooperative innovation strategies (e.g. cooperation within the supply chain, with market actors, knowledge producers, government bodies or consulting firms). Still universities and R&D organizations remain key producers and providers of knowledge, research and S&T results. Science-industry interaction is "one of the most prominent institutional interfaces for knowledge diffusion" (Robin and Schubert, 2013).

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 vs. applied and multidisciplinary vs. mono-disciplinary (Brennenraedts et al., 2006). The diversity of knowledge types makes a case for cooperation between academia and industry, which may be initiated both by firms (such as contract research) and scientific institutions (such as spinouts) (Perkmann and Walsh, 2007).

Science institutions fill in a specific niche in undertaking long-term basic research, providing access to international knowledge networks and conducting applied research and experimental development. Public research is an essential input in production processes of innovative firms, particularly in the initial stages of the innovation processes when "there is still low demand for the outcomes of innovation activities" (Jensen et al., 2003). New scientific and technological knowledge (not always oriented towards industrial application) may contribute to the realization of more advanced, radical innovations (Kaufmann, Tödtling, 2001), development of products, services and technologies brand new to the market (De Faria et al., 2010; Veugelers and Cassimann, 2005). Moreover, being a source of innovation public research can enhance the development of new technologies for economic and social purposes (Cohen et al., 2002; Mansfield, 1998; OECD, 2016). Results from Lee (2000) conclude that the key motivations of firms when collaborating with universities include research on product development, "blue sky" (explanatory) research in search of new technology and research oriented on technical problems solution.

Public science institutions could be considered as knowledge nodes (Schmidt, 2013). Instead of being providers of new knowledge, they often act as knowledge consumers. On the one hand, universities and research organizations accumulate knowledge generated not only within but also outside the organization, linking various knowledge sources. On the other hand, there are cases when the knowledge flow is bi-directional. According to Arza (2010), this is facilitated by proactive innovation strategies of companies and intellectual strategy (learning with respect to the subsequent application) of public science institutions.

However, firms often face a number of bottlenecks in appropriating the acquired knowledge for private goals. It is linked with the divergence of objectives between industry and science (Bruneel et al., 2010; Fiaz and Naiding, 2012). While science institutions are concerned first of all with research and education, the basic direction of firm activity is capturing valuable knowledge that can be leveraged for competitive advantage and an appreciation of the value of the firm. The contradictory relationship between industry and science is characterized by scientists' willingness to publicly disclose scientific and technological results and firms' desire to conceal research novelty. Therefore, the success of interactions depends heavily on the effectiveness of intellectual property (IP) system and an opportunity to ensure that the interests of both sides are respected at the highest level.

Regarding intellectual co-benefits, cooperation between industry and science institutions facilitates learning opportunities for all involved actors which in turn indirectly contribute to generating original creative ideas. This is achieved either through joint R&D and development of a joint innovation trajectory or by staff exchange among cooperation partners, including staff hiring and training (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 of demand for and supply of skills. The fact that human capital is "an essential input to innovation" (OECD, 2012) should also be taken into consideration.

Access to financial and in-kind resources is also a motivating factor behind cooperation between industry and science. Often, companies become initiators of innovation projects are ready to invest considerable effort and money for the success. Economic benefits are related to the achievement of extra funding and access to tangible assets (i.e. equipment, laboratories, material) (Tartari and Breschi, 2012). The support of industry-science collaborative research, 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; Veugelers and Cassimann, 2005).

In sum, science-industry cooperation in innovation activities is highly beneficial and may provide firms with access to knowledge, technology, network, contacts, talent, and resources of various kind. Yet, because of difference in norms and rules, which regularize science-industry interactions and high information asymmetries between partners, strong science-industry linkages are not frequent. The maturity of the 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 the case of developing countries, institutions (including public institutions, universities and R&D organizations, private sector actors, education and financial systems) are weak and have serious flaws. (Fischer et al., 2017; Rapini et al., 2009). This may negatively affect the spread and intensity of interactions between knowledge producers and private sector.

2.2 The diverse nature of science-industry linkages

Science-industry relationship has a multi-faceted nature and focuses on an intensive network-focused interaction during which knowledge, information and other resources are exchanged or co-produced across both sectors (Perkmann and Walsh, 2007; Zaichenko et al., 2014). A number of factors determine the form of interaction between academy and industry, the most valuable of which are the type of knowledge transferred, the direction of the knowledge flow, characteristics of knowledge senders and receivers (including geographical proximity to each other), and also the alleged intensity and duration of relations. The stream of research focuses on the forms of knowledge interactions between both sectors and channels of knowledge transfer, proposing various classifications.

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 are consistent with the goals of private companies. 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. Thereby, the majority of firms can easily implement the results. Research partnerships, by contrast, generate intellectual outputs that are high of academic relevance, but inappropriate for business goals. Research partnerships include collaborative R&D agreements with knowledge providers, also known as sponsored research. Often, both forms of interaction between industry and science are practiced simultaneously.

Schartinger et al. (2002) argue, that in addition to "contract research" (including consulting) 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). "Different types of knowledge interactions represent different strategies" (Schartinger et al., 2002) and aim 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 flow predetermine the choice of interaction pattern.

According to Bekkers and Bodas Freites (2008) there are four typical ways of knowledge transfer between industry and science sectors: codified output, collaborative and contracted research, personnel exchange and informal contacts. They explain 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.

Another classification of types of knowledge relations is developed by, Lehner and Kaufmann (2009). The authors distinguish between two dimensions: formalization (degree of commercialization) and dynamism of knowledge relations, leading to the following four modes of interactions. "Market relations" are traded relations and include transfer of explicit pieces of knowledge (e.g. patents, machinery) from R&D sector to industry in exchange for money. Static relations with a transmission of untraded knowledge represent "knowledge externalities and spillovers" which in particular result from informal face-to-face contacts and staff mobility. Dynamic relationship between scientific institutions and business sector support the collective learning practiced in form of "cooperation" (i.e. formal agreements) or "informal networks" that are largely based on social capital and trust. Moreover, since an exchange of scientific (often tacit) knowledge requires intensive personal contacts, spatial proximity of parties (e.g.

on local or regional level) facilitates innovation relationships, knowledge exchange and spillovers (Tödling et al., 2009).

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 et al. (2002) taxonomy, they established a more detailed classification that comprises 40 possible ways of knowledge transfer. The authors argue that the choice of knowledge transfer mechanisms stems from the phase of the innovation cycle and the innovation system in general.

