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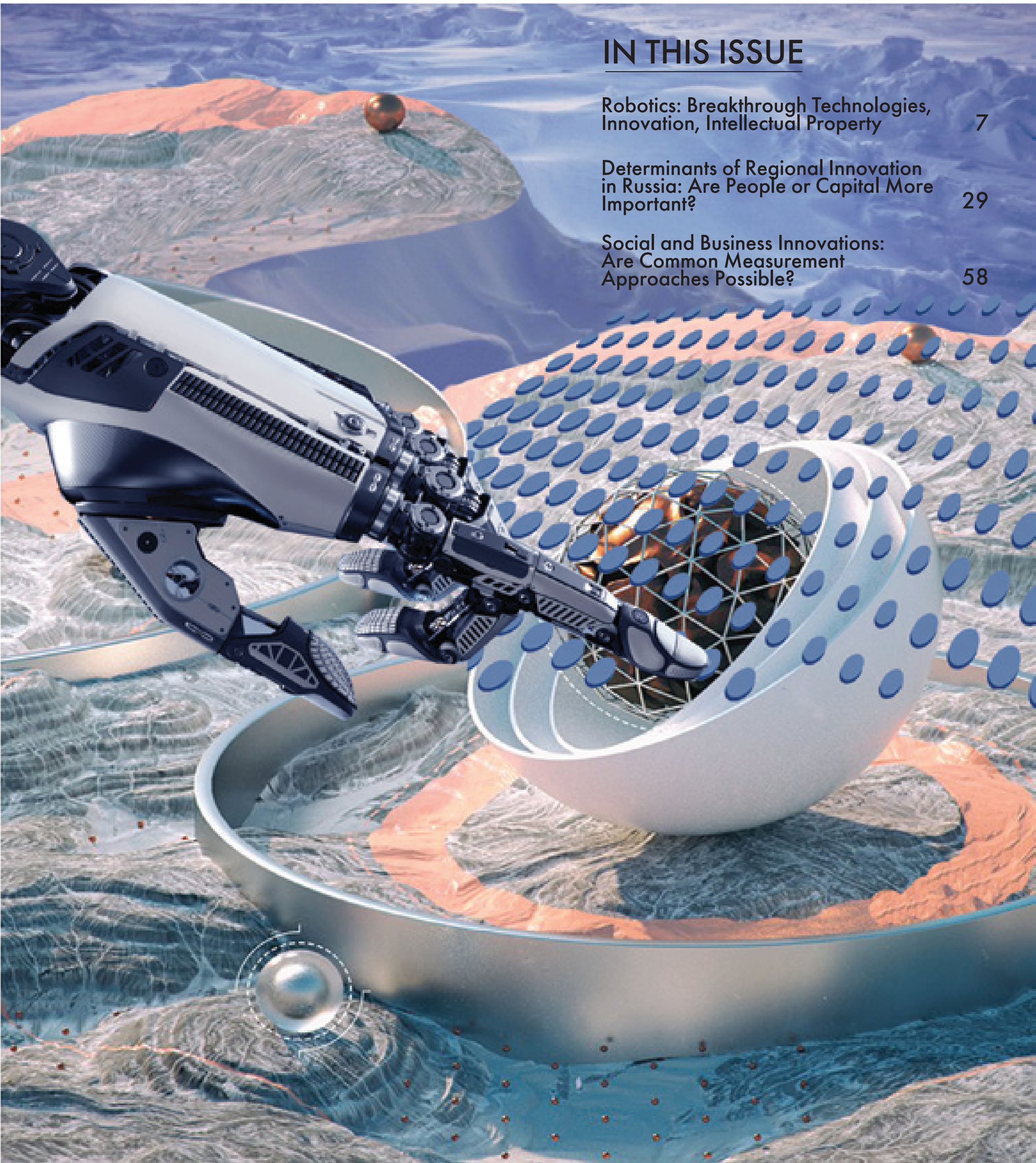

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Foresight and STI Governance (formerly Foresight-Russia) — a research journal established by the National Research University Higher School of Economics (HSE) and administered by the HSE Institute for Statistical Studies and Economics of Knowledge (ISSEK), located in Moscow, Russia. The mission of the journal is to support the creation of Foresight culture through dissemination of the best national and international practices of future-oriented innovation development. It also provides a framework for discussing S&T trends and policies.

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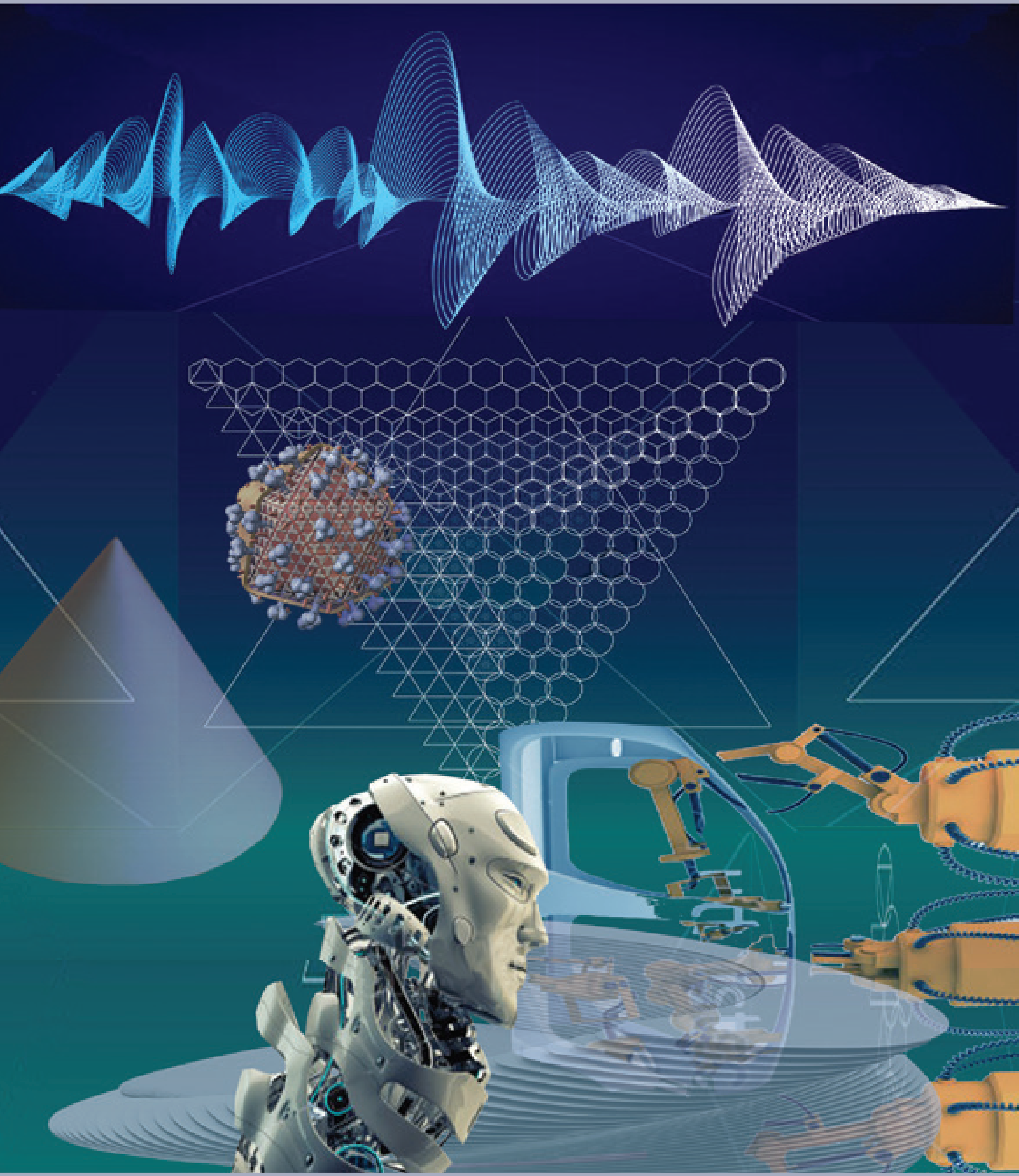

Robotics: Breakthrough Technologies, Innovation, Intellectual Property

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Abstract

Robotics technology and the increasing sophistication of artificial intelligence are breakthrough innovations with significant growth prospects. They have the potential to disrupt existing socio-economic facets of everyday life. Yet few studies have analysed the development of robotics innovation. This paper closes this gap by analysing current developments in innovation in robotics; how it is diffused, and what role is played by intellectual property (IP). The paper argues that robotics clusters are mainly located in the US and Europe, despite a growing presence in South Korea and China. The robotics innovation ecosystem builds on cooperative networks of actors, including individuals, research institutions, and firms. Governments play a significant role in supporting robotics innovation through funding, military demand, and national robotics strategies. Robotics competitions and prizes provide an important incentive for innovation. Patents are used to exclude third parties to secure freedom of operation, license technologies, and avoid litigation. The countries with the highest number of patent claims are Japan, China, South Korea, and the US. The growing stock of patents owned by universities and PROs, particularly in China, is noteworthy too. Automotive and electronics companies are still the largest patent filers, but medical technologies and the Internet are emerging as new actors in the field. Secrecy is often used as a tool to appropriate innovation. Copyright protection is relevant to robotics also, mainly for its role in protecting software. Finally, open-source robotics platforms are increasingly used in the early stages of the innovation process as they allow new actors in the robotics field to optimize their initial spending on innovation.

Keywords: robotics; robot; artificial intelligence; innovation; patent; trade secret; intellectual property; copyright

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At bottom, robotics is about us. It is the discipline of emulating our lives, of wondering how we work.

Rod Grupen, Director of the Laboratory for Perceptual Robotics
University of Massachusetts Amherst

The rising sophistication of robots and artificial intelligence (AI), and its consequences, are currently the subject of numerous debates. The fact that humanoid robots have recently been trialed in supermarkets, schools, hospitals and retirement homes in Europe, the United States, and Japan has given the field of robotics new prominence in the public eye.

Technologists, economists, lawyers, and experts from other disciplines are speculating about the potential uses of robotics innovation and its socio-economic impacts. In economic circles, the debate often focusses on the potential impact, positive and negative, of employing robots. Social scientists are debating the social influence of artificial companions. Hollywood movies such as *Ex_Machina* or *Her*, too, have put the spotlight on the potential upcoming superiority of AI, which could rival human intelligence. Observers agree unanimously that the pervasive uptake and impact of robotics innovation is imminent, and potentially far-reaching.

Yet, despite the attention devoted to this expanding field of technology, few studies have analyzed the developments of robotics innovation and the underlying innovation ecosystem. Moreover, while the role of intellectual property (IP) is analyzed with respect to numerous high-technology fields, such as information-, nano-, or biotechnology, few studies are devoted to the use and uptake of various forms of IP for robotics innovation. The few articles devoted to robotics innovation in prominent innovation journals date back to the 1990s [*Kumaresan, Miyazaki*, 1999].

This paper aims to fill this gap by providing an up-to-date analysis of the robotics innovation system, and the corresponding role of IP. It first describes the history of robotics innovation, then assesses robotics' underlying economic contribution. Next, the paper describes the robotics innovation ecosystem; and finally analyses the uptake and relevance of different strands of IP to robotics innovation.

The present paper is part of a broader series of studies completed in preparation for WIPO's *World IP Report 2015*, 'Breakthrough Innovation and Economic Growth' [WIPO, 2015]. That report explores the concrete linkages between innovation, IP, and growth in six areas of breakthrough innovation (airplanes, antibiotics, semiconductors, 3D printing, nano-technology and robotics).

The Development of Robotics

Robotics is the field of technology that drives the development of robots for application in areas as diverse as car factories, construction sites, schools, hospitals, and private homes. Industrial robot arms have been in use in automotive and other manufacturing businesses for more than three or four decades. However, various strands of existing and newer research fields such as artificial intelligence (AI) and sensing, have been combined in more recent years to produce autonomous and 'advanced' robots for widespread use in the social and economic spheres.

In part driven by aforementioned Hollywood movies, most laypersons perceive 'robots' to be primarily, or exclusively, humanoid robots. However, humanoid robots are only a small subset of the broader robotics industry.

The Encyclopedia Britannica defines a robot as 'any automatically operated machine that replaces human effort.' According to the International Federation of Robotics (IFR), '[a] robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks' [IFR, 2015]. In turn, the majority of practitioners and scholars consider a robot to be any "machine capable of sensing its environment and reacting to that environment based on an independent decision-making capability." [*Springer*, 2013, pp. 1-5].

The term autonomy is often used to underline the difference between robots and other machines where a robot would have the ability to interpret its environment and adjust its actions to achieve a goal. In terms of technological trajectory, robots are evolving from programmed automation, over semi-autonomous to more autonomous complex systems. Fully autonomous systems are able to operate and make 'decisions' to complete tasks without human interaction.

A **remote control device** is a device that can be controlled from a remote location. Based on the most common definition of a 'robot', remote controlled devices would not be considered a 'robot'. Nevertheless, the robotics industry has accepted certain purely remote controlled devices as falling within its domain. For example, telepresence devices are often referred to as robots, or even robotic-telepresence devices, despite the fact that some telepresence devices are purely remote controlled. The same is true for certain toys and educational devices. Examples of remote controlled devices frequently considered to be within the bounds of the robotics industry include telepresence robots, remotely controlled humanoid robots, robotic assisted surgical devices, exoskeletons, and Unmanned Aerial Vehicles (UAV), also known as Unmanned Aerial Systems (UAS) or 'drones.'

Semi-autonomous devices still interact with and are controlled by human operators, but are not purely remote controlled devices as they only provide guidance to their human operators to ease and/or assist in the device's operation. Robots whose actions are managed by a human operator is generally considered semi-autonomous. Semi-autonomous features are increasingly becoming more common in cars, as well as certain industrial robots that require an operator to provide detailed commands.

Fully autonomous devices are able to operate and make 'decisions' within the environment for which it was designed; they are able to further the assigned task without human interaction. Fully autonomous devices are not typically designed to think creatively, but there is some admittedly blurred lines as certain fully autonomous devices are necessarily designed to operate in unpredictable environments for which their decisions are not predetermined.

AI is generally considered to be a niche area of computer science, focused on computer-based devices that are capable of making intelligent human-like decisions. Although admittedly a blurry line, one divide between fully autonomous and AI is the difference between a device making basic unsophisticated decisions (autonomy) and one that is capable of making creative decisions. AI is considered by some practitioners to be within the robotics industry, but many other practitioners consider artificial intelligence to be its own field of technology with potentially profound implications on the robotics industry. The latter view is based on the understanding that artificial intelligence is grounded in Computer Science without necessarily any hardware application. Although artificial intelligence incorporated into a movable hardware device is an anticipated reality within the robotics industry, it can stand entirely separate from any hardware device.

History of Robotics

Industrial arms for automation

Robots, in their most basic form, are not new. The history of robotics started in ancient Greek with *automatons,* essentially non-electronic moving machines that displayed moving objects. The invention of simple automatons continually evolved thereafter, but robots in their current form took off with the process of industrialization, essentially to perform repetitive tasks.

More recently, a few key inventions in two areas stand out as having led to the first incarnation of robots for industrial automation [IFR, 2012]. First, *control systems* allowing humans or computers to control and steer robots from a distance, and second, *mechanical manipulation systems* such as robotic arms or legs to move or grab objects.