More recently, some new mechanisms for the commercialization of publicly developed R&D have emerged, for example, public-private partnerships, open science initiatives (student-based start-ups) and entrepreneurial channels (financing and mobility schemes) (OECD, 2016).

Companies choose the type of knowledge and/or technology transfer depending on the goal of cooperation. 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 are often representative of strategic collaborations, characterizing by deeper interactions between scientific institutions and businesses. The result of R&D-oriented cooperation is often linked to the adoption of technologies, developed by universities and R&D organizations. Science-industry linkages oriented to consultancy, training and other non-R&D activities are mostly of an operational nature (Rapini et al., 2009). The object (or the knowledge exchange content) of interactions between knowledge producers and private sector predetermine the outcome of joint efforts and their impact on innovative performance of firms.

Hence, knowledge and technology created by universities and research organizations reach markets through many channels, which vary across industries, scientific disciplines, in the types of knowledge transferred, in the intensity of personal contacts, framework conditions, and individual and organization’s specificities. These factors serve also for the basis for classifying various forms of interactions between industry and science.

2.3 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.

Russia has got a significant scientific heritage from the Soviet period, which obviously cannot contribute to modern economy but eliminates the need to build the system from scratch. There is a lack of diversity in types of organizations conducting R&D. The majority of public research in Russia is carried out by research 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.

Nearly 41% of all R&D is conducted by public research organizations that are organizationally separate 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 conduct relatively small share of R&D: 8.8% and 24.9% respectively. 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, the development of the S&T complex and innovation sphere is characterized by “a complex of structural, resource, and institutional problems and imbalances” (Gokhberg and Kuznetsova, 2011). 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, although "technology-based start-ups and fast-growing innovative companies, including small and medium-sized enterprises (SMEs)" (Gokhberg and Kuznetsova, 2015) are one of the key knowledge and technology producers. In Russia, the share of GERD funded by government still exceeds (more than 60%), while the contribution made by industry remains small (actually fell 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, flexible respond to changes in internal and external environment, sustained growth of R&D productivity, etc. 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. All this reduces prospects for S&T progress.

All discussed above features of S&T development in Russia define the conditions under which interactions between industry and knowledge producers (R&D organizations and universities) occur. A more detailed analysis of network cooperation in Russia reveals that industry is weakly involved in cooperation with universities and research organizations (Gokhberg and Kuznetsova, 2011; Zaichenko et al., 2014; Roud and Vlasova, 2016). The question of factors influencing the decision on cooperation and the object of interaction remains open.

3 Data and methods

3.1 Econometric models

A number of empirical studies have explored the determinants of science-industry (e.g. Bayona et al., 2002; Belderbos et al., 2004; Simachev et al., 2014; Veugelers and Cassiman, 2005). They indicate the importance of firm size, R&D intensity (as a proxy for the absorptive capacity), government support and characteristic of conducting continuous R&D as drivers for cooperation. Nevertheless, Eom and Lee (2010) and Mohnen and Hoareau (2003) did not find that R&D intensity contribute positively towards explaining linkages with universities and research organizations. Industry characteristics are also variables that influence the decision of firms to cooperate with knowledge producers (e.g. Arranz and Fdez. de Arroyabe, 2008; Franco and Gussoni, 2010; Tether, 2002).

In recent years, more and more studies have focused on studying the impact of cooperation with the knowledge production sector on firms' innovation performance, but the results are contradictory. Arvanitis et al. (2008) and Lööf and Broström (2008) find for Swedish innovative companies that collaboration with universities has a positive influence on innovation activity of manufacturing firms and on sales of new products provided that interaction are oriented on research activities. 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 firms' innovation output using data from Germany and Denmark, respectively. In contrast, evidence contradicting the importance of cooperation with knowledge producers 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).

The relatively few studies are trying to investigate empirically what are the determinants of forms and channels of science-industry interaction. Nevertheless, this has a significant impact on the quality of cooperation and possible effects for the firm's activities. 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 of their interaction.

Each firm chooses between two alternatives: to cooperate with universities or with research organizations. We also consider that it is possible to interact with universities and scientific organizations simultaneously. There is also a possibility to engage in cooperation with both partners 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. In an econometric context, if equations are statistically correlated, the independent estimation of them creates a selection bias problem. Thus, for modeling of such decision-making process, we estimate a bivariate probit model.

Secondly, we investigate in what forms industry and science interact. The aim is to identify the factors that determine the decision of an innovative company to adopt the technologies developed by universities and research organizations as opposed to purchasing S&T service. We assume several modes of science-industry interaction in innovation activities. Since the dependent variable is discrete, takes on more than two outcomes that have no natural ordering, we estimate a multinomial logit model (MLM) (Greene, 2012, 803-805). We perform maximum likelihood estimation (MLE) to calculate the probability to choose one of the strategies. This method is considered as simultaneously estimating binary logits for all comparison among alternatives on the assumption of their independence. We draw conclusions about the direction, significance and magnitude of the relationship between a predictor and the choice outcomes based on the marginal effects.

3.2 General information on data source

The empirical analysis uses data from a specialized survey entitled "Monitoring the innovation activity of actors of the innovative process" (https://www.hse.ru/en/monitoring/innproc/) conducted in 2014-2015 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 (OECD, 2005) as well as techniques from the long-running 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 (http://www.isi.fraunhofer.de/isi-en/i/projekte/fems.php). 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.

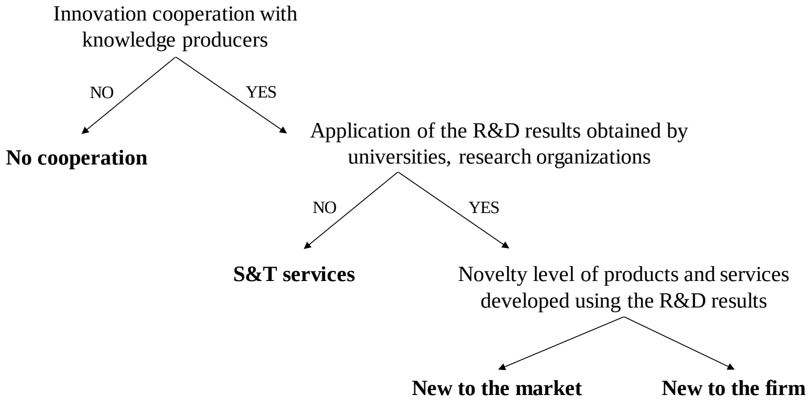
In this paper, we look at the subset of the innovation-active manufacturing firms that replied positively to a question regarding the implementation any type of innovation during the last three years ("Which of the following types of innovations have been successfully implemented in your company in the period from 2011 to 2013?"). 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. The sample of 805 innovative manufacturing companies are representative of innovation cooperation patterns in Russian manufacturing sector. The brief sample characteristics are presented in Table A1 in Appendix 1.

3.3 Models specification

To identify the key factors that influence the likelihood to cooperate with knowledge producers in innovation activities we estimate a bivariate probit model. The empirical model includes two dummies for innovation cooperation types with the different possible partners: universities (y_1) and research organizations (y_2). The response variables are constructed from a question: "With whom cooperates your enterprise while generation and implementation of innovations?" We also consider the possibility of simultaneous interaction with universities and scientific organizations within a framework of a joint strategy.

To investigate in what forms industry and science interact, 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).

Figure 1. Interaction strategies with knowledge producers



According to Table 1, the intensity of interaction with knowledge producers – with universities and R&D organizations – is low (less than 30% for each group). More than 65% of companies 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 (43.8%). 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%).

Table 1. Descriptive statistics for different science-industry cooperation modes [a]

Variable	Observations	Frequency (0)	Frequency (1)
Cooperation with universities	805	626 (77.8%)	**179 (22.2%)**
Cooperation with research organizations	805	587 (72.9%)	**218 (27.1%)**
Cooperation with universities **and** research organizations	805	684 (85.0%)	121 (15.0%)
Cooperation with knowledge producers (universities **and/or** research organizations)	805	**530 (65.8%)**	276 (34.2%)
Application of the R&D results/ Adaptation of technologies developed by knowledge producers	805	**141 (17.5%)**	664 (82.5%)
Novelty level of products and services developed using the results achieved by knowledge producers:			
New to the firm	805	732 (90.9%)	**73 (9.1%)**
New to the market	805	744 (92.4%)	**61 (7.6%)**

[a] Response variables in bold

We use the same set of explanatory variables in both models. Potential determinants of cooperative behavior patterns (explanatory variables) are grouped into six categories according to the review of theoretical and empirical studies on cooperative strategies (for details, see Roud and Vlasova, 2016). The characteristics we focus on are measures of general characteristics, level of competition, technological opportunities, absorptive capacity, appropriability conditions and public support. Given the central importance attached by the political bodies to building and supporting industry-science linkages, we include several possible obstacles to adopt the technologies as explanatory variables in the multinomial logit model. For the more detailed construction of the response and explanatory variables, see Table A2 in the Appendix 2. The means and standard deviations for the each group of determinants are presented in Table A3 in the Appendix 3.

General characteristics. This group includes basic firm characteristics, such as size (*size*) represented as a logarithm of average number of employees and included in the model as a continuous variable; experience on the market (*age_less5*); ownership (*state* or *foreign*) and profitability, variables assessing the operating results as a return on sales index (*ROS*). Furthermore, we include four industry dummy variables based on NACE Rev 1.1 to indicate sectoral differences.

Level of competition. This group of variables is related to the competition on the market and market development strategies. We measure competition as number of competitors on the market, differentiating between *monopoly, oligopoly* and *competitive market*. The choice of markets that innovative companies consider as highly potential for further development (*local, regional*, *national* and *foreign*) also influence competitive intensity.

Technological opportunities. The third group of variables is related to the firm innovativeness. We include variables measuring the innovation intensity, i.e. the share of innovation expenditures in the total turnover: *low* – less than 2.5%, *medium* – from 2.5% to 10% and *high* – more than 10%. At the center of interest are variables for types of innovations, which are important for the commercial success. We include three dummy variables for *continuous R&D*, development and/or implementation of significantly improved or fundamentally new types of products (*product_inn)* and process (*process_inn*). Furthermore, there are two period variables (*product_long* and *process_long*), when the process of development and/or implementation of innovations is long and takes more than 3-5 years.

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). Absorptive capacity is measured along three dimensions: staff skills (*staff_high*) – the share of employees with a high education qualification and/or doctor degree, the value of the cooperation partners' efforts (*own_effort*) – takes the value 1 if the majority of implemented innovations were developed predominately by company's own efforts, and corporate culture. Culture variables measure the company management attitude towards the involvement of external partners at various stages of development and implementation of innovations (*culture_coop_external*), independent exchange of idea among the various units of the company (*culture_coop_internal*) and the presence of developed standard procedures for interaction with the implementing partners of research and development (*culture_coop_procedures*).

Appropriability conditions. We include two variables measuring the firm's ability to protect their intellectual assets and innovations from imitation. We distinguish between formal methods to protect the innovation (*formal*), such as patenting of inventions, industry designs and utility models, registration of trademarks and information units, etc. and informal mechanisms (*informal*), such as confidentiality agreements with the company's personnel or commercial confidentiality ("know-how").

Public support. Variables in this group indicate the availability of financial and other support by public authorities. The mechanisms of public support are presented by three dummy variables. Companies may receive public support through tax remissions and preferences, depreciation bonuses, subsidizing of interest rates on loans (*ps_horizontal*) or receive targeted support (*ps_targeted*), including contracts under federal targeted programs, state grants. Moreover, there are various networking measures (*ps_networking*), such as programs for creation and support of technology platforms and regional innovation clusters.

4 Estimation results

Table 2 contains the estimation results of the bivariate probit model and the marginal effects corresponding to the coefficients from the Appendix 4 Table A4. We create a separate Table 3 for barriers-determinants from the multinomial logit model for a more convenient interpretation of the results.

The estimation results of the determinants of innovation cooperation with knowledge producers suggest that company and industry characteristics are more important that public incentives aiming to promote industry-science cooperation. Despite the fact that industry-science linkages are weak, those that cooperate, highly appreciate the contribution of universities and research organizations. This is indicated by the negative significant coefficients of the *own_effort* variable.