As for mechanical manipulation systems, the first industrial robot was developed in 1937 in the form of a small crane. In 1942, William Pollard and Harold Roselund, both employees of DeVilbiss Company, filed a patent for the first programmable mechanized paint-sprayer. The development of robotic legs and arms was furthered by William Walter, who built the first autonomous robot in the late 1940s [US Patent 2,679,940]. However, the real breakthrough that propelled the development of the robotics industry is attributed to George Devol, who invented and patented the first automatically operated programmable robotic arm in the mid-1950s [*Nof*, 1999]. Devol then partnered with Joseph Engelberger, considered by many scholars to be the 'Father of Robotics',[1] to create a company called Unimation. This marked the beginning of the commercialization of industrial robots [*Rosheim*, 1994]

Robotic arms have since been fine-tuned and improved. The first computer-controlled revolute electric arm, for instance, was developed at the Case Institute of Technology, Case Western Reserve University, US. In 1969, researchers at Stanford University invented the so-called Programmable Universal Manipulation Arm that enabled a more sophisticated control for assembly and automation [*Scheinman*, 2015]. One of these researchers, Victor Scheinman, started Vicarm Inc., which proved fundamental to the development of the robotics industry; he ultimately sold the company to Unimation in 1977.

Largely based on the work of the aforementioned inventors and firms, the first commercial robots were deployed in General Motors' assembly lines in the USA in 1961 [IFR, 2012]. The first industrial robot in Europe, a Unimate, was installed in Sweden in 1967. In 1969, the company Trallfa of Norway offered the first commercial painting robot. In 1973, ABB Robotics and KUKA Robotics introduced the first robots in the market. Since then the robotics industry has been continually working to improve the functionality and control of robotic mechanical parts.

Approximately a decade after Devol filed his patent, Japanese companies began to develop and produce their own robots pursuant to a license agreement with Unimation. By 1970, robotic manufacturing had proliferated throughout the automotive industry in the US and Japan. By the late 1980s, Japan – led by the robotics divisions of Fanuc, Matsushita Electric Industrial Company, Mitsubishi Group, and Honda Motor Company – had become the world leader in the manufacture and use of industrial robots.

Parallel key inventions in the area of packaging robots – for instance, the Delta packaging robot developed at the Federal Institute of Technology of Lausanne that yielded 28 patents – modernized the packaging industry.

A full-scale humanoid robot developed at Waseda University in Japan laid the foundation for follow-on innovation in the field. It facilitated enhanced human–robot interaction relevant to today's consumer-oriented robot markets. While many historians have discussed evidence of early pre-computer based use of 'legs' for movement, the initial breakthroughs concerning machines that could walk on two or more legs occurred in the 1960s and 1970s. Yet, such technology is not yet prevalent within commercialized products despite decades of research in the field.

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[1] It should be noted, however, that many scholars and practitioners, especially those that consider remote controlled devices to be part of the robotics field, also consider Nikola Tesla to be the 'Father of Robotics' based, at least in part, on his 1898 invention and patent of a remote controlled boat (see United States Patent No. 613,809).

Autonomous systems built on artificial intelligence and connectivity

In the journey towards more capable robots, researchers have worked on increasing autonomy and improving interaction between humans and robots. New materials and innovations in various fields outside the robotics area such as artificial intelligence (AI), mechatronics, navigation, sensing, object recognition, and information processing are the core technological developments furthering robotics today [*Kumaresan, Miyazaki*, 1999].

In particular, innovation in software and AI will be key technologies for next-generation robots that can effectively manoeuvre and circumvent obstacles. The seminal breakthrough in developing algorithms instrumental for robotic path planning took place in the mid-1980s and is credited to Randall Smith and Peter Cheeseman [*Smith and Cheeseman*, 1986]. The result of such seminal research on the problem of Simultaneous Localization and Mapping (SLAM) led to the development of SLAM algorithms. Many robotics companies still use SLAM algorithms to this date, albeit with modifications tailored to the environment and purpose of their specific robot. Algorithms have become central to the development of robots that can make increasingly complex decisions; for instance, for simulating emotions in home or service robots. Researchers are currently working on software that will mimic the human brain, honing language and decision-making skills.

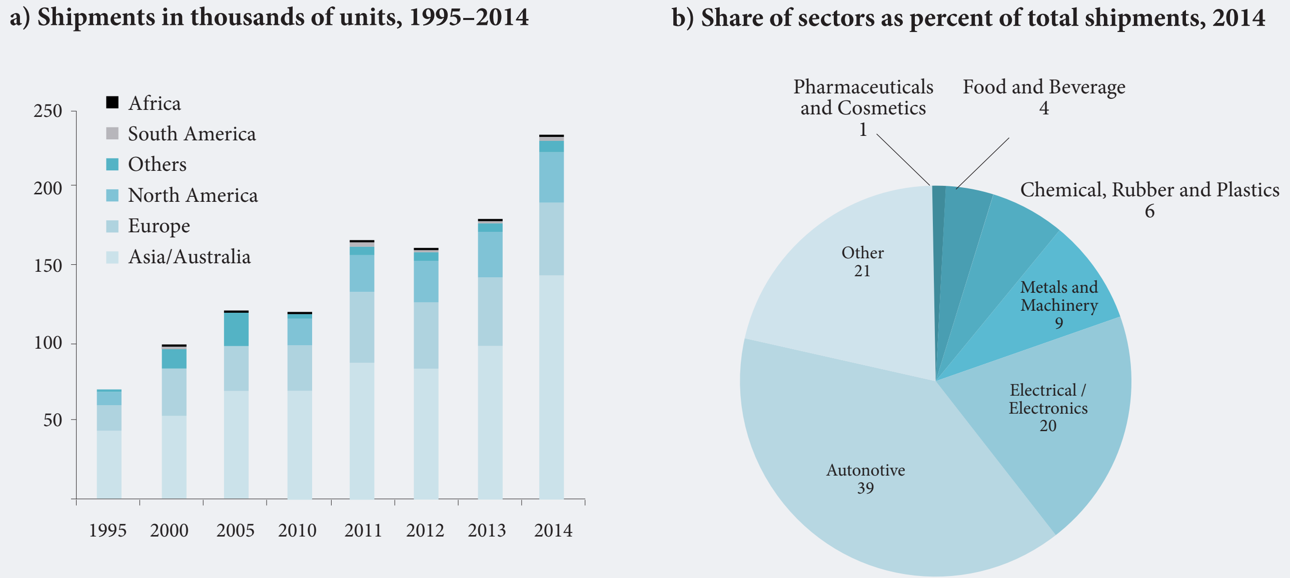
Due to improved connectivity, sensors, and processing power, robots are becoming increasingly data-driven, and linked over more intelligent networks. As such, innovation is increasingly about software and hardware integration and the development of so-called integrated robotic and intelligent operational systems. On the application level, the development of autonomous vehicles and drones is seen as an extension of robotics.

The Economic Contribution of Robotics

The industrial robot market has been estimated to be worth USD$29 billion in 2014, including the cost of software, peripherals, and systems engineering (Table 1). The number of robots sold reached about 230,000 units sold in 2014, up from about 70,000 units in 1995 (Figure 1a). This is projected to increase rapidly in the next few years.

Interestingly, the respective shares of various world regions in global robotics sales have changed little. Asia leads in this area, followed by Europe and North America, while sales in South America and Africa are rather small in volume. Within Asia, China has gone from no robots in 1995 to becoming the largest market for robots, overtaking Japan. South Korea is now the second biggest user of industrial robots in Asia.[2]

Figure 1. **Key indicators of global trade in industrial robots**



a) Shipments in thousands of units, 1995–2014

b) Share of sectors as percent of total shipments, 2014

Note: The regions as shown here follow the definition of the IFR.

Source: Authors' calculation based on IFR World Robotics Database, 2014.

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[2] In terms of robotic density, as of 2014 the Republic of Korea had the highest robot density in the world, with 437 units per 10,000 persons employed in the manufacturing industry, followed by Japan (323) and Germany (282). In comparison, China's density was 30, Brazil's 9, and India's 2 [IFR, 2014a].

Table 1. **Different estimates of the robotics industry revenues**

Определение	Оценка	Источник
Global market for industrial robotics	USD 29 billion (2014) USD 33 billion (2017)	[IFR, 2014a]
Global market for industrial robotics	EUR 50-62 billion (2020)	[euRobotics, 2014]
Global market for service robots	USD 3.6 billion (of which USD 1.7 billion for domestic use)	[IFR, 2014b]

In terms of sectors, the automotive industry continues to be the main driver of automation, followed by electronics (Figure 1b). Innovation will enable more flexible and small-scale manufacturing.

A novel robotics field is the production and use of service robots in areas outside of manufacturing. This category includes robots intended for 'professional use' in agriculture, mining, transport (including the large field of unmanned aerial and land vehicles), health, education, space and sea exploration, unmanned surveillance, and other fields [IFR, 2014b].

The total number of professional service robots reached USD 3.6 billion in 2014, projected to lead the growth of upcoming robotic use [IFR, 2014b]. The largest markets are Japan, South Korea, the US, and Europe and the sectors leading their use are defence, logistics, and health. Surgical robot device markets, valued at USD 3.2 billion in 2014, are anticipated to reach USD 20 billion by 2021 [Wintergreen Research Inc., 2015].

In addition, robotics in personal and domestic applications - another novel field - has experienced strong global growth with relatively few mass-market products. These include floor-cleaning robots, mowers, robots for education, and assistive robots for the elderly [IFR, 2014b].

A few consultancy reports have emphasized the wide range of savings generated through advanced robotics in healthcare, manufacturing, and services. These reports predict high benefits to economic growth. The McKinsey Global Institute estimates that the application of advanced robotics could generate a potential economic boost of USD 1.7 trillion to USD 4.5 trillion a year by 2025, including more than USD 2.6 trillion in value from healthcare uses [McKinsey Global Institute, 2013]. However, quantifying the productivity-enhancing contribution of robots in definite terms is challenging.

Robots can increase labour productivity, reduce production costs, and improve product quality. In the service sector in particular, robots can also enable entirely new business models. In part, the economic gains of robots are directly linked to substituting – and thus automating – part of the currently employed workforce [Metra Martech, 2011; *Miller, Atkinson*, 2013; *Frey, Osborne*, 2013; *Brynjolfsson, McAfee*, 2014]. On the one hand, productive labour helps keep manufacturing firms competitive, avoiding their relocation abroad, and creating higher-wage jobs. The robotics industry has been particularly focused over the past several years on alleviating fears that it will cause a decrease in available jobs. Indeed, the industry has conducted research and found evidence to support projections that increased employment opportunities will follow from the advancement and proliferation of robotics [Metra Martech, 2011]. This above all concerns certain high-income nations as a result of manufacturing re-shoring (also called manufacturing in-shoring); in other words, manufacturing previously outsourced to nations with cheaper labour will be relocated to high income nations as robotics would reduce the cost of manufacturing [*Green*, 2012; *Christensen et al.*, 2013]. If such predictions are accurate, it may be true that the proliferation of robotics will increase jobs and economic growth in high income countries. However, in the manufacturing sector if the primary concern remains low labour costs, the creation of jobs in high income countries may be at the expense of jobs in middle and low income countries.[3]

On the other hand, the use of robots is certain to eliminate both low-skilled but also some types of higher-skilled jobs hitherto unaffected by automation. Yet, there are still multiple sources that predict robotics, as a whole, will lead to an increase in available jobs. Many of these later reports focus only on the loss of current jobs [*Frey, Osborne*, 2013] and do not account for the creation of new job types that may not exist today. On balance, the employment effect of robotics is currently uncertain.

A little researched issue is the extent to which robotic innovations have diffused to low- and middle-income countries, and the effects of this diffusion. Nevertheless, it is expected that firms involved in manufacturing and assembly activities for global or local supply chains, will need to upgrade their use of robots, including those in middle-income or even low-income economies where they have so far competed on cheap labour alone.

Although the location of companies developing robots and robotics products appears to be occurring in specific high income nations, the impact of certain robotics technologies may have an impact, akin to that of the Internet, in middle and low income countries. In the same way that the Internet has allowed certain jobs to be performed remotely, whether from a location in the same region or a different continent, robotics technologies such as telepresence robots or remotely controlled robots with arms will augment the type of jobs that can be performed from a remote location. As the Internet continues to evolve, it will inspire a natural progression from sensing at a distance to taking action at a distance. This extension of

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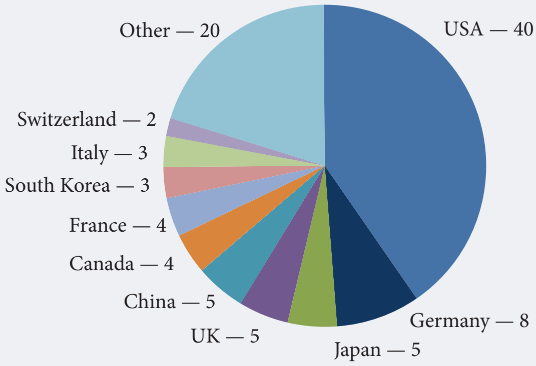
[3] From 2013 in China, we see low demand for robotics. Experts predict that China's demand for robotics will increase due to the need for China's manufacturing industry's to stay competitive [RBR Staff, 2012].

Figure 2. **Main geographic location of robotics companies, 2015 (%)**



Source: authors' calculations based on available information from robotics-focused associations and groups, including The Robot Report's Global Map [*Tobe*, 2015], as well as from the publicly available listing of companies from the Robotics Industry Association (RIA).

the Internet into the physical world will serve to further blur the boundaries among community, communication, computing, and services and inspire new dimensions in telecommuting and telepresence applications. Hybrid solutions are likely to emerge that enable distributed human cognition and enable the efficient use of human intelligence. Such solutions will combine the robotics-enabled capability to remotely and autonomously perceive situations requiring intervention with the Internet-enabled capability for human operators to take action from a distance on an as-needed only basis [*Christiansen, et al.*, 2013, p. 66]. As the Internet and robotics technology continue to evolve and make the location of an employee secondary to the ability to perform certain tasks, any nation with sufficiently fast and reliable internet service could enable its citizens to compete for jobs. In particular, middle and low income countries may be able to compete for jobs requiring a higher level of intellect or creativity in higher income countries. This phenomenon already exists as a result of the Internet, with certain companies thriving because of their wide geographical reach for skilled labour [*Halzack*, 2014]. Such tasks are primarily restricted to purely Internet-based deliverables but with the advancement of certain robotics technologies, they could involve physical jobs as well. Although middle and low-income nations may not benefit from such advancements if they have slow, unreliable, or heavily restricted Internet, technologies are being developed to resolve such limitations [*Garside*, 2014; *Dockterman*, 2014; *McNeal*, 2014].

The Robotics Innovation System

With the evolution from the era of industrial automation to the use of advanced robotics across the economy, the robotics innovation system also changed. In its present day form, this system can be characterized by a few key traits.

Robotics clusters with strong linkages between actors

Robotics innovation predominantly occurs within a few countries and clusters [*Green*, 2013]. These clusters thrive on the interface between public and private research, with firms commercializing the resulting innovation.

Robotics clusters are mainly located in the US, Europe (in particular, Germany and France, and to a lesser extent the UK), and Japan. They are increasingly found in South Korea and China (Figure 2).[4] Applicants from these countries account for the vast majority of patent applications in the field of robotics (Figure 3). Relative to GDP, Canada, Denmark, Finland, Italy, Israel, the Netherlands, Norway, the Russian Federation, Spain, the UK, Sweden, and Switzerland stand out as economies with the largest presence of innovative robotics firms.

In the early stages of robotics, the key players were inventors from the US, Europe, and slightly later, Japan. In the early 2000s, key actors also started to come from South Korea and then China [UKIPO, 2014]. Within these few countries, robotics clusters are concentrated around specific regions, cities, or top universities in the field. For example, Boston, Silicon Valley, and Pittsburgh in the US are generally regarded as the three main robotics clusters. In Europe, the Île-de France region (particularly for civilian drones), Munich in Germany, Odense in Denmark, Zürich in Switzerland, and Robotdalen in Sweden are prominent. In Asia, Bucheon in Korea, Osaka and Nagoya in Japan, and Shanghai and Liaoning Province in China are key robotics clusters.