Table 2. Determinants of cooperative strategies with knowledge producers

		Bivariate probit model: fact of cooperation		Multinomial logit model (marginal effects): mode of interaction			
		Universities	Research organizations	No cooperation with R&D sector	Cooperation - S&T services	Cooperation - Application - New to the firm	Cooperation - Application - New to the market
General characteristics	Size	0.101**	0.096**	-0.035***	0.016	0.016***	0.002
		(0.044)	(0.045)	(0.013)	(0.011)	(0.006)	(0.002)
	Age_less5	-0.495	-1.031***	0.133**	-0.073	-0.048***	-0.012
		(0.305)	(0.395)	(0.053)	(0.049)	(0.017)	(0.008)
	Foreign ownership	-0.241	-0.171	0.116***	-0.088**	-0.027	-0.001
		(0.227)	(0.231)	(0.045)	(0.036)	(0.018)	(0.009)
	State ownership	0.300*	0.166	-0.061	0.065	-0.005	0.001
		(0.167)	(0.166)	(0.060)	(0.054)	(0.019)	(0.008)
	Return on sales:					*Baselevel: Negative*	
	ROS (0-5%)	0.160	-0.0739	-0.019	-0.026	0.043	0.003
		(0.158)	(0.160)	(0.048)	(0.039)	(0.028)	(0.009)
	ROS (more than 5%)	0.127	0.0515	-0.049	0.055	-0.002	-0.004
		(0.147)	(0.147)	(0.044)	(0.037)	(0.021)	(0.008)
	Industry:					*Baselevel: Low-tech industries*	
	High-tech	0.742***	0.892***	-0.320***	0.155**	0.087*	0.077*
		(0.186)	(0.186)	(0.074)	(0.069)	(0.047)	(0.044)
	Medium high-tech	0.518***	0.438***	-0.203***	0.149***	0.019	0.036
		(0.157)	(0.158)	(0.057)	(0.051)	(0.027)	(0.023)
	Medium low-tech	0.357**	0.0390	-0.0905	0.009	0.015	0.066*
		(0.160)	(0.168)	(0.056)	(0.043)	(0.026)	(0.035)
Level of competition	Market structure:					*Baselevel: Competitive market*	
	Monopoly	0.0649	-0.128	0.032	-0.062*	0.008	0.023
		(0.149)	(0.156)	(0.044)	(0.032)	(0.022)	(0.015)
	Oligopoly	0.0547	0.129	-0.017	0.007	-0.003	0.013
		(0.126)	(0.128)	(0.038)	(0.032)	(0.017)	(0.010)
	Markets for future development:					*Baselevel: Local markets*	
	Regional	0.0167	0.341	-0.073	0.096	-0.021	-0.002
		(0.261)	(0.313)	(0.093)	(0.089)	(0.032)	(0.020)
	National	0.322	0.769***	-0.182**	0.131*	0.025	0.026
		(0.243)	(0.295)	(0.078)	(0.071)	(0.037)	(0.025)
	Foreign	0.415	0.684**	-0.238**	0.192*	0.017	0.029
		(0.266)	(0.315)	(0.109)	(0.110)	(0.046)	(0.042)
Technological opportunities	Share of development and implementation costs in the total turnover:						
	High	0.110	0.0760	0.028	-0.046	-0.010	0.028
	(more than 10%)	(0.192)	(0.200)	(0.056)	(0.043)	(0.024)	(0.021)
	Medium	0.0468	0.291*	-0.081	0.051	0.033	-0.003
	(2.5-10%)	(0.153)	(0.156)	(0.049)	(0.042)	(0.025)	(0.008)
	Low	-0.0008	0.0154	-0.013	0.019	-0.002	-0.005
	(less than 2.5%)	(0.155)	(0.162)	(0.048)	(0.042)	(0.021)	(0.008)
	Continuous R&D	-0.0022	-0.0784	0.035	-0.062**	0.002	0.024**
		(0.123)	(0.127)	(0.037)	(0.031)	(0.017)	(0.011)
	Product innovation	-0.159	-0.161	0.062	-0.063	0.009	-0.008
		(0.156)	(0.160)	(0.052)	(0.047)	(0.020)	(0.011)
	Process innovation	-0.0306	-0.0818	0.0005	0.003	-0.006	0.004
		(0.158)	(0.158)	(0.047)	(0.039)	(0.023)	(0.009)
	Long product innovation	0.0968	-0.114	0.014	-0.019	0.003	0.003
		(0.151)	(0.159)	(0.046)	(0.037)	(0.020)	(0.008)
	Long process innovation	0.154	0.208	-0.042	0.045	0.005	-0.008
		(0.160)	(0.162)	(0.053)	(0.046)	(0.022)	(0.007)
Absorptive capacity	High qualification of the	0.003	0.002	-0.0005	0.0007	-0.0002	0.0001
	staff	-0.0024	-0.0024	(0.001)	(0.0006)	(0.0003)	(0.0001)
	Culture - external	0.288**	0.191	-0.084**	0.035	0.033*	0.016*
	cooperation	(0.121)	(0.125)	(0.039)	(0.033)	(0.019)	(0.009)
	Culture - procedures for	0.170	-0.191	-0.007	0.011	-0.002	-0.002
	cooperation	(0.122)	(0.129)	(0.038)	(0.033)	(0.016)	(0.007)
	Culture - internal	-0.026	-0.023	0.016	0.011	-0.025	-0.002
	cooperation	(0.115)	(0.117)	(0.035)	(0.030)	(0.015)	(0.006)
	Own effort	-0.663***	-0.358***	0.156***	-0.067**	-0.064***	-0.024**
		(0.111)	(0.114)	(0.038)	(0.031)	(0.021)	(0.011)
Appropriability conditions	Methods of intellectual property protection:						
	Formal	0.365***	0.153	-0.056	0.034	0.007	0.015*
		(0.128)	(0.130)	(0.037)	(0.031)	(0.017)	(0.008)
	Informal	0.301**	0.431***	-0.129***	0.105***	0.012	0.012*
		(0.124)	(0.129)	(0.037)	(0.030)	(0.015)	(0.007)
Public support	Public support measures:						
	Horizontal	0.213	0.0945	-0.0901**	0.060	0.024	0.006
		(0.135)	(0.138)	(0.047)	(0.039)	(0.021)	(0.008)
	Targeted	-0.098	0.080	0.021	-0.036	0.009	0.005
		(0.136)	(0.137)	(0.040)	(0.033)	(0.019)	(0.008)
	Networking	0.277	0.308	-0.094	0.011	0.089*	-0.007
		(0.190)	(0.189)	(0.071)	(0.052)	(0.047)	(0.006)
	Constant	-2.294***	-2.457***				
		(0.356)	(0.399)				
Number of observations		805		805			
LogL		-650.123		-591.773			
Likelihood-ratio test		chi2(1) = 82.188 Prob >chi2 = 0.000		chi2(150) = 415.98 Prob >chi2 = 0.000			
Cross-equation error correlation (ρ)		0.722*** (0.0867)		-			
Pseudo R2		-		0.2601			

* significant at 10%; ** significant at 5%; *** significant at 1%
Standard errors in parentheses

The results provide support for the general theory, revealing that the size and the level of technological intensity in the industry positively and highly significantly affects the propensity to cooperate with representatives of the science sector. The likelihood of collaboration with research organizations increases for long-established firms, which connect the prospects of business development with national and foreign markets, as well as have a greater innovation intensity (share of innovation expenditure in the total turnover is higher than 2.5%). The propensity to engage in innovation cooperation with universities increases for the state-owned enterprises.