Some companies that excel in robotics innovation are located outside these clusters. They are usually well established in the automotive sector. Increasingly, reputed Internet companies are also entering the field

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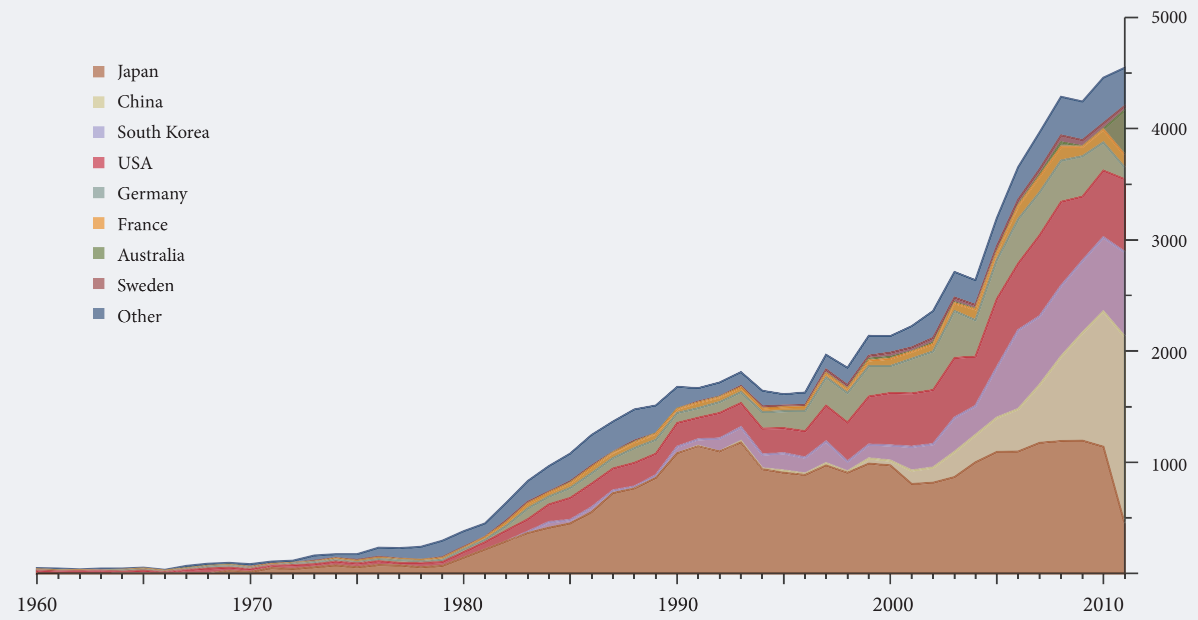
[4] Although there is no standard global database for all robotics companies, there have been some attempts to compile such lists [*Tobe*, 2015].

Figure 3. **First patent filings in the field of robotics by origin and type of applicant, 1960–2011**



Note: Only the first filings with at least one patent granted within the patent family are counted.

Source: WIPO based on the PATSTAT database.

of robotics since they have the solid experience, financial means, and the skills to hire robotics experts. China has seen a strong surge in robotics patents and it also hosts some of the fastest-growing robotics companies such as DJI (Drone Company), as well as new industrial robot manufacturers such as Siasun and Estun that have driven down the cost of industrial robots.

Highly dynamic and research-intensive collaborative robotics innovation ecosystem

The robotics innovation ecosystem comprises a tight and cooperative network of actors, including individuals, research institutions, and universities, as well as large and small technology-intensive firms. Robotics brings together diverse science and technology breakthroughs to create new applications.

Select public research institutions are also crucial actors in the robotics innovation ecosystem. Public Research Organizations (PROs) of note include the Korean Institute of Science and Technology, the Fraunhofer institutes in Germany, the Industrial Technology Research Institute in Taiwan (Province of China), and the Russian Academy of Sciences. Examples of leading universities include McGill (Canada), Carnegie Mellon (the US), ETH (Switzerland), Imperial College (UK), Sydney University (Australia), Osaka University (Japan), and the Shanghai Jiao Tong University (China).

Traditionally, these science institutions play an important role in innovation by conducting long-term research whose commercial applications will only be realized far in the future [*Nof*, 1999, p. 33] As depicted in Figure 4, the role of academic and public institutions, as well as that of individual entrepreneurs, varies through time and across countries. In addition, academic institutions continue to play a major role in furthering development in robotics through creating spin-outs and spin-offs, patents and through close collaboration with firms [*Nof*, 1999]. Collaboration between firms and PROs is tight too; for instance, the firm KUKA is developing lightweight robots with the German Institute of Robotics and Mechatronics. Furthermore, the increased number of formal robotics degrees offered by academic institutions has been critical in the development and diffusion of skills, as corporations tend to hire recent graduates.

There are also examples of universities collaborating with the private sector beyond monetary support for robotics research, including joint development agreements to build robotic technology aided solutions for private companies.[5]

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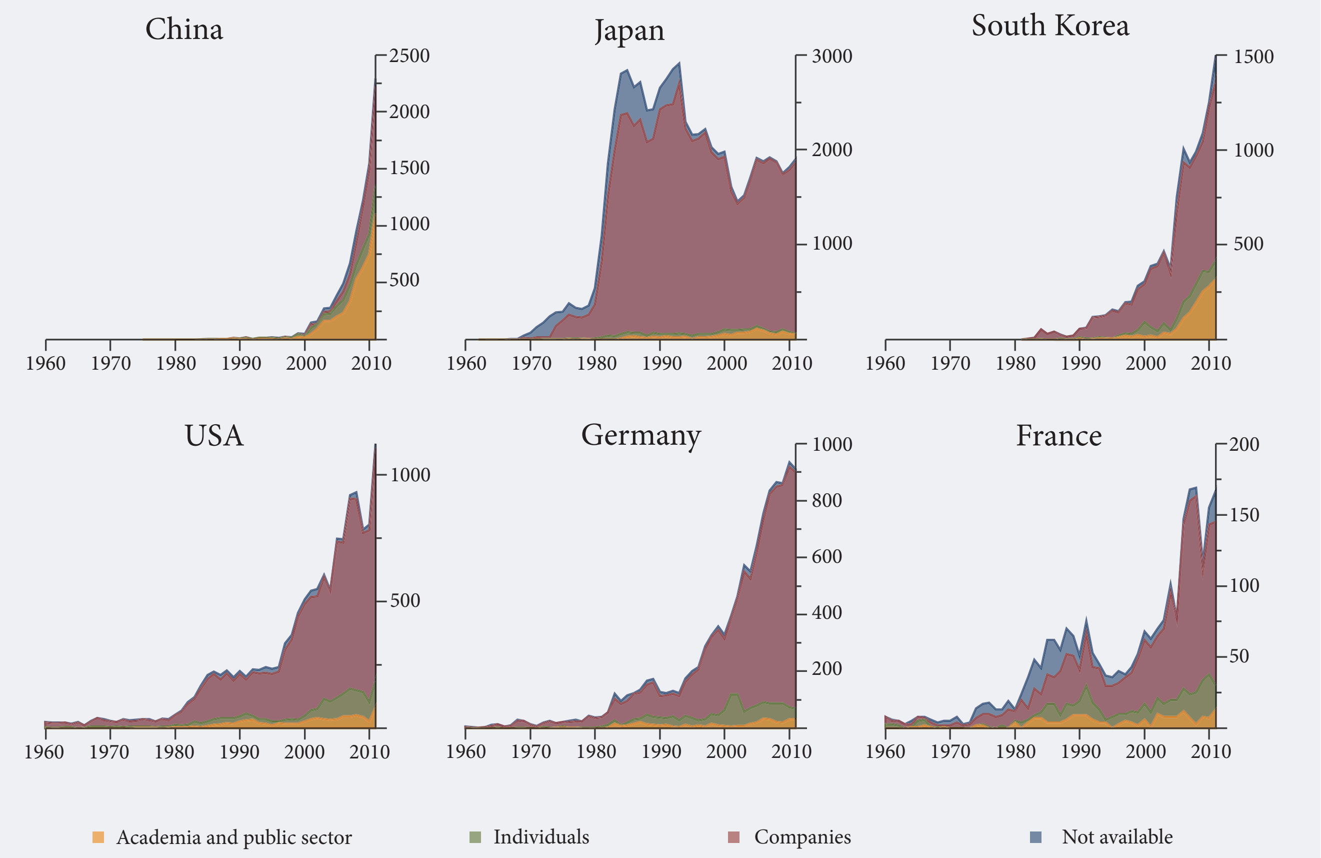
[5] [RBR Staff, 2013b] discusses Carnegie Mellon University's five-year joint development agreement with Anglo American Plc, pursuant to which CMU's Robotics Institute will design, build and deploy mining robots, robotics tools and autonomous technologies in partnership with Anglo American's internal Technology Development Group. See also Deere & Company's joint development with University of Illinois as evidenced in jointly assigned United States Patent Nos. 7,587,081; 8,712,144; 8,737,720; and 8,855,405; and Deere & Company's joint development with Kansas State University (as evidenced in the jointly assigned United States Patent Nos. 7,792,622; 7,684,916; 7,580,549; and 7,570,783); and MAKO Surgical Corp.'s joint development with the University of Florida (as evidenced in jointly assigned United States Patent Nos. D625,415 and D622,854).

Figure 4. **Geographic distribution of robotics innovations by country of origin: 1960-2011**



Source: WIPO based on the PATSTAT database.

Universities may be more willing to focus on research and development that may not have immediate commercialization potential. However, they still strive to protect their inventions, which in future may lead to new robotics products or companies. Indeed, research institutions conducting research in the field of robotics frequently patent inventions. Additionally, there are numerous companies within the industry that are 'spinoffs' or 'spinouts' of research and development projects conducted at universities [*Cellan-Jones*, 2014].[6]

Three main types of innovative robotics firms can be identified:

1. Small company startups or specialized robotics firms that are often created by individual inventors affiliated with academic robotics centers or clusters, sometimes with significant direct or indirect government support. An example is Universal Robots, which emerged from a robotics cluster in Demark with links to the Danish Technological Institute, receiving initial government and seed funding.

Although parts of the industry are more mature today, the potential for small robotics startups is still large. In the early stage of radical innovation, small startups demonstrate more agility and speed, and closer interaction with academia. In addition, innovation ecosystems are becoming more specialized, allowing for niche specialist companies. Third-party external developers are increasingly part of the robotics innovation system because robotics platforms, often based on open source software architectures, are the starting point for further development. Further, a growing number of companies provide robotics-related services such as mobility or machine management systems. The rise of new, more consumer-oriented robotics firms and new funding mechanisms enable start-ups to appear. For instance, Play-I (now called Wonder Workshop) focuses on creating educational toy robots and recently raised money through crowd-funding platforms.

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[6] Startup companies in the robotics field that are spinoffs/spinouts of research conducted in a university setting are common in the US but also occur quite often in Europe and Asia. Examples include Oxbotica (a spinout of Oxford University), Empire Robotics (a spinoff of Cornell University), Autonomous Solutions, Inc. (a spinoff of Utah State University), and Blue Belt Technologies, Inc., RE2, Inc., and Medrobotics Corp. (all spinoffs of Carnegie Mellon University). Medrobotics Corp. recently raised USD 20 million in a Series F funding round. In late 2013, Google acquired Meka Robotics (a spinoff of Massachusetts Institute of Technology) and Schaft Inc. (a spinoff of University of Tokyo).

2. Large, established robotics companies such as ABB (Switzerland), Kawasaki Heavy Industries, Yaskawa and Fanuc (Japan) and KUKA (Germany) that are active in robotics R&D, and initially focused on industrial robot research and production alone. Scale matters, as innovating in the field of industrial robotics hardware is particularly capital-intensive and research takes years to materialize. Major clients in the automotive sector, for instance, are only willing to buy from large, trusted, established companies to avoid safety risks. In addition, large robotics firms are emerging thanks to the growing demand for service and household robots. Although still making most of its revenue from the development and sale of robots for military applications, iRobot (US) is one such example. Initially a spin-off from MIT, it is now a large company producing robots for security purposes, businesses, as well as private households.

3. Large firms outside the robotics industry have also gained related competencies. Firms such as BAE Systems (UK) in the area of defence, aerospace, and security continue to be important players for robotics innovation. In addition, firms in the automotive sector continue to be significant, not least due to their extensive use of robots. A newer development is the increasing involvement of electronics and ICT firms such as Samsung (South Korea) and Dyson (UK). As robotics becomes more reliant on connectivity and ICT networks, Internet or IT-related firms such as Amazon, Google and Facebook (of the US) as well as Indian ICT services firm such as Infosys, Alibaba of China and Foxconn of Taiwan are joining the fray. They often acquire shares in, or take full ownership of, established robotics firms. Moreover, firms in the health sector are increasingly prominent in robotics research. Market leaders in the area of surgical robots include Intuitive Surgical, Stryker, and Hansen Medical.

As the advantages of robotics have become increasingly visible to non-robotics companies, traditional companies have stepped up their focus on obtaining robotics capabilities to provide business solutions. Such a desire to embrace robotics technology has materialized into significant strategic business decisions that include acquisitions of robotics companies whose technology could directly benefit the acquiring company's business and/or could replace the acquiring company's business.[7] Traditional companies also enter into joint development agreements with robotics companies for the purpose of developing robotics solutions aimed at the traditional companies' business.[8] Alternatively, these traditional companies create their own internal robotics divisions by hiring individuals with robotics experience,[9] and by forming strategic alliances to create a new robotics ecosystem or 'cluster'.

Recently private companies are attempting to tackle particularly difficult problems in the robotics industry by using monetary incentives through crowdsourcing competition programmes. For example, in September 2014, Amazon Inc. announced the 'Amazon Picking Challenge', in which corporate and university teams had to solve the complicated problem of warehouse picking [*Romano,* 2014; *Gamell,* 2014]. This type of 'challenge' is similar to the open entry competitions like the United States' Defense Advanced Research Projects Agency (DARPA) Robotics Challenge or the prior DARPA Grand Challenge.

Publicly available information concerning formal partnerships and joint development agreements, as well as analyses of patent filings covering robotics technology suggest a significant degree of collaboration for development of robotics technology [UKIPO, 2014, pp. 13–16]. There are several reasons for the greater amount of collaboration in the robotics industry compared to other industries:

1. When it comes to government contracts, and particularly defence contracts with the United States government, the project is sometimes divided among more than one robotics company. The government will frequently award the design and fabrication of the mechanical and electrical aspects to one company, and hand over the software design and building to a different company [Robotics Trends Staff, 2007].

2. The problems that robotics companies tackle are often extremely complex involving multiple disciplines. Most small and medium robotics companies do not have experts from all the engineering disciplines necessary to build a sophisticated robot. The complexity of the technological challenges in building such products explains why even large robotics companies enter into joint development agreements with each other.[10]

3. Customized autonomous systems are now common in medical device manufacturing companies, pharmaceutical companies, and laboratories. Some companies and labs have an internal robotics and automation group that work on certain projects independently, as well as collaborate with specialized robotics companies whenever presented with a particularly time consuming or otherwise challenging assignment.[11]

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[7] Notable examples of traditional companies acquiring robotics companies include (i) Amazon.com Inc.'s acquisition of Kiva Systems, Inc.; (ii) Stryker Corp.'s acquisition of MAKO Surgical Corp.; and (iii) Advantech Co.'s acquisition of LNC Technology [*Letzing,* 2012; *Walker and Stynes,* 2013; *Chen,* 2013].

[8] Notable examples of traditional companies entering into joint development agreements with robotics companies for the purpose of developing robotics technology directly applicable to the traditional company's business include (i) Anglo American's partnership with Autonomous Solutions, Inc.; (ii) Lowe's Companies, Inc.'s partnership with Fellow Robots; and (iii) John Deere's joint development with iRobot Corporation. These joint development agreements materialized in jointly assigned patents (United States Patent Nos. 8,874,300; 7,894,951; 8,020,657; and 8,473,140).

[9] In 2014, Amazon.com Inc. advertised for jobs for individuals with experience and skills relevant to its then recently formed drone division [*Anders*, 2014].