Our findings for the effects of absorptive capacity show that supportive culture for the involvement of external parties in innovation process encourages firms to cooperate with universities. Meanwhile, there is no influence of the type of innovation and the duration of their development on the probability of cooperation with knowledge producers.

Following the fact that firms often face problems in appropriating the commercially valuable research results, effective legal and informal appropriability mechanisms significantly increase the likelihood of firms to engage in cooperation with knowledge producers.

The cross-equation correlation between the decisions to cooperate with universities and research organizations is positive (0.722), and highly statistically significant, suggesting that there are other unobserved characteristics that influence both decisions. The null hypothesis indicating that the two equations are independent is rejected, justifying the use of bivariate probit model.

The results of multinomial logit model estimation suggest that the profiles of firms interested in the technology acquisition and adaptation differ significantly from profiles of firms oriented towards consulting activities and purchasing other S&T services. The findings show that the existence of high absorptive capabilities increase the firm's probability to be involved in R&D-oriented partnerships with knowledge producers (instead of the absence of cooperation and consulting, technical forms of cooperation). If the management of the company approves cooperation with external parties in innovation projects, the quality of cooperation increases – firms adopt technologies developed by universities and research organizations and create products and services with a high level of novelty. Moreover, adopters of new technologies generally evaluate the capabilities of R&D organizations higher than other firms.

We find a significant positive effect of performing R&D in-house on a continuous base on the likelihood to develop major innovations (products or services new to the market). Firms considering continuous R&D as critical to business success would rather not cooperate with knowledge producers than cooperate without the goal of application the R&D results into innovation processes. The results confirm the importance of effective and strategic management of intellectual property when developing new products/services using the knowledge obtained from universities and research organizations. For companies cooperating with the aim of purchasing S&T services (instead of adopting the technologies) effective informal appropriation mechanisms play an important role (the marginal effect for *informal* variable is relatively large).

The decision, whether or not to adopt the technologies developed by universities and research organizations is practically not predetermined by the availability of public support and level of competition in the market. Nevertheless, the lack of competition reduces the likelihood of innovation cooperation with knowledge producers for technical, consultancy, training and other activities. Focus on global markets as opposed to local niches significantly fosters cooperation with a view to purchase S&T services.

The estimation results support the idea that R&D intensive interactions with representatives from science sector (oriented towards R&D results application and technologies adoption) tend to be concentrated in high-tech sectors. The inclination to adopt the technologies developed by research organizations and universities and develop innovations to the firm increases as firm gets larger and older. Innovation cooperation aimed at purchasing S&T services as opposed to adopting the technologies is also more frequent in high- and medium-high technology manufacturing sectors. However, foreign stakeholder participation in company management decisions hampers such form of cooperation (the foreign ownership variable has a significantly negative impact).

To understand the nature of industry barriers to adopt the technologies developed by universities and research organizations in case of cooperation, we explore the different obstacles that companies face. As recognized by innovation-active companies, key barriers imply the lack of financial resources (44.3%) and high economic risks of new technologies adoption (41.1%) (Table A3). Nevertheless, the importance of each of the barriers varies significantly depending on the form of cooperation.

Table 3. Barriers to the application of R&D results achieved by universities and research organizations

	No cooperation with R&D sector	Firms that cooperate with R&D sector in innovation activities		
		S&T services	Application_ New to the firm	Application_ New to the market
Lack of financial resources	-0.033	-0.014	**0.051*** **	-0.004
	(0.038)	(0.031)	(0.019)	(0.006)
High economic risks of new technologies adoption	0.016	0.004	-0.022	0.002
	(0.036)	(0.031)	(0.015)	(0.006)
S&T results are not ready for practical introduction in innovation processes	**-0.095***	0.047	**0.052***	-0.004
	(0.054)	(0.043)	(0.031)	(0.007)
Greater competitiveness of foreign technologies	0.036	-0.044	0.013	-0.005
	(0.042)	(0.033)	(0.022)	(0.007)
Lack of qualified personnel (engineers, technologists)	-0.011	-0.011	0.014	0.007
	(0.051)	(0.042)	(0.025)	(0.011)
Strong competition from imported goods and services	-0.009	0.028	-0.009	**-0.011***
	(0.049)	(0.044)	(0.018)	(0.007)
Technological risks related to the application of R&D results	-0.013	0.028	-0.007	-0.008
	(0.053)	(0.047)	(0.020)	(0.007)
Strong competition from other on domestic producers of goods and services	0.036	-0.059	0.018	0.005
	(0.052)	(0.039)	(0.029)	(0.012)
Other	-0.015	0.015	0.007	-0.007
	(0.062)	(0.053)	(0.031)	(0.007)
Poor innovation infrastructure	**0.110****	**-0.077****	-0.029	-0.003
	(0.043)	(0.036)	(0.018)	(0.009)
Lack of information on new technologies in the company	0.020	-0.015	-0.001	-0.004
	(0.057)	(0.048)	(0.027)	(0.009)
Lack of cooperative ties with research organizations	0.059	-0.010	**-0.045*****	-0.004
	(0.053)	(0.048)	(0.016)	(0.009)
Lack of qualified specialists to ensure the transfer of S&T results (economists, lawyers)	0.036	0.004	-0.022	**-0.018****
	(0.059)	(0.053)	(0.020)	(0.007)
The disparity between the level of pilot research projects and the latest S&T achievements	-0.023	0.045	-0.028	0.006
	(0.069)	(0.062)	(0.020)	(0.015)
Legal and administrative barriers to the transfer and adoption of S&T results	-0.123	0.052	0.045	0.026
	(0.076)	(0.059)	(0.042)	(0.022)
Poor management in research organizations	0.025	0.012	-0.022	**-0.015****
	(0.061)	(0.055)	(0.023)	(0.006)
Poor management in firms	-0.042	0.058	0.0002	**-0.016****
	(0.070)	(0.064)	(0.029)	(0.007)
General insufficient innovation legal and normative support	-0.172	0.083	0.081	0.009
	(0.107)	(0.087)	(0.064)	(0.017)