[10] A notable example of joint development agreements between robotics companies includes iRobot Corporation's joint development and licensing agreement with InTouch Technologies Inc. [InTouch Health, 2011]. This agreement was reinforced by the jointly assigned United States Patent No. 8,718,837.

[11] Although internal robotics and automation divisions within traditional companies are not necessarily publicly promoted, a search of robotics-focused patents assigned to traditional companies outside the technology industry demonstrate that robotics related innovation is at least occurring within traditional companies in areas relevant to those companies' business. For example robotics and automation related patents assigned to Pfizer Inc. (United States Patent Nos. 5,370,754; 6,489,094); Abbott Laboratories (United States Patent Nos. 6,588,625; 8,318,499); and Deere & Company (United States Patent Nos. 7,861,794; 8,195,342; 8,295,979; and 8,874,261).

The high degree of collaboration surrounding the development of robotics technology suggests that joint development projects as well as personal contacts, are both meaningful mechanisms and avenues through which knowledge and skills relevant to robotics technology are diffused. Although the degree to which such knowledge and skills are diffused through scientific publications and the publication of patent applications remains unknown, this study is confident that both these publication mechanisms are used within robotics for acquiring knowledge of technological developments within the industry. Informal interviews with IP directors in numerous prominent robotics companies confirmed that several robotics companies regularly monitor the patent applications published by their competitors. This is done to:

- learn about new technological developments in the sector relevant to their business;
- obtain insights into a competitor's plans to either improve an existing product or create a new one, and find out whether a competitor is attempting to obtain patent protection for something that should be challenged as either non-novel or obvious.

However, it is not merely competing robotics companies who monitor the publication of patent applications. When patent applications are published concerning an invention of particular interest, especially when it relates to a potentially transformative technology for a publicly well-known company, it is common for the patent application to become the subject of an article.[12]

Generally, the exchange of knowledge within the robotics ecosystem currently seems extensive and fluid. This is benefited by the science-intensive nature of robotics innovation and the strong role of science and research institutions, but also by the admittedly nascent phase of many advanced robotics developments. Scientific papers and conferences – such as the International Symposium on Industrial Robots – play a key role in the transfer of knowledge. Moreover, robotics contests and prizes rewarding solutions to specific challenges enable researchers to learn and benchmark their progress, and to close the gap between robotics supply and demand.

Finally, decentralized software-enabled innovation is likely to increase in the future as robots become more widespread, and robot platforms and systems more standardized. In practice, a wider set of external firms and partners will be able to deliver customized solutions to existing proprietary robotic software platforms. This will enable greater modularity in innovation.

Government support for orchestrating and funding innovation

Governments and their institutions have played a major role in supporting robotics innovation. In particular, governments have funded technological advancements in the defence sector, which are kept confidential for some time. Later, these advancements are ultimately disclosed for non-military and commercial purposes, which contributes to progress in the robotics industry [*Springer*, 2013, pp. 15–16].

Beyond important research funding and standard innovation support measures, a few specific policy mechanisms deserve to be mentioned:

- *Creation of special research institutions or research networks:* Examples include the Swiss National Centre of Competence in Research Robotics, which federated research labs, and the Korea Robot Industry Promotion Institute, set up to promote technology transfer.
- *R&D grants and public procurement:* Governments, and often the military, fund robotics innovation and create demand via grants or pre-commercial procurement. In the US, R&D contracts mainly with the National Institutes of Health and DARPA are the primary catalysts [*Mireles*, 2006; *Springer*, 2013; *Siegwart*, 2015]. Pre-commercial procurement of robotics solutions for the healthcare sector, for instance, is part of the EU Horizon 2020 grants. Governments have also incentivized innovation and advancement within the robotics industry through various types of incentive programmes. In the United States, for example, the government incentivized private companies and universities to create autonomous vehicles by offering a substantial monetary sum to whomever accomplishes a set task [*Mireles,* 2006]. Other governments have provided tax breaks for robotics companies, though some argue that such incentives primarily incentivize the relocation of robotics companies rather than innovation. On the other hand, some countries provide grants for prototype-stage products to be used within an industry with potential customers. This alleviates the particularly lengthy time gap between the creation of a functional prototype and a commercialized product that has been more rigorously tested and satisfies arduous regulatory requirements [Technopolis, University of Manchester, 2011].
- *Organizer of contests, challenges, and prizes:* Japan organizes Robot Olympics; the UK recently held a competition for driverless vehicles; and the DARPA Robotics Challenge is a landmark.
- *Incentives for collaboration, technology transfer, and incubation:* Through grants or contracts, governments frequently encourage collaboration and technology transfer. The EU Horizon 2020 Robotics project, for instance, stimulates public-private collaborative projects of a multi-disciplinary nature. In addition, government activities aim to facilitate cluster development, entrepreneurship, and industry networking. In France, for example, the government created the seed fund 'Robolution Capital.'
- *Regulations and standards:* Legal scholars disagree about the extent to which regulations actually spur or inhibit the growth of technological advancement in the robotics industry. Nevertheless

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[12] See for example [*Falconer,* 2014], who analyses Sony Corporation's potential strategy to develop personal robots based on the publication of United States Patent Application No. 2014/0074292, filed on April 16, 2012, entitled 'Robot device, method of controlling robotic device, computer program, and program storage medium'.

> there seems to be a general consensus that half-fledged, categorical regulations have the potential to restrict such advancements [RoboLaw, 2014, p. 10; *Pilkington,* 2014]. One of the primary areas in need of attention is the reform of current safety standards applicable to robotics, particularly those requiring a clear separation of workspace between humans and robots. Safety is a multidimensional issue extending beyond technology to include numerous governmental and industry standards as well as independent certification and liability exposure. Clear standards are needed for both professional and personal robotics to provide all stakeholders with the transparency necessary for rapid innovation and adoption [*Christensen et al.,* 2013, p. 84]. Furthermore, governments can also hinder innovation in the private sector via burdensome regulations [The Economist, 2014; RoboLaw, 2014, p. 10] Yet, aside from the restrictive regulations applicable to drones and Unmanned Aerial Vehicles (UAVs) in several nations, no regulations exist specifically for most other robotics related technologies.[13]

In addition to the above, many of the more developed countries, including China, have announced special robotics action plans in recent years. These strategies generally include specific monetary investments for robotics research and innovation, measures to improve robotics education, and technology transfer (Table 2).

Robotics Innovation and Intellectual Property

The focus of robotics innovation is shifting from industrial automation to more advanced robotics involving various technological fields, actors, and economic sectors. As a result, related IP and other strategies to appropriate returns on innovation investment are embryonic and our understanding of what they should look like is incomplete. In addition, recognizing the broad scope of the robotics industry is important because the large variety of robotics products and their applications means that there is no 'one-size-fits-all' IP strategy for robotics companies. Furthermore, observations and trends related to one segment are not necessarily relevant to other segments of the robotics industry.

Some tentative findings on appropriation strategies do, however, emerge based on existing literature, data, and insights from industry practitioners and robotics researchers.

Methodology of patent analysis

Part of the empirical analysis of this paper relies on a tailor made patent mapping. The patent data for these mappings come from the WIPO Statistics Database and the EPO Worldwide Patent Statistical Database (PATSTAT, April 2015).

The patent mapping strategy was adapted from the seminal work by the UKIPO [UKIPO, 2014]. This work combines the *Cooperative Patent Classification (*CPC) and International Patent Classification (IPC) symbols with text terms searched for in titles and abstracts. In particular, we have included the following list of IPC and CPC symbols: B25J 9/16, B25J 9/20, B25J 9/0003, B25J 11/0005, B25J 11/0015, B60W 30, B60W2030, Y10S 901, G05D 1/0088, G05D 1/02, G05D 1/03, G05D2201/0207, and G05D 2201/0212; we complemented these with the following terms: *robot*, *robotics*, and *robotic*.

The resulting sample was benchmarked against a list of seminal patents and a list of robotics companies. The latter was compiled – along with their geographic locations and the company type – based on information about robotics companies available to robotics-focused associations and groups, including The Robot Report's Global Map, as well as from the publicly available listing of companies from the Robotics Industry Association (RIA). These sources are useful to corroborate the location of robotics companies and the formation of robotics clusters. However, identifying robotics companies by such

Table 2. **National robotics initiatives**

Initiative	Jurisdiction (Year of initiative)
National Robotics Initiative Advanced Manufacturing Partnership	United States (2011)
France Robots Initiatives (Feuille de Route du Plan Robotique)	France (2013/2014)
Robotics Project Horizon 2020	European Union (2015)
New Industrial Revolution Driven by Robots ('Robot Revolution')	Japan (2015)
Next-Gen Industrial RobotizationSouth Korea (2015)	South Korea (2015)
Robotics Technology Roadmap in 13th Five-Year Plan (2016-2020)	China (2015)

Source: compiled by the authors.

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[13] Regulation concerning UAVs exists in Canada, Australia, the United States, and in European countries whose airspace is regulated by the European Aviation Safety Agency. The United Nations is proposing to introduce amendments to the 1968 Vienna Convention on Road Traffic in consideration of driverless/autonomous vehicle technology [UN, 2014]. ; Legislation also exists in several states of the United States concerning driverless cars, including in California (SB 1298), Florida (CS/HB1207), Michigan (SB 0169, 0663), Nevada (AB 511, SB 140), and the District of Columbia (B19-0931).

robotics-focused associations and groups has certain shortcomings in the way that they are used herein. Nonetheless, it appears that the shortcomings are minor and do not significantly impact the conclusions derived from the data (Figure 2 and footnote 4).

The main unit of analysis is the first filing of a given invention. Mappings include registration data on utility models whenever available. Consequently, the date of reference for patent counts is the date of first filing. The only departure from this approach occurs when analysing the share of patent families requesting protection in each patent office (Figure 7). In this case, we used an extended patent family definition – known as the INPADOC patent family – rather than relying on first filings. In addition, only patent families with at least one granted application have been considered for this analysis, and the date of reference is the earliest filing within the same extended family. The main rationale for using the extended patent family definition and imposing at least one granted patent within the family is to mitigate any underestimation. Underestimation could be a problem because of complex subsequent filing structures (such as continuations and divisionals), and small patent families of lower quality (such as those filed in only one country and either rejected or withdrawn before examination).

The origin of the invention is attributed to the first applicant of the first filing; when this information was missing, we applied an imputation strategy. When information about the first applicant's country of residence in the first filing was missing, we adopted the following sequence:

- Extract country information from the applicant's address and name;
- Check information about the companies referred to;
- Rely on the most frequent first applicant or first inventor's country of residence within the same patent family (using the extended patent family definition), or the IP office of the first filing as a proxy for origin.

We categorized applicants into three broad categories:

- State-owned and private companies;
- Government institutions (ministries, state departments, and related entities), public research organizations, and public and private universities;
- Individuals, including those who may or may not be affiliated with companies, research organizations, or other entities.

All unclassified first applicants were grouped into a fourth category called 'data unavailable'.

To assign broad type categories to each first applicant, we performed a series of automated steps for each of the six innovation fields underlying the case studies. We manually cross-checked the results of this automated process, particularly for the top applicants of each type. This prompted us to revise the strategy and adjust the parameters in several iterations.

The starting point was the original information about the first applicant's name from the first filing. When this name was missing, we used the most frequent first applicant's name within the same patent family using the extended definition. We automatically parsed this list of improved first applicants' names in several iterations to: (i) harmonize capital and small letters; (ii) remove symbols and other redundant information (such as stop words and additional geographical references that are useful to get information on applicants' country of residence); and (iii) obtain any valuable information on applicant names to determine whether the applicant is affiliated with a company or research or public sector organization.

Subsequently, we carried out a fuzzy string search using Stata's *matchit* command to detect alternative spellings and misspellings in applicant names.[14] Consolidating the corporations also meant we could reclassify some unclassified applicant names as companies. Finally, we imputed the remaining unclassified records into the category of individuals only when they either appeared as inventors in the same patent or were flagged as individuals in the WIPO Statistics Database for patent families containing a PCT application. Analysis of the unclassified records indicates that most of them have missing applicant names in PATSTAT. Most of these missing names refer to original patent documents not in Latin characters and without subsequent patent filings.

The rankings provided for robotics consolidate the patent filings of different first applicants. We carried out a manual examination and consolidation for the most frequent applicants. Corporate or firm applicants sharing a common ultimate owner were consolidated into one applicant. In the case of the top 30 companies, we used the ownership profiles in the *BvD Ownership Database*. Only subsidiaries that were directly or indirectly majority-owned were taken into account in the consolidation process.

Patenting: their roles, functions, and potential challenges

Patents are a particularly important IP right for robotics companies because of the significant amount of capital frequently required for research and development prior to the manufacturing of a commercially ready product. Indeed, the large pre-market research and development costs coupled with slow regulatory clearance can create a context in which trailblazing robotics companies may feel that patent protection is necessary to recoup their investment. In absence of such protection, newcomers would be able to enter the market, after the "trail has already been blazed" at a lower cost for research and development and have to overcome fewer regulatory hurdles [*Cooper,* 2013; *Nobile, Keisner,* 2013].

For inventions discoverable through reverse engineering or other legal means, patent protection is typically favoured over trade secrets. It is understood that many robotics companies whose competitive

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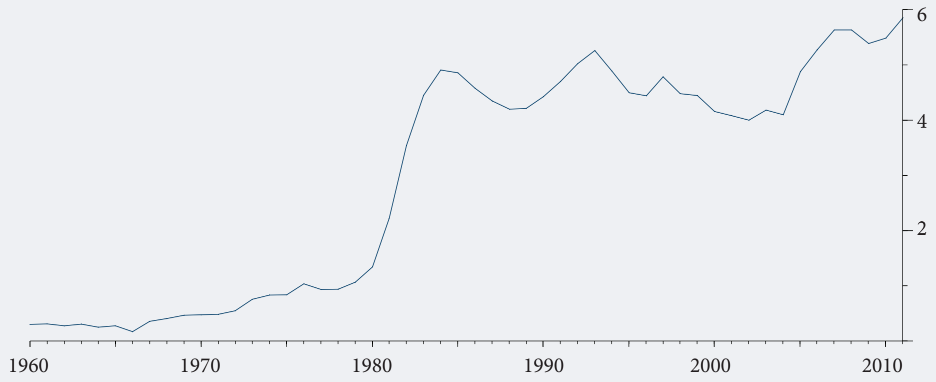
[14] This is available from the Statistical Software Components (SSC) archive and from the WIPO website.

Figure 5. **Dynamics of patenting in robotics (number of first patent filings by country of origin): 1960-2011 (*% of total filings*)**



Source: WIPO based on the PATSTAT database.

advantage is perceived to be their sophisticated software designed to enable robotic hardware devices, may use complicated software that cannot be easily reverse-engineered. This is particularly the case with software-based electro-mechanical devices.

Although deterring and excluding competitors is frequently a primary consideration of robotics startups, another common incentive for seeking patent protection concerns the perceived advantages to startups when seeking investment [*Keisner,* 2012]. This is because, for example, early-stage investors are generally reluctant to sign non-disclosure agreements [*Zimmerman,* 2014]. This motivation for startups to file patent applications was corroborated by several directors of IP for robotics startups during informal interviews.

As a result, key robotics inventions are frequently patented by their original inventor (who are often researchers). The original inventors then frequently start their own company or transfer their IP to existing manufacturing firms.

In the 1980s, robotics patents increased rapidly as broad-based automation of factories flourished and robotics research was ramped up. Robotics-related first filings approximately quadrupled during this decade (Figure 3). More importantly, these filings outpaced patent filings from other technological fields. The share of total patents from robotics increased from 0.13% in 1980 to 0.53% in 1993 (Figure 5).Then, after a relatively flat period of patenting activity during the 1990s and the first half of the 2000s, the shift to more advanced robotics gave another boost to robotics patenting that continues to this day. In a period of increased overall patenting activity, robotics absolute patent filings roughly doubled and the share increased from 0.4% in 2004 to 0.6% in 2011 (Figure 5).

The fact that robotics inventive activity is concentrated in a few nations, including the innovating Asian countries, is reinforced by patent data. Figure 3 shows the number of first patent filings worldwide in robotics between 1960 and 2012. It shows the importance of the US, Europe, and later Japan, in the innovation. The recent emergence of South Korea in the early 2000s and then China as important players is noteworthy [UKIPO, 2014]. While the share of China in total robotics patents in 2000 was only 2%, that figure rose to 37% by 2011. South Korea's share stood at 17% in 2011, while Japan's share fell from 45% in 2000 to 10% in 2011.[15]

Figure 6 indicates the origin of first patent filers in two periods, 1980–1990 and 2000–2012. In the more recent period, the countries with the highest number of filings are Japan, China, South Korea, and the US, with each filing more than 10,000 patents and together accounting for about 75 percent of robotics patents. This feat is followed by Germany with roughly 9,000 patents and France with over 1,500. Other countries such as Australia, Brazil, a number of Eastern European countries, the Russian Federation, and South Africa also show new robotics patenting activity, albeit at a lower level.

Indeed, in terms of robotics innovation and company startups, the majority of activity rests in high-income countries, except for China.

Robotics patenting is geographically highly concentrated, with Japan as the leading destination (accounting for close to 39% of all robotics patents), followed by the US and China (with almost 37%), and Germany with 29%. Other major European countries and South Korea are close behind. On the other hand, only 1.4% of all robotics patents are filed on average in low- and middle-income countries.

Automotive and electronics companies are still the largest filers of patents relating to robotics (Table 3). Yet new actors are emerging from different countries and sectors such as medical technologies. These

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[15] Note that proportions are calculated considering only first filings with at least one patent granted within the patent family.

firms' robotics patent portfolios are increasing, as firms file patents themselves thanks to their own R&D or purchase companies with a stock of granted patents.

The large and growing stock of patents owned by universities and PROs is noteworthy too. Table 4 lists the most important patent holders, now largely dominated by Chinese universities. This facilitates the commercialization of new technologies but also poses new challenges for managing these sizeable portfolios.

It is challenging to understand the various factors leading firms to file for patents. No large-scale survey of robotics firms or other solid quantitative work exists that would shed light on this question. Providing a definitive answer on the impacts of robotics patenting on innovation via disclosure, licensing, and IP-based collaboration is also difficult. However, several findings emerge from the views of industry experts, including both lawyers and roboticists. As in other high-tech sectors, robotics firms seek to use patents to exclude third parties, secure freedom to operate, license and cross-license technologies and, to a lesser extent, avoid litigation. For small and specialized robotics firms

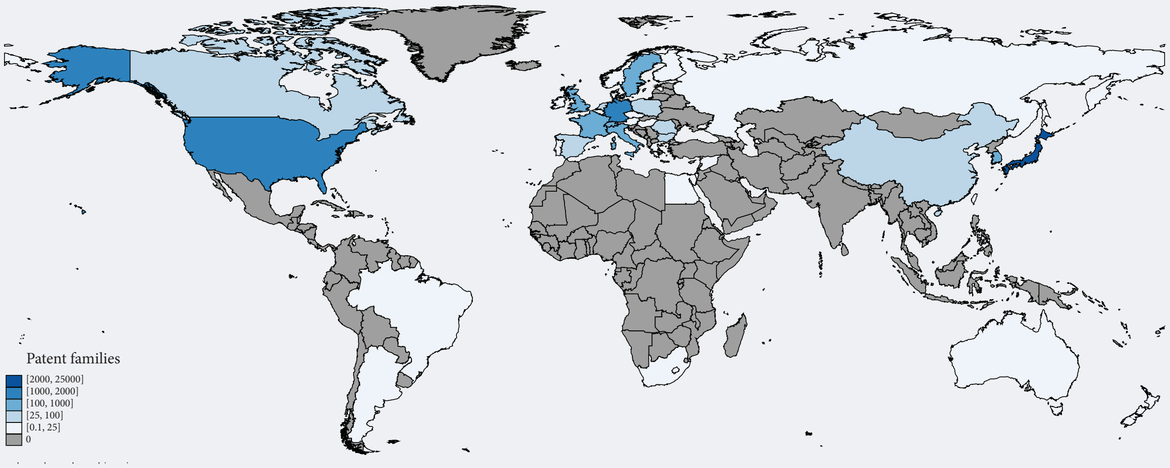
Table 3. **Top 10 robotics patent filers: 1995 - present**

Company	Country	Number of first patent filings
Toyota	Japan	4189
Samsung	South Korea	3085
Honda	Japan	2231
Nissan	Japan	1910
Bosch	Germany	1710
Denso	Japan	1646
Hitachi	Japan	1546
Panasonic (Matsushita)	Japan	1315
Yaskawa	Japan	1124
Sony	Japan	1057

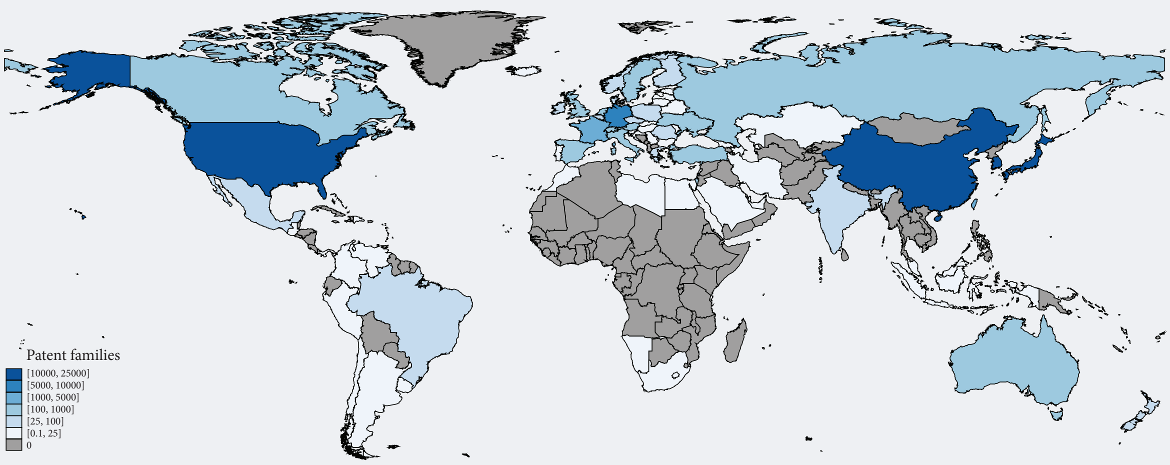
Source: WIPO based on the PATSTAT database.

Figure 6. **Dynamics of geographical diversity in robotics innovation (number of first patent filings globally)**

a) 1980–1990



b) 2000–2012



Source: WIPO based on the PATSTAT database.

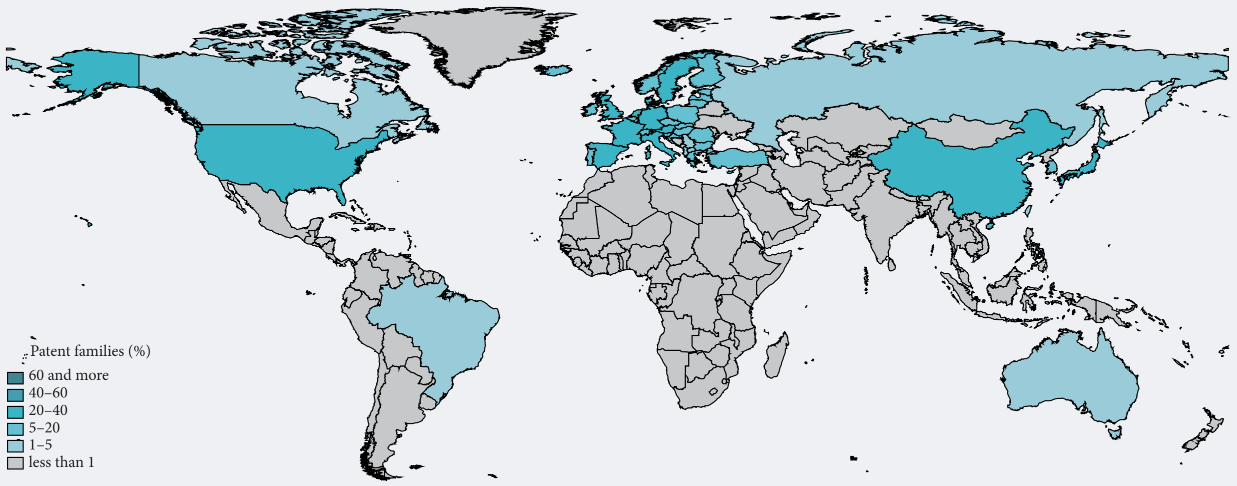
Table 4. **Top-10 robotics patent holders among universities and PROs, 1995 – present**

Name of organization	**Number of patents issued**	**Country**
Top 10 patenting worldwide		
Shanghai Jiao Tong University	811	China
Chinese Academy of Sciences	738	China
Zhejiang University	300	China
Korea Institute of Science and Technology, KIST	290	South Korea
Electronics and Telecommunications Research Institute, ETRI	289	South Korea
Tsinghua University	258	China
Harbin Engineering University	245	China
National Aerospace Laboratory	220	Japan
Harbin Institute of Technology	215	China
Korea Advanced Institute of Science and Technology, KAIST)	188	South Korea
Top 10 patenting worldwide (excluding China)		
Korea Institute of Science and Technology, KIST	290	South Korea
Electronics and Telecommunications Research Institute, ETRI	289	South Korea
National Aerospace Laboratory, JAXA	220	Japan
KAIST	188	South Korea
Deutsche Zentrum für Luft- und Raumfahrt	141	Germany
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung)	91	Germany
University of Korea	85	South Korea
Hanyang University	84	South Korea
Seoul National University	77	South Korea
National Institute of Advanced Industrial Science and Technology, AIST	69	Japan

Note: Depending on the legislation and policy in place, academic inventors may file patents under their own name or that of their spin-off company in certain countries [WIPO, 2011]. These patent filings are not captured here.

Source: WIPO based on the PATSTAT database.

Figure 7. **Main geographical areas of robotics patenting (share of robotics-related patent families worldwide for which applicants have sought protection in a given country)**



Source: WIPO based on the PATSTAT database.

in particular, patents are a tool to seek investment or defensively protect their IP assets against other, often larger companies. In terms of the impacts of patenting on innovation, at present the innovation system appears relatively fertile. Collaboration – including between universities and industry – is strong, and there is extensive cross-fertilization of research. Patents seemingly help firms specialize, which is important for the evolution of the robotics innovation system. It is also true that patenting prevents market entry or restricts robotics innovation by limiting access to technology. The available evidence shows little or no litigation occurring in the field of robotics. Indeed, most of the disputes over robotics IP in the past 10 years have involved just one company, iRobot.

Moreover, the importance of particular patents for robotics innovation is hard to verify. Currently, no patents have been flagged as standard-essential, and no known patent pools exist in the area of robotics. Further, there are few formal and disclosed collaborations or exchanges in which IP is central. Only one major licensing deal in the recent history of robotics has received much attention: the joint development and cross-licensing deal between iRobot Corp and InTouch Technologies in July 2011. That said company acquisitions involving the transfer of IP are growing steadily.

Firms use patents to learn about new technology developments, gain insights into competitors' plans for improving or creating products, and to find out whether competitors are attempting to obtain patent protection that should be challenged. Forward patent citations within and outside robotics are often used as an indicator of incremental innovation; that is, of processes in which earlier inventions are built upon. However, especially in the US patent system, forward patent citations are a mere legal obligation, making impact assessment harder. As a result, the overall value of patent disclosure in the area of robotics remains largely unassessed.

Many of the above questions will only be resolved over time. Arguably, IP is not yet fully used in advanced robotics and so its potential impact remains to be realized. Compared with the past, today's robotic innovation system involves more actors, new technology fields, and significantly more patent filings. We can start to see more intensive, offensive, and defensive IP strategies that are present in other high-technology fields.

A vital question is whether the increased stakes and commercial opportunities across various sectors will tilt the balance toward costly litigation, as in the case of other high-tech and complex technologies. For the moment, the number of IP disputes involving robotics companies is too small to extract any meaningful insight about the effectiveness of the IP system. One noticeable trend is that the majority of IP disputes over the past ten years involved a single well-known United States based robotics company (iRobot Corp). These lawsuits include one in 2005 against Koolatron & Urus Indus; one in 2007 against Robotic FX; several in 2013 in Germany against Elektrogeräte Solac Vertrieb GmbH, Electrodomésticos Solac S.A., Celaya, Emparanza y Galdos Internacional S.A., Pardus GmbH, and Shenshen Silver Star.[16] To date, there has only been one recent IP dispute in which the lawsuit went to a final judgment and appeal.[17] This makes it difficult, if not impossible, to assess whether the judicial system adequately resolves IP disputes involving robotics related technologies.

There have been few cases in which non-practicing entities have targeted robotics companies with a lawsuit.[18] In particular, press reports mention the dangers of patent trolling in the field of surgical robots and medical robotics.

Two elements could increase the likelihood of disputes. First, experts consulted in this study have raised concerns that overly broad claims are being made in the case of robotics patents, especially with respect to older patents. While patent infringement disputes between robotics companies appear to be resolved effectively by current judicial systems,[19] certain patent infringement disputes have led some professionals within the robotics industry to question the breadth of patent claims contained in older patents [*Tobe*, 2012].

Second, in certain countries the patentability and novelty of computer-related inventions generally are a matter of debate. This is particularly true in the US, where the recent Supreme Court decision in Alice Corp. vs. CLS Bank seems to have reinforced a restrictive approach towards patent eligibility of software [*Thayer, Bhattacharyya,* 2014a, 2014b]. Given the large and growing software-related component of robotics innovation, concerns about software patentability may pose a challenge in relation to current and future robotics-related patents.

Robotics platforms: the co-existence of IP and open source

As described earlier, robotics platforms in universities and businesses have become central to robotics innovation. Such platforms, such as the Robot Operation System (ROS), are increasingly based on open source software. Open source robotics platforms invite third parties to use and/or improve existing content without the formal negotiation or registration of IP rights. Instead, software or designs are

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[16] For more detail on these lawsuits and their conclusions, see [*Keisner et al.,* 2015].

[17] This was the lawsuit between the firms InTouch Health and VGo Communications, which both independently developed telepresence robots. For more detail, see [*Keisner et al.,* 2015; *Nobile,* 2013].

[18] Some examples include the lawsuits between Roy-G-Biv. Corp. v. Fanuc Ltd. (in 2007), and Roy-G-Biv Corp. v. ABB, Ltd., Honeywell Int'l, Inc., and Siemens Corp. (all in 2011). For more detail, see [*Keisner et al.,* 2015].

[19] It should be noted that, for the purpose of this study, the effective resolution of an IP dispute does not take into consideration the resources expended by companies in asserting or defending a claim, which varies greatly between countries based on differences in judicial systems. This includes the large difference in resources expended in a lawsuit based on discovery rules and whether there are fee-shifting rules.

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The core idea is simple. Actors distinguish between two stages of innovation. In the early stages, there is the collaborative development of robotics software, platforms, and innovation. Such innovation may be substantial, but it is essentially pre-competitive because the fields of use are relatively basic and do not serve to differentiate products. Actors therefore apply cooperative open source approaches to obtain common robotics platforms, as this allows them to share the substantial up-front investment needed, avoid duplication of effort, and perfect existing approaches.

In the later stages, innovative firms invest in their own R&D efforts and strive to protect their inventions far more vigorously, especially those elements of robotics innovation that differentiate end-products.

This parallel application of cooperative and competitive approaches results in a co-existence of competitive and open source-inspired approaches to handling IP.