* Derived from full marginal effects estimation for the multinomial logit model

Table 3 shows that non-cooperators often reference to insufficient innovation infrastructure, while companies focusing on purchasing S&T services as opposed to adopting the technologies less frequently complain about the lack of development innovation infrastructure. Enterprises that chose to adopt the developed technologies and create innovations new to the market consider poor management in companies and research bodies and strong competition from imported products and services as the main constraints in applying scientific and technological results. The lack of qualified personnel to ensure the transfer of S&T results (e.g. lawyers, economists, managers) is also a major constraint for the technologies adoption and innovations of high novelty creation.

Firms that use technologies developed by universities and research organizations to create innovations new to the firm most often note the lack of financial resources and insufficient readiness of S&T results for practical implementation as significant barriers. At the same time, they less frequently complain about the lack of collaborative links with research organizations.

5 Discussion and conclusions

This study analyzes the importance of cooperation with knowledge producers (i.e. universities R&D organizations) for the development of innovation activities, particularly the determinants of the industry-science linkages. We investigate the motives leading firms to interact with universities and public research institutions and the modes of interaction, which indirectly determine the effect of cooperation on the firms' innovative performance.

We present an econometric analysis on the internal factors (such as absorptive capacity and technological opportunities), external conditions (such as competition regime and public support), as well as barriers faced by industries when attempting to adopt new technologies, using the firm-level data for Russian innovative manufacturing enterprises.

The results confirm that the scale of industry-science linkages in Russia is generally hampered by low propensity of business to the R&D-based innovation strategies (dominance of imitation and borrowing of ready-made solutions). Only 22.2% of innovative manufacturing companies maintain the on-going interaction with universities and 27.1% – with research organizations. However, those that cooperate, praise the contribution of research organizations and universities.

The obtained results 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. Our analysis show that large state-owned companies operating in technology-intensive sectors, that rate innovation cooperation with external parties as important and are able to appropriate the returns to innovative activities, have a higher probability of cooperation with universities. The propensity of cooperation with R&D organizations, in turn, increases as firms get larger and older, invest significant resources in innovation activities and focus on global markets as opposed to local niches. The decision on cooperation with knowledge producers is not associated with the internal R&D activities, profitability of the firm and its innovation strategy, which indicates the development of historically established collaborative links (instead of the establishment of new partnerships).

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. The profiles of companies vary significantly depending on the form and purpose of the cooperation. The decision whether or not to adopt technologies greatly depends on the extent to which firms are able to benefit from external knowledge flows, importance of global markets for business development and various firm-specific (such as size, age and ownership structure) and industry characteristics (such as competitive regime, technology intensity).

Among the main problems faced by companies when attempting to adopt the 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.

Moreover, our results suggest that the direct impact of public support measures on the probability to cooperate and to adopt the technologies is lower than the effect of general environment characteristics and the level of absorptive capacity. The existing STI policy framework (including various horizontal, networking and focused measures) seems not to encourage new industry-science linkages, only supporting existing cooperation (e.g. in terms of length of contracts). The receipt of public support is also weakly related to the decision whether or not to adopt the technologies, i.e. there is no direct connection between public incentives and higher quality (R&D intensive) partnerships.

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Appendix 1

Table A1

Sample characteristics

Manufacturing sector	Innovation-active	Cooperation with knowledge producers
Food and Beverages	83	16
Textiles, clothing and shoes	58	11
Wood and paper	50	9
Printing and Publishing	47	6
Petrochemistry, coal and nuclear fuel	21	6
Rubber, plastics and nonmetallic goods	55	12
Chemical production	54	29
Pharmaceuticals	41	23
Metallurgy	51	20
Metallic products	60	19
Machinery and Equipment	94	51
Precision instruments and computers	44	29
Railway transport and shipbuilding	43	11
Automobiles	27	12
Aircraft and space	23	17
Other manufacturing	54	5
Total	**805**	**276**

Appendix 2

Table A2

Definition of the explanatory variables

	Variable	Description
General characteristics	Size	Log of the average number of employees in 2013 (at least 10)
	Age_less5	Dummy variable with value 1 if a firm was established after 2010
	Foreign ownership	Dummy variable with value 1 if a firm has foreign ownership
	State ownership	Dummy variable with value 1 if a firm has state ownership
	Return on sales:	
	ROS (0-5%)	Dummy variable with value 1 if the return on sales in 2013 (before tax) was 0-5%
	ROS (more than 5%)	Dummy variable with value 1 if the return on sales in 2013 (before tax) was more than 5%
	Industry:	
	High-tech	Dummy variable with value 1 if a firm belongs to high technology manufacturing based on NACE Rev. 1.1 codes (24.4, 30, 32, 33, 35.3)
	Medium high-tech	Dummy variable with value 1if a firm belongs to a medium-high technology industry based on NACE Rev. 1.1 codes (24, 29, 31, 34, 35)
	Medium low-tech	Dummy variable with value 1 if a firm belongs to a medium-low technology industry based on NACE Rev. 1.1 codes (23, 25 to 28, 35.1)
	Base level: Low-tech	Dummy variable with value 1 if a firm belongs to a low technology industry based on NACE Rev. 1.1 codes (15 to 22, 36, 37)
Level of competition	Market structure:	
	Monopoly	Dummy variable with value 1 if a firm has no direct competitors or has less than 2
	Oligopoly	Dummy variable with value 1 if a firm has 2-5 main competitors
	Base level: Competitive market	Dummy variable with value 1 if a firm has more than 5 main competitors
	Markets for future development:	
	Base level: Local	Dummy variable with value 1 if prospects for company development are associated with local markets
	Regional	Dummy variable with value 1 if prospects for company development are associated with regional markets
	National	Dummy variable with value 1 if prospects for company development are associated with national markets
	Foreign	Dummy variable with value 1 if prospects for company development are associated with foreign markets
Technological opportunity	Share of development and implementation costs in the total turnover:	
	Base level: no costs	Dummy variable with value 1 if there were no costs for implementation of new products in 2013
	Low_inno_int	Dummy variable with value 1 if the share of innovation expenditures in the total turnover in 2013 is less than 2.5%
	Medium_inno_int	Dummy variable with value 1 if the share of innovation expenditures in the total turnover in 2013 is from 2.5 to 10%
	High_inno_int	Dummy variable with value 1 if the share of innovation expenditures in the total turnover in 2013 is more than 10%
	Continuous R&D	Dummy variable with value 1 if continuous research and development is critical to business success
	Product_inn	Dummy variable with value 1 if product innovations are critical to business success
	Process_inn	Dummy variable with value 1 if process innovations are critical to business success
	Long_product inn	Dummy variable with value 1 if the period of product innovation development / implementation is more than 3-5 years
	Long_process inn	Dummy variable with value 1 if the period of process innovation development / implementation is more than 3-5 years