Various non-profit organizations and projects support the development, distribution, and adoption of open-source software for use in robotics research, education, and product development. The iCub, for instance, is an open-source cognitive humanoid robotics platform funded by the EU, which has been adopted by a significant number of laboratories. Poppy is an open-source platform developed by INRIA Bordeaux for the creation, use, and sharing of interactive 3D-printed robots. Other examples include the Dronecode project and the NASA International Space Apps Challenge.

This trend could entail an increasing shift toward engaging end-users or amateur scientists to interact with and improve existing robotics applications. In fact, many user-oriented, low-cost platforms built for home or classroom use, like TurtleBot and LEGO Mindstorms, are built on open source platforms.

This open-platform approach is not limited to software; it can also encompass blueprints such as technical drawings and schematics, including designs. The Robotic Open Platform (ROP), for instance, aims to make hardware designs of robots available to the robotic community under an Open Hardware license, whereby advances can be shared within the community.

In general, it will be interesting to see how well the robotics innovation system preserves its current fluid combination of proprietary approaches for those aspects of IP where the commercial stakes are higher. The same can be said for non-proprietary approaches to promote more general aspects of relevant science through contests and collaboration among young roboticists and amateurs interested in open-source applications. In light of the high degree of collaboration in the robotics industry, as well as many countries' interest in fostering robotics innovation, it is timely for countries to re-examine their laws on joint IP ownership. Many national laws on joint IP ownership produce unexpected and unfair results in practice, unless the persons or entities involved contract around such laws.

Protecting robotic breakthroughs via technological complexity and secrecy

Potentially more important than patents, the technological complexity and secrecy of robotics systems are often used as a key tool to appropriate innovation. This is true for standard mechanical, hardware-related components. There are multiple reasons why a robotics company may prefer to keep certain technologies or information as trade secrets rather than seeking patent protection. The first two reasons, which are not necessarily unique to robotics, are related either to the difficulty in obtaining patent protection or to the issue that IP could not be reverse engineered by even the most sophisticated competitors. This is frequently the case with robotics companies who believe that their manufacturing process could not be identified without a competitor actually observing the manufacturing process. The same is frequently true for testing methods of a robot's performance. However, some robotics companies have survived with relatively few competitors, and believe that their work, although comprised of software and hardware, is so advanced that only a select few could reverse engineer their products. Robotics companies that make a limited number of highly expensive robots are typically not afraid that competitors will gain physical possession of such robots to reverse engineer them, as that proposition is often impracticable [*Keisner*, 2013b].

Additionally, many small and mid-size robotics companies prefer trade secrets because they want to avoid the onerous costs and fees that come with filing patent applications.

There are also historical reasons why robotics companies choose to retain information as trade secrets. In the 1980s, robotics made several significant advances and firms filed many patents (Figures 3 and 5). However, only a few of these inventions were commercialized quickly. In other words, firms spent large amounts of money to obtain patents that expired before their products were commercialized. Thus, patents can be costly without necessarily bringing any reward, especially for innovations that may be decades away from use in a market-ready product.

Trade secret protection is also important when employee mobility is high. Robotics companies have sought to protect their trade secrets when an employee joins a competitor. Many robotics companies bolster the protection of their trade secrets with restrictive covenants as permitted by the relevant jurisdiction.[20]

Finally, the recent questions around the patentability of software in the US and elsewhere could increase the incentive to protect related inventions via secrecy.

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[20] For example, MAKO Surgical Corp.'s lawsuit against Blue Belt Technologies, and ISR Group's lawsuit against Manhattan Partners. For more detail, see [*Keisner*, 2013a, b; *Keisner et al.*, 2015; *Cole*, 2014].

The role of being first-to-market, reputation, and strong brands

Being first to market, a strong after-sales service, reputation, and brand name, have all been critical in past robotics innovation, and remain so today, especially since the industry has moved away from serving factories and into applications with direct consumer contact.

In the case of industrial automation, automotive companies prefer to only deal with a few trusted operators who are able to produce many reliable robots and service them dependably. Initially, Unimation dominated the supply of industrial robots; later, large firms such as Fanuc held sway. Experience and a solid reputation and brand continue to be critical in the health sector, educational institutions, and the military. Examples of such trusted brand names in the area of medical robot makers are DaVinci surgical robot, CorPath vascular surgery robots, and the Accuray CyberKnife Robotic Radiosurgery System. In the military and related fields, brands also matter as evidenced by the use of trademarks such as Boston Dynamics' 'BigDog'. Strong brands are particularly important when robots are sold directly to end-users; for example, the 'Roomba vacuum cleaner' relies strongly on its trademark value.

Most companies trademark their company names and robot names. This means that a growing number of trademarks include the term 'robot'.

Industrial design rights and trade dress

Next to patents, industrial designs that protect the ornamental features of a robot as registered IP forms also play an important role in helping firms appropriate the returns to their investments in R&D.

Another form of IP is trade dress, a source-designating type of IP that refers generally to the total image of a product [*Reese,* 1994; USPTO, 2014]. Within the robotics industry, trade dress is a right generally used to describe the total image of a robot or robotics product.[21] Some nations do not distinguish between trade dress rights and trademark rights as both are considered source-identifying forms of IP. Other countries provide protection for trademark rights under a sufficiently broad definition such that it could be extended to other source-identifying forms of IP, including registered trade dress rights.[22]

Within the robotics industry, there are only a few examples of lawsuits asserting trade dress infringement claims based on the 'look and feel' of a robot. However, there are no known cases in which such a trade dress infringement claim has been entertained.[23]

Copyright and robotics

The issue of copyright protection is relevant to robotics in several respects. Copyright protection is especially an issue in the area of software codes that have been 'reduced to writing' and are believed to be unique and original. In practice, robotics companies typically use copyright enforcement to prevent others from copying or simply accessing their computer code. Another example where copyright protection could be used for robotics but is not a common practice in the industry is for a unique aesthetic design, such as a design pattern on a robot.

It is generally accepted within most countries that circumventing an electronic barrier in order to gain access to copyrightable computer code is a violation of the 1996 WIPO Copyright Treaty (Article 11). This is particularly important for the robotics industry because most robotics companies employ electronic barriers to restrict access to their robot's computer code. In the United States, the case law over the past several years also shows a trend suggesting that the US, which is a signatory to the WIPO Copyright Treaty, would need to conform to the laws of most other nations and Article 11 of the WIPO Copyright Treaty. Circumventing an electronic barrier to access copyrightable code – even if there is no act of copying giving rise to an independent claim for copyright infringement – would still constitute a violation of the United States' Digital Millennium Copyright Act (DMCA), which is the United States' implementation of the WIPO Copyright Treaty [US Senate, 1998; *Keisner,* 2012]. The European Union has similarly taken measures to harmonize its laws with the WIPO Copyright Treaty by prohibiting the circumvention of electronic barriers to access protected copyrightable works: for example, the implementation of Article 6 of the European Directive 2001/29/EC [European Parliament, 2001].

Despite the fact that some national laws may provide for reverse engineering exceptions, copyright related anti-circumvention laws have also been invoked when an amateur scientist decrypts and changes software code. Although never to date the subject of a court decision, there have been cases where companies have made claims regarding violation of the US Digital Millennium Copyright Act (DMCA) due to unauthorized access to the company's robot's software code. For instance, when a hacker decrypted the software code for Sony's robotic-dog, Aibo, and circulated the new software to other consumers such that they could 'teach' the robotic-dog to speak and dance, Sony asserted that such acts were a violation of the DMCA and demanded the removal of the software [*Mulligan, Perzanowski,* 2007].

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[21] Similar to trade dress rights, industrial design rights protect the visual design of an object. As a result of The Hague Agreement Concerning the International Deposit of Industrial Designs, there is now a procedure for international registration of an industrial design, effective in several countries, via a single application [WIPO, 2014].

[22] For example, see India's Trade Marks Act of 1999. In addition, [Tiwari, 2005, p. 480] points out that Indian courts have shown the propensity to address the issues of trade dress protection within the broad parameters of the law on substitution.

[23] For example, the lawsuits between iRobot Corporation and Urus Industrial Corporation (2005) and between Innovation First, Inc. and Urban Trend, LLC (2010). In both cases, the lawsuits were settled and consent judgments filed. For more detail, see [*Keisner et al.,* 2015].

Robot-inventors as the subject of copyright

In the future, robots – when carrying out set tasks – are likely to produce new solutions to problems, and in so doing potentially create physical or intangible products or outputs. These outputs could (at least in theory) be perceived as IP – new inventions, creative works, or trademarks. This element of robotics innovation could raise interesting questions as to the set-up and boundaries of the current IP system. Are objects, software code, or other assets created autonomously by a robot copyrightable or patentable? If so, how? Further, who would own these IP rights – the producer, the user, or the robot itself? [*Leroux,* 2012]. Some countries such as Japan and South Korea are seriously considering extending rights to machines.

Some case law is relevant too. For instance, the US Copyright Office recently determined that a photographer did not own the copyright to a photograph taken by a monkey who temporarily 'borrowed' his camera [McAfee, 2014; US Copyright Office Practices, 2014] Given that ruling, some practitioners question whether photographs taken by robots would be protected by copyright – at least in the US [*Fischer,* 2014; *McAfee,* 2014].

In the UK, on the other hand, there is dedicated legislation suggesting that copyright protection can be avoided for robot-generated works. Although it is debated how such legislation should be applied, it is nonetheless an area of IP law applicable to robotics in which it appears that contradictory rules are emerging between countries with significant roles in the robotics industry [RoboLaw, 2014, p. 19] . In New Zealand, the law suggests that original works created by a human are still eligible for copyright protection under its 1994 Copyright Act, even if the work is created with the help of software, robots, or artificial intelligent systems [*Grierson et al.,* 2011]. Ownership of such works, however, would belong not to the robot or intelligent system, but instead to the person(s) who created or utilized the robot or intelligent system that ultimately created the work. In comparison, however, IP practitioners in Australia have noted, in light of some of the same case law referenced by New Zealand practitioners, that the laws providing for copyright protection of computer-generated works involve numerous aspects. Moreover, these practical aspects make it difficult to assert protection over a work generated by a computer, robot, or intelligent system [*Clark, Kovacic,* 2011].

A full legal assessment of the issues relating to autonomous robot creation is beyond the scope of this paper. Nevertheless, the question of who owns the IP rights over creations produced by robots will surely be a matter of future discussions.

Conclusion

Few studies have analysed the developments of robotics, the underlying innovation eco-system, and the role of IP. Here we aim to fill this gap by providing an up-to-date assessment of the robotics innovation system. We analysed original patent landscape data to shed light on robotics filing strategies and to identify top filers. We also went beyond the use of patents to analyse the role of trade secrets, industrial design, brands, and copyright. To conclude, we demonstrated how developments in the robotics industry could lead to new questions, such as who owns the IP of works or inventions created by robots themselves.

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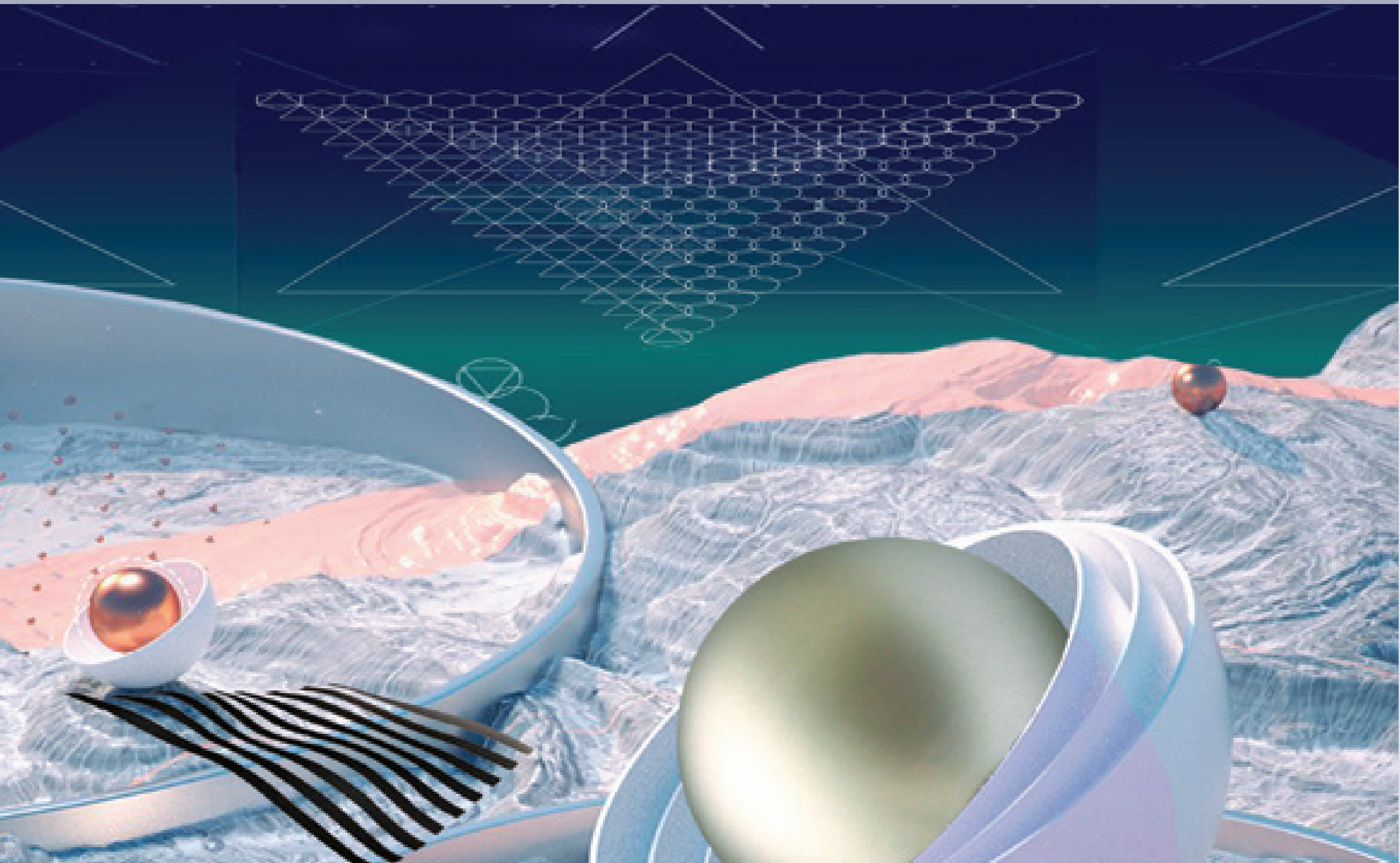

Determinants of Regional Innovation in Russia: Are People or Capital More Important?

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Abstract

Spending on innovation increased annually in the 2000s in Russia's regions, but innovation productivity varies greatly between regions. In the current climate of sanctions between Russia and Western countries and limitations on international technology transfer, there is a growing need to analyse the factors influencing regional innovation. Previous empirical studies using a knowledge production function approach have found that the main factor of growth in regional innovation is increasing spending on research and development (R&D).

Our econometric analyses show that the quality of human capital, a product of the number of economically active urban citizens with a higher education (the so-called creative class) has the greatest influence on the number of potentially commercializable patents.

Other significant factors were buying equipment, which indicates a high rate of wear and tear of Russian machinery, and spending on basic research. The 'centre-periphery' structure of Russia's innovation system favours the migration of highly qualified researchers to leading regions, which weakens the potential of the 'donor regions'. However, at the same time, we see significantly fewer limitations on knowledge spillovers in the form of patents and — in this case — proximity to the 'centres' is a positive factor.

Keywords: patenting level; human capital; knowledge spillovers; regions of the Russian Federation; knowledge production function; R&D; creative class

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The economic crisis in Russia and its aftermath led to a significant fall in the rate of growth. In such circumstances, diversification of the Russian economy is required, including significant changes in manufacturing processes and the creation of new products [*Gokhberg, Kuznetsova,* 2010; 2011]. Borrowing new technologies is limited in the current climate of sanctions between Russia and Western countries, so studying the factors determining innovation becomes more relevant and necessary. To date, Russia has created a significant number of support instruments for innovation and the necessary infrastructure in the majority of regions [*Barinova et al.,* 2014]. Spending on innovation has increased year on year, and yet we see a strong divergence between regions in terms of results. A common, yet often criticized, indicator of innovation is the number of registered intellectual property (IP): patents, utility models, industrial prototypes, etc. Patents have been used as an indicator of IP for many decades [*Griliches,* 1979, 2007]. Yet although patents can be considered a result of inventions, not all patents will be commercialized and become an innovative product or process.

Initially, the need for a regional analysis of innovation was disputed and there are still debates about which territorial level is preferable to study when looking at innovation [*Brenner, Broekel,* 2009]. The need to study regional factors of innovation is justified by ideas about knowledge spillovers and tacit knowledge. By this, we mean the particularities of different types of knowledge, the opportunity to use knowledge an infinite number of times, and limited chances to stop other agents from using this knowledge. Thus, innovation by one agent leads to positive, spillover effects for others, i.e., knowledge spillovers [*Acs et al.,* 2009; *Feldman,* 1999; *Meissner,* 2012; *Pilyasov,* 2012; *Dettmann et al.,* 2014].[1] Besides, tacit knowledge cannot be fully formalized and is transferred 'from teacher to student' [*Polanyi,* 1966]. Localization and creation of knowledge occur on both local and regional levels.

In this paper, we aim to assess the main factors of innovation at a regional level in Russia between 1998 and 2011 using official regional statistics and datasets of the Organization for Economic Cooperation and Development (the OECD). Data on patents, as with all statistics on innovation in Russia, are not always reliable [*Bortnik et al.,* 2013; *Baburin, Zemtsov,* 2013]. Hence, our first hypothesis is:

H1: innovation activity in Russia is hard to model econometrically.

Second, we hypothesize that human capital is a more important factor affecting innovation in Russia than R&D spending because of the ineffectiveness of R&D funding. However, in the 2000s the significance of human capital declined because of researchers' increasing average age [HSE, 2014] and the decline in the quality of education. Thus:

H2: Human capital is more important as a factor affecting innovation in Russia than R&D spending because of the ineffectiveness of R&D funding.

Third, we investigate the relationship between inter-regional (i.e. between sub-national regions) knowledge transfer and innovation. Thus we posit that:

H3: Inter-regional knowledge transfer in Russia has a positive effect on innovation.

Literature review and conceptual framework of the study

In the present study, we use the model of the knowledge production function (KPF). The KPF model describes the linkages between R&D spending, human capital, and innovation output. The KPF was first developed by Paul Romer, Zvi Griliches, and Adam Jaffe in the late 1980s. According to [*Romer,* 1986], new knowledge is produced as a result of using concentrated human capital *H* and the existing stock of knowledge *A*. The resulting new knowledge takes the form of new technologies:

$$dA/dt = \delta H^{v} \times A^{s}, \tag{1}$$

where δ is the coefficient of the productivity H, and

v and *s* are the empirical coefficients.

The coefficient *s* is positive if the knowledge generated from previous research increases the productivity of the research sector.

Romer's model theoretically sets out the influence of endogenous factors on economic growth, although several of its assumptions (for example, innovation only occurs in the R&D sector, and identifying total factor productivity, TFP, only with innovation) are not supported by empirical evidence.

Griliches defined a knowledge production function based on a simple model of 'inputs-outputs' [*Griliches,* 1984]. He showed that R&D expenditures influence the production of certain unobservable knowledge that has economic value. Yet only some of this knowledge can be identified and measured. Besides, a significant amount of knowledge determines TFP, and hence cannot be identified with TFP. Griliches measures innovation output as patents:

$$Patent = f(RnD\_\exp), \tag{2}$$

where:
Patent is the number of patents;
RnD_exp — spending on R&D.

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[1] Knowledge spillovers refer to a process when knowledge created by one firm or organization can be used by another entity without the need for compensation, or for a payment less than the value of the knowledge itself [*Pilyasov*, 2012].

Griliches pointed out that both current and historical spending on R&D influence knowledge accumulation. The process of doing research and development is protracted and includes the acquisition, adaptation, and use of production factors. Indeed, much literature in innovation studies emphasize the cumulative effect of R&D spending in previous periods of time. Another determinant of the process of raising the technological level in a given economic sector is the positive externalities from knowledge in other sectors i.e. knowledge transfer.

An expanded version of the KPF model includes human capital either operationalized as the number of years of education or the number of employed in R&D. In this paper, we use this expanded version with Romer's specification (equation 1 above). In this case, innovation depends on the number of R&D employees and R&D expenditure.[2]

Many empirical studies have used a KPF approach. The majority of these studies find that R&D spending, knowledge spillovers, the level of economic diversification, and human capital have significant effects on innovation output (Table 1).

Brenner and Broekel suggest an alternative model that departs from the main assumptions of the KPF approach [*Brenner, Broekel,* 2009]. Their critique of the knowledge production function is that innovation processes are clearly probabilistic in nature, in contrast to deterministic production processes. Knowledge — used to create innovation — never decreases, contrary to the supply of natural resources. They underline that a region is not an innovator by itself but rather part of a regional community of separate individuals that participates in innovation processes. It is impossible to generate more innovation only by increasing funding and hiring new researchers because innovation processes are, to a large extent, cumulative and involve much tacit knowledge. Thus, a long time is needed for sufficient scientific information, knowledge, and skills to accumulate and enable a sustainable, innovation-generating centre to form in a given location. With time, the corresponding institutional structures that can store, absorb, transfer, and reproduce knowledge and competencies will be created (e.g. universities). Moreover, given sufficient time research centres will be able to take root in the region. All these institutions help in producing knowledge spillovers, although the presence of institutional and cross-disciplinary barriers reduce any possible positive externalities and spillovers of knowledge. Brenner and Broekel's alternative model highlights the key role of human capital, entrepreneurial spirit, and related traits for innovation.

Table 1. **Summary of key empirical studies examining the factors of innovation**

Author(s)	Methodology	Dependent variable	R&D expenditure	Knowledge spillovers	Agglomeration effects*	Human capital	Key findings
[*Jaffe,* 1989]	Panel regression with fixed effects	Number of applications for national patents	+	+			Key influence of R&D spending, positive influence of co-location of state and private research centres (knowledge spillovers)
[*Feldman, Florida,* 1994]	Least squares	New production	+	+	+		Significant and positive influence of private and state R&D co-financing
[*Bottazzi, Peri,* 2003]	Panel regression with fixed effects	Number of national patents per one R&D employee	+	+	+		Influence of R&D spending of neighbouring regions sharply decrease if the distance between regions exceeds 300km
[*Shterzer,* 2005]	Panel regression with fixed effects	Number of applications for national patents	+		+	-	Positive impact of research funding, and negative impact of potential knowledge spillovers
[*Leslie, O'hUallachain,* 2007]	Least squares	Number of commercialized patents	+	+	+	+	Greater role of region's structural indicators and human capital on innovation output compared to R&D spending
[*Suslov,* 2007]	Panel regression with fixed effects	Share of innovative enterprises		-		+	Number of researchers has significant effect on regions' patenting activity
[*Mariev, Savin,* 2010]	System GMM estimation	Volume of innovative production	+	-			Positive impact of FDI on innovation activity and tendency for innovation to be concentrated in certain regions
[*Archipova, Karpov,* 2012]	System of simultaneous equations	Number of patents and share of innovative enterprises	+	+			Significant relationship between patenting and innovative activity, and significance of applied research funding
[*Crescenzi, Jaax,* 2015]	Panel regression with fixed effects	Number of applications for PCT patents	+	+	+	+	R&D spending in neighbouring regions has significant effect on regions' patenting activity

* Level of economic diversification, urbanization, and population density used as indicators of agglomeration effects.

Source: compiled by the authors.

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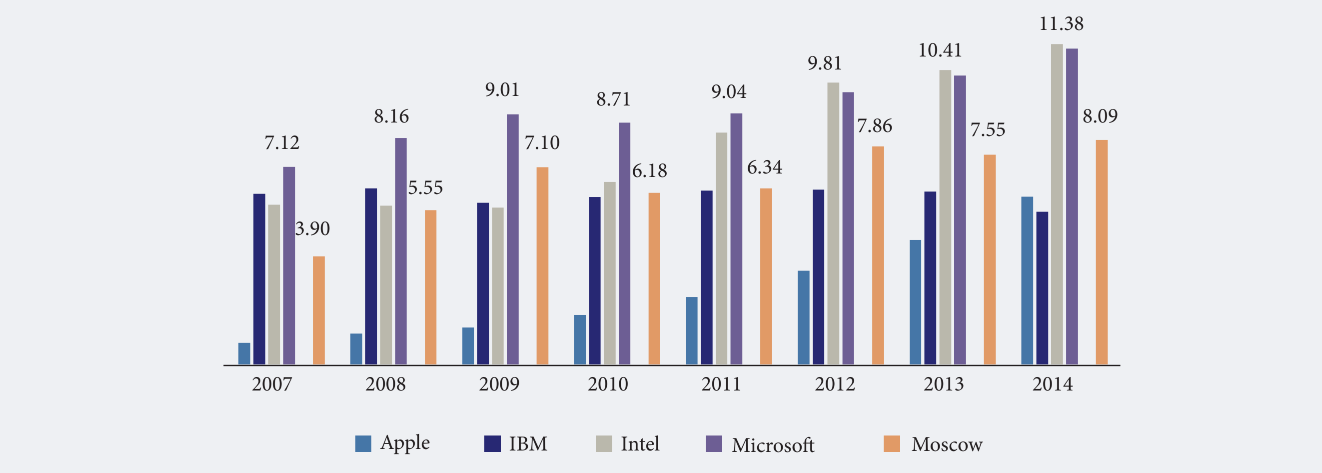
[2] Empirical models use either the first or the second variable, not both as they are often strongly correlated with each other [*Fritsch, Franke,* 2003].

Figure 1. **R&D expenditures of the largest IT multinationals compared to Moscow city** (***billon USD***)



Source: compiled by the authors based on data available on the website Statista.com. Availavle at: www.statista.com, accessed 17.06.2015.

Data and methodology

Empirical studies from a variety of countries have found a positive influence of private investment on innovation output. The largest technological firms (such as Apple, Samsung, and Google) invest heavily in R&D, have their own R&D divisions, run joint research projects, and support start-ups. Figure 1 below shows that even Russia's biggest patent producer (Moscow city) spends far less on R&D than many of these multinationals.

Meanwhile, the largest companies in Russia are primarily active in extracting natural resources, thus their R&D input is significantly lower. At the same time, the lion's share of patents belongs to research organizations and individuals. This indicates the weak state of the market for innovation and the low demand for advanced technologies from state bodies, and state-owned and private firms.

On average, Russian regions have a low share of commercialized patents; in the 2000s, this share did not exceed 7% [NBK--group, 2013]. A indicator of the low quality of patents in Russia's regions is the high volatility in the number of patent applications over time and the excessively high number of patents per capita in some regions. For example, Ivanovo region saw its number of patent filings increase by about 13 times in just two years from 2006 to 2008[3] without any corresponding increase in R&D funding or numbers of researchers [*Baburin, Zemtsov,* 2013]. In other regions of Russia, patent activity is very low and is likely random in nature.

Using PCT-applications data (Patent Cooperation Treaty) can give more reliable information about the level and quality of inventive activity. PCT patents protect the rights of inventors in the territory of countries that have signed up to the Paris Convention. Applying for a PCT patent is generally considered much harder than for a Russian or domestic patent because the verification process and registration of the patent can take several years. The costs at different stages of the checking process can add up to USD 3000. Despite the fact that PCT patents have greater potential to be commercialized,[4] a significant drawback of using PCT-Patent statistics is the very low levels of PCT patenting in most Russian regions.

In this paper, we carry out a series of regression analyses to identify the determinants of regional innovation activity. We use panel data from 67 regions of the Russian Federation in the period from 1998 to 2011. The source of these data is the official statistical handbooks entitled 'Russian Regions: social and economic indicators'[5] as well as datasets of the OECD (Table 2). We excluded regions from our sample where the variation coefficients for the number of granted patents was more than 0.4 because this indicates unstable patenting activity. We assumed that if the dynamics of patenting in the region during the 2000s dramatically changed, these shifts were likely caused by errors in statistical accounting of regional patent offices. In reality, it is virtually impossible to hugely increase the number of patent applications in a region in a single year without an accompanying rise in R&D spending and researcher numbers. Hence we excluded these regions from our analysis.

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[3] A search of the patent database using Google Scholar revealed that thousands of applications were registered (the majority by teams of inventors) by Professor Yulia Schepochkina of Ivanovo State Polytechnic University (Available at: https://scholar.google.ru/scholar?as_vis=1&q=ю.а.+щепочкина&hl=ru&as_sdt=0,5, accessed 30.04.2015). Some of the most significant inventions include: 'A method to produce composites for preparing drinks' (RF №2497416), 'Flying apparatus' (RF №2387574), and 'Billiard ball' (RF №2546478).

[4] Some studies show that the quality of PCT patents is sometimes questionable For example, the Chinese state actively encourages patenting and it is a criterion for giving employees salary raises and for career promotions [*Lei et al.,* 2012].

[5] Available at: http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/publications/catalog/doc_1138623506156, accessed 12.09.2015.

Because of our concerns about the reliability of Russian patent data and their inconsistencies with innovation regionally, we developed a new indicator reflecting the number of potentially commercializable patents (*Innov*) (Figure 2):

$$Innov = 0.08 \times Pat\_rus + 0.5 \times PCT \, , \tag{3}$$

Where:
Pat_rus is the number of submitted patent applications registered by agencies of the Federal Service for Intellectual Property (Rospatent);
PCT — the number of submitted PCT patent applications.

The coefficients here reflect the rate of commercialization for each type of patents. For Russian patents, the average coefficient rate does not exceed 8%, while for PCT patents it is about 50% on average.[6] The disadvantage of this approach is that it assumes all regions have the same commercialization rates. It is clear that this is far from reality but there are no accessible and accurate patent commercialization data disaggregated to the regional level in Russia. The majority of innovations are generated in the largest regional research centres. The *Innov* indicator over the time period examined had a positive trend in the majority of Russia's regions. Figure 3 shows nominal R&D expenditures by region relative to gross regional product (GRP)() in 1998 prices:

$$, \quad RnD\_any_t^{*} = \frac{RnD\_any_t}{Y_t} \times Y_{1998} \times \prod_{i=1998}^{t-1} phc_i \, , \tag{4}$$

Where:
$Rnd\_any^{*}_{t}$ — real internal spending in 1998 prices on all types of R&D for the period *t*;
Rnd_any_{t} — nominal spending on all types of R&D in the period *t*;
Y_{1998} — gross regional product at the end of 1998;
Y_t — GRP over the period *t*;
phc_t — index of the volume for the period *t* relative to the previous year.

Internal current spending on basic research are actual expenditures expressed in monetary form for experimental or theoretical research that aims to produce new knowledge without any mention of possible future applications of this resulting knowledge. Applied research seeks ways to use the results from basic research, and methods to address specific, existing problems. Given their largely academic nature, we expect basic and applied research to have less influence on our dependent variable than spending on development. The latter is systematic work based on cumulative knowledge (both basic and applied) that strives to create new products, services, processes, and systems, or improve existing ones. We calculated spending based on statistical reporting carried out by individual organizations in the reporting year.