Table A2 continued

	Variable	Description
Absorptive capacity	Staff_high	Share of graduated employees and employees with a Candidate of Sciences, Doctor of Sciences (or PhD) degree in the total staff number
	Culture_coop_external	Dummy variable with value 1 if the company management welcomes the involvement of external partners at various stages of development and implementation of innovations
	Culture_standard procedures	Dummy variable with value 1 if the company developed standard procedures for interaction with the implementing partners of research and development
	Culture_coop_internal	Dummy variable with value 1 if the company management welcomes the independent exchange of idea among the various units of the company
	Own effort	Dummy variable with value 1 if the majority of implemented innovations were developed predominately by company's own efforts
Appropriability conditions	App_formal	Dummy variable with value 1 if the firm uses formal methods of intellectual property protection (industrial property rights, copyrights)
	App_informal	Dummy variable with value 1 if the firm uses informal methods of intellectual property protection (secrecy, restricted access to knowledge, confidentiality, etc.)
Public support	PS_horizontal	Dummy variable with value 1 if the firm received horizontal public support between 2011 and 2014 (tax remissions and preferences; depreciation bonuses, etc.)
	PS_targeted	Dummy variable with value 1 if the firm received targeted public support between 2011 and 2014 (state grants, the introduction of new technical regulations, standards, etc.)
	PS_networking	Dummy variable with value 1 if the firm received networking public support between 2011 and 2014 (maintenance of information networks, creation and support of technology platforms and regional innovation clusters, etc.)

Appendix 3

Table A3

Descriptive statistics for explanatory variables

Variable	Obs.	Mean	S.D.	Min	Max
General characteristics:					
Size	805	5.438	1.488	2.30	12.58
Age_less5	805	0.055	0.227	0	1
Foreign ownership	805	0.070	0.255	0	1
State ownership	805	0.130	0.337	0	1
Return on sales:					
ROS (0-5%)	805	0.302	0.459	0	1
ROS (more than 5%)	805	0.463	0.499	0	1
Industry:					
High-tech	805	0.149	0.356	0	1
Medium high-tech	805	0.258	0.438	0	1
Medium low-tech	805	0.229	0.420	0	1
Level of competition:					
Market structure:					
Monopoly	805	0.196	0.397	0	1
Oligopoly	805	0.308	0.462	0	1
Markets for future development:					
Regional	805	0.244	0.429	0	1
National	805	0.475	0.500	0	1
Foreign	805	0.191	0.394	0	1
Technological opportunities:					
Low_inno_int	805	0.308	0.462	0	1
Medium_inno_int	805	0.319	0.467	0	1
High_inno_int	805	0.135	0.342	0	1
Continuous R&D	805	0.747	0.435	0	1
Product_inn	805	0.922	0.269	0	1
Process_inn	805	0.988	0.111	0	1
Long_product inn	805	0.226	0.419	0	1
Long_process inn	805	0.189	0.392	0	1
Absorptive capacity:					
Staff_high	805	33.520	23.588	0	100
Culture_coop_external	805	0.424	0.494	0	1
Culture_standard procedures	805	0.386	0.487	0	1
Culture_coop_internal	805	0.427	0.495	0	1
Own effort	805	0.637	0.481	0	1
Appropriability conditions:					
App_formal	805	0.611	0.488	0	1
App_informal	805	0.599	0.490	0	1
Public support:					
PS_horizontal	805	0.244	0.429	0	1
PS_targeted	805	0.271	0.445	0	1
PS_networking	805	0.096	0.294	0	1

Table A3 continued

Variable	Obs.	Mean	S.D.	Min	Max
Barriers:					
Poor management in research organizations	805	0.073	0.261	0	1
Poor management in firms	805	0.071	0.257	0	1
S&T results are not ready for practical introduction in innovation processes	805	0.168	0.374	0	1
Technological risks related to the application of R&D results	805	0.117	0.321	0	1
The disparity between the level of pilot research projects and the latest S&T achievements	805	0.080	0.271	0	1
High economic risks of new technologies adoption	805	0.411	0.492	0	1
Lack of financial resources	805	0.443	0.497	0	1
Greater competitiveness of foreign technologies	805	0.163	0.369	0	1
Strong competition from other on domestic producers of goods and services	805	0.117	0.321	0	1
Strong competition from imported goods and services	805	0.144	0.351	0	1
Legal and administrative barriers to the transfer and adoption of S&T results	805	0.078	0.269	0	1
Lack of qualified specialists to ensure the transfer of S&T results (economists, lawyers)	805	0.086	0.280	0	1
Lack of qualified personnel (engineers, technologists)	805	0.148	0.355	0	1
Lack of information on new technologies in the company	805	0.094	0.293	0	1
Lack of cooperative ties with research organizations	805	0.091	0.287	0	1
Poor innovation infrastructure	805	0.101	0.301	0	1
General insufficient innovation legal and normative support	805	0.048	0.215	0	1
Other	805	0.112	0.315	0	1

Appendix 4

Table A4

Factors determining the modes of interaction (multinomial logit model)

		Cooperation-**S&T services**	Cooperation-Application_ **New to the firm**	Cooperation-Application_ **New to the market**
			Base category: No cooperation with knowledge producers	
General characteristics	Size	**0.150***	0.137	**0.353*****
		(0.087)	(0.139)	(0.121)
	Age_less5	-0.776	-1.184	-1.884
		(0.606)	(0.971)	(1.182)
	Foreign ownership	**-0.917***	-0.231	-0.812
		(0.499)	(0.565)	(0.626)
	State ownership	0.445	0.121	-0.0131
		(0.345)	(0.491)	(0.422)
	Return on sales:		*Baselevel: Negative*	
	ROS (0-5%)	-0.152	0.199	**0.714***
		(0.323)	(0.518)	(0.424)
	ROS (more than 5%)	0.412	-0.179	0.026
		(0.286)	(0.499)	(0.430)
	Industry:		*Baselevel: low-tech industries*	
	High-tech	**1.272*****	**2.468*****	**1.593*****
		(0.380)	(0.700)	(0.484)
	Medium high-tech	**1.077*****	**1.678****	0.620
		(0.305)	(0.674)	(0.451)
	Medium low-tech	0.183	**2.059*****	0.390
		(0.330)	(0.696)	(0.461)
Level of competition	Market structure:		*Baselevel: competitive market*	
	Monopoly	-0.502	**0.905****	0.0987
		(0.324)	(0.451)	(0.406)
	Oligopoly	0.0698	0.652	-0.0262
		(0.249)	(0.422)	(0.350)
	Markets for future development:		*Baselevel: local market*	
	Regional	0.634	-0.0202	-0.335
		(0.562)	(1.261)	(0.782)
	National	**1.069****	1.602	0.705
		(0.530)	(1.138)	(0.725)
	Foreign	**1.271****	1.488	0.642
		(0.572)	(1.175)	(0.782)
Technological opportunities	Share of development and implementation costs in the total turnover:			
	High	-0.373	**1.026***	-0.249
	(more than 10%)	(0.419)	(0.532)	(0.561)
	Medium	0.418	-0.077	0.656
	(2.5-10%)	(0.301)	(0.520)	(0.408)
	Low	0.140	-0.282	-0.026
	(less than 2.5%)	(0.313)	(0.547)	(0.431)
	Continuous R&D	**-0.453***	**1.197*****	-0.008
		(0.250)	(0.439)	(0.339)
	Product innovation	-0.448	-0.469	0.0930
		(0.314)	(0.541)	(0.445)
	Process innovation	0.015	0.213	-0.117
		(0.307)	(0.590)	(0.441)
	Long product innovation	-0.151	0.155	0.042
		(0.312)	(0.465)	(0.399)
	Long process innovation	0.322	-0.477	0.144
		(0.316)	(0.518)	(0.423)
Absorptive capacity	High qualification of the staff	0.006	0.003	-0.004
		(0.005)	(0.007)	(0.007)
	Culture - external cooperation	0.331	**0.952****	**0.700****
		(0.250)	(0.412)	(0.335)
	Culture - procedures for cooperation	0.075	-0.086	-0.028
		(0.253)	(0.418)	(0.337)
	Culture - internal cooperation	0.0496	-0.150	-0.505
		(0.235)	(0.365)	(0.326)
	Own effort	**-0.626*****	**-1.352*****	**-1.231*****
		(0.227)	(0.361)	(0.307)
Appropriability conditions	Methods of intellectual property protection:			
	Formal	0.294	**0.985****	0.213
		(0.255)	(0.455)	(0.359)
	Informal	**0.885*****	**0.890****	0.402
		(0.264)	(0.429)	(0.327)

Continued Table A4

		Cooperation-**S&T services**	Cooperation-Application_ **New to the firm**	Cooperation-Application_ **New to the market**
		Base category: No cooperation with knowledge producers		
Public support	Public support measures:			
	Horizontal	**0.474***	0.444	0.526
		(0.269)	(0.424)	(0.350)
	Targeted	-0.271	0.259	0.144
		(0.282)	(0.414)	(0.354)
	Networking	0.199	-0.374	**1.179*****
		(0.398)	(0.589)	(0.439)
Barriers	Lack of financial resources	-0.048	-0.180	**0.926*****
		(0.248)	(0.394)	(0.338)
	High economic risks of new technologies adoption	0.004	0.074	-0.446
		(0.241)	(0.378)	(0.324)
	S&T results are not ready for practical introduction in innovation processes	0.404	-0.104	**0.879****
		(0.294)	(0.483)	(0.400)
	Greater competitiveness of foreign technologies	-0.364	-0.376	0.180
		(0.309)	(0.500)	(0.385)
	Lack of qualified personnel (engineers, technologists)	-0.056	0.386	0.263
		(0.344)	(0.494)	(0.426)
	Strong competition from imported goods and services	0.183	-0.818	-0.161
		(0.312)	(0.587)	(0.426)
	Technological risks related to the application of R&D results	0.185	-0.540	-0.128
		(0.334)	(0.603)	(0.458)
	Strong competition from other on domestic producers of goods and services	-0.498	0.193	0.256
		(0.411)	(0.593)	(0.469)
	Other	0.110	-0.475	0.147
		(0.394)	(0.626)	(0.569)
	Poor innovation infrastructure	**-0.769***	-0.300	-0.874
		(0.426)	(0.636)	(0.618)
	Lack of information on new technologies in the company	-0.130	-0.266	-0.0470
		(0.404)	(0.678)	(0.550)
	Lack of cooperative ties with research organizations	-0.142	-0.307	**-1.452***
		(0.391)	(0.658)	(0.805)
	Lack of qualified specialists to ensure the transfer of S&T results (economists, lawyers)	-0.0232	**-2.038***	-0.549
		(0.408)	(1.238)	(0.596)
	The disparity between the level of pilot research projects and the latest S&T achievements	0.290	0.326	-0.646
		(0.409)	(0.707)	(0.696)
	Legal and administrative barriers to the transfer and adoption of S&T results	0.470	**1.122***	0.809
		(0.395)	(0.578)	(0.522)
	Poor management in research organizations	0.0410	**-1.451***	-0.554
		(0.407)	(0.849)	(0.700)
	Poor management in firms	0.381	-1.591	0.0610
		(0.403)	(1.126)	(0.589)
	General insufficient innovation legal and normative support	0.470	**1.122***	0.809
		(0.395)	(0.578)	(0.522)
	Constant	**-4.225*****	**-7.660*****	**-5.742*****
		(0.802)	(1.566)	(1.098)
Likelihood-ratio test: chi2(158) = 415.98, Prob >chi2 = 0.000				
Number of observations = 805, LogL = -591.773, Pseudo R2 = 0.2601				
* significant at 10%; ** significant at 5%; *** significant at 1% Standard errors in parentheses				