Most existing studies operationalize human capital as the number of R&D staff. This indicator represents the number of employees doing work that accumulates and systematically increases the total volume

Table 2. **Description of independent variables**

Indicator	Description	Expected impact on innovation
Current R&D expenditures in 1998 prices (equation 4)		
Rnd_exp	Total current R&D expenditures (million roubles)	+
By type of expenditures		
Rnd_infra	Current expenses on acquisition of equipment (million roubles)	+
Rnd_salary	Current expenses on researchers' salaries (million roubles)	+
By type of work		
RnD_basic	Current expenses on basic research (million roubles)	±0
Rnd_appl	Current expenses on applied research (million roubles)	±0
RnD_dev	Current expenses on developmental research (million roubles)	+
Human capital (equation 5)		
HC_urb	Number of economically active urban residents with a higher education (thousand people)	+
RnD_empl	Number of R&D researchers (people)	+
Agglomeration effects		
Pop_density	Population density	+
Urban	Share of urban inhabitants (%)	+
Knowledge spillovers		
Know_spill	Potential for interactions between researchers from different regions of Russia (equation 6)	+
Neigh_innov	Level of average patenting activity in neighbouring regions	+

Source: compiled by the authors.

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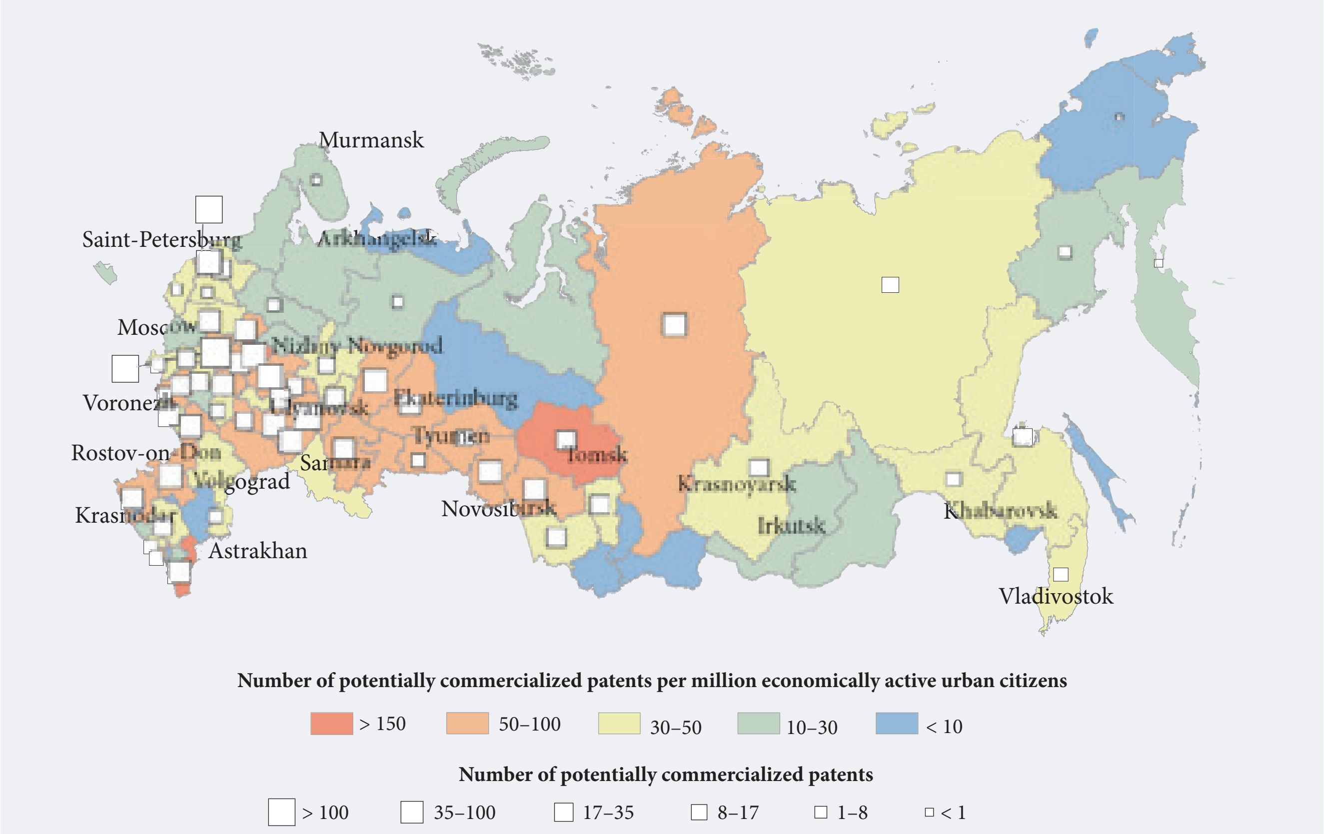
[6] Based on the PCT Yearly Review 2013 [WIPO, 2013], about half of all submitted patent applications are granted. The resulting commercialization of PCT patents is close to 100%.

Figure 2. **Potentially commercializable patents in Russian regions in 2012**



Source: compiled by the authors.

of scientific knowledge. However, in today's innovation systems, professional researchers are not the only people creating new technologies. Hence, we chose to develop a new indicator of human capital that represents the number of economically active urban residents with a higher education (HC_urb)[7] (Figure 4). We calculate this indicator using the following equation:

$$HC\_urb = Econ\_Act \times Urban \times High\_empl\,, \tag{5}$$

Where:
$Econ\_Act$ — the number of economically active population (*thousand people*);
$Urban$ — the share of urban population (%);
$High\_empl$ — the proportion of employees with a higher education (%).

The main advantage of this new indicator is that it factors in all potential innovators. These are people who have sufficient knowledge to carry out systematic research when there are well-developed infrastructures. The indicator does, however, tend to understate the level of human capital in less urbanized regions, and overestimate it in the innovation-leading regions. This may be because of the links between the indicator's components: for example, a large proportion of employees with a higher education is closely correlated with a greater share of the urban population. However, we argue that this limitation is not very significant because the heterogeneity unaccounted for in the indicator only acts on the outcome measure in one direction and does not lead to the crowding together of regions. We also employ another indicator of human capital to assess regional innovation: the number of economically active urban residents, calculated as per equation (5) without the factor $High\_empl$.

To measure potential knowledge spillovers related to interactions between researchers from different regions, we developed the indicator *Know_spill,* based on gravity models:[8]

$$Know\_spill_i = \sum_j \frac{\sqrt{RnD\_\_empl_i \times RnD\_empl_j}}{R_{ij}^{\alpha}}\,, \tag{6}$$

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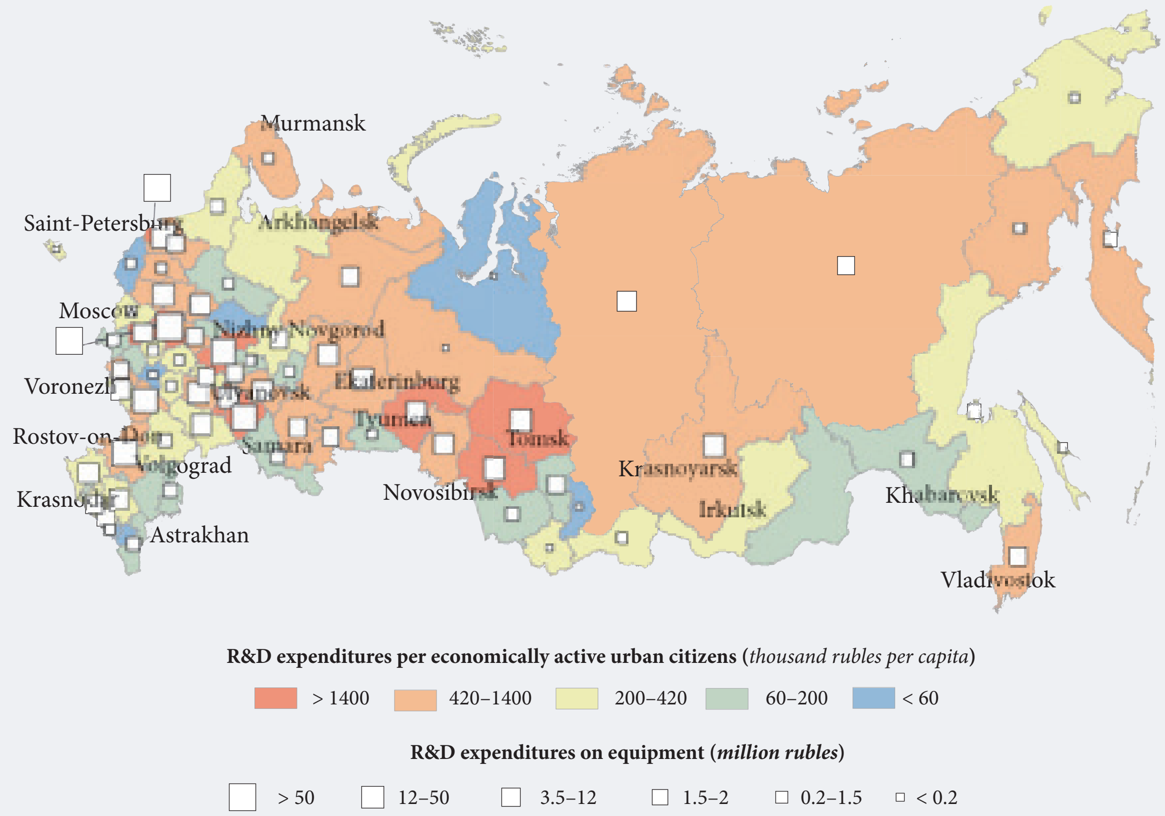
[7] The creative class as defined broadly [*Florida,* 2002] is what Zubarevitch calls residents of the 'first Russia' [*Zubarevitch,* 2010, 2013]. This is where human capital is concentrated.

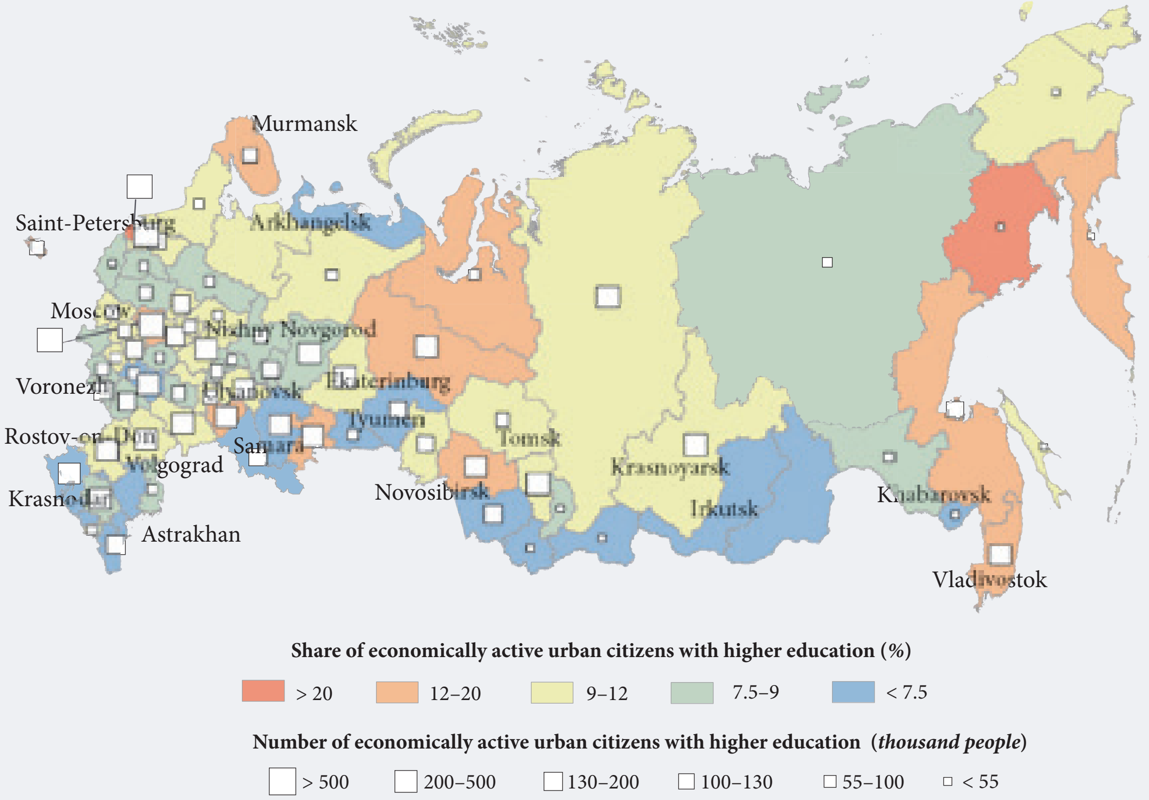
[8] It is assumed that there is an inverse dependence between the potential interactions and distance between regions. Examples of calculating market potential using gravity models can be found in [*Hanson*, 2005; *Head, Mayer,* 2004].

Figure 3. **R&D spending in regions of Russia, 2012**



Source: compiled by the authors.

Figure 4. **Number of economically active urban residents in Russian regions, 2012**



Source: compiled by the authors.

Where:
RnD_empl_i — number of R&D staff of region i;
RnD_empl_j — number of employees in regions j, located at a distance of R_{ij}[9];
α – the coefficient of resistance from the environment (measures the extent to which the geographical distance reduces interactions among researchers).

We also assumed a known critical distance $Dist_{crit}$, beyond which the interaction between researchers in two, statistically average regions *(Mean(RND_empl))* becomes insignificant (δ – the threshold number of interactions below which the interaction is insignificant, e.g. one):

$$\frac{\sqrt{Mean(RnD\_empl_i)\cdot Mean(RnD\_empl_j)}}{Dist^{\alpha}_{crit}} \leq \delta\,;\ \alpha \geq \frac{\log\left(\frac{Mean(RnD\_empl_i)}{\delta}\right)}{\log\left(Dist_{crit}\right)} \qquad (7)$$

Based on existing studies on knowledge spillovers, we expect that researchers from two, statistically average regions situated 120km[10] apart cannot produce more than one interaction, while α for Russian regions is equal to:

$$\log\left(\frac{9774.36}{1}\right)\Big/\log(120) = 1.919067.$$

The advantages of this indicator are its universality, straightforward nature, and positive experiences of using it in gravity models. As another measure of potential inter-regional knowledge spillovers, we also use the average level of patenting activity in neighbouring regions. To assess the impact of agglomeration effects, we used indicators of population density and the share of the urban population.

We employed a fixed effects model, and specified it to take account of the non-random sample. We also ran the F, LM, and Hausman tests to specify the model in each of the cases studied. The test model took the form:

$$\ln(Innov_{i,t}) = \alpha + \beta_1 \times \ln(Rnd\_any_{i,t}) + \beta_2 \times \ln(Hum\_Cap_{i,t}) + \beta_3 \times \ln(Agglom_{i,t}) + \beta_4 \times \ln(KSpill_{i,t}) + \varepsilon_{i,t} \qquad (8)$$

Where:
i — region of Russia in time t;
Rnd_any — all types of R&D expenditures;
Hum_Cap — indicators of human capital;
KSpill — measures of potential knowledge spillovers;
Agglom — indicators of potential agglomeration effects.

Because all the above factors were expressed by several variables, we carried out thorough checks to detect possible multicollinearity using the coefficient of increased dispersion and pair-wise correlation matrices.

Table 3. **Innovation production (*Innov*) in regions of Russia by number of potentially commercializable patents**

Leading regions for innovation production	Moscow (1119) St Petersburg (306.4) Moscow region (231)
‘Outsider’ regions for innovation production	Pskov region (8.1) Novgorod region (7.1) Zabaikal krai (4.1)
Mean	47.17 (~Krasnoyarsk krai)
Median	21.25 (~Kursk region)
Standard deviation	114.58
Asymmetry	7.17
Skewness (peaked or flat nature of data relative to a normal distribution)	59.19
Coefficient of variation	2.42
Coefficient of variation	0.84

Source: compiled by the authors.

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[9] We measured the distance by the length of railway tracks between the regional capital cities. Where there was no railway line, we used the length of highways, and occasionally we used the length of rivers.

[10] The numbers of joint patents, articles, and patent citations decreases quite quickly with increasing geographical distance. [*Jaffe et al.*, 1992; *Adams, Jaffe*, 2002; *Adams et al.*, 2005; *Maurseth, Verspagen*, 2002; *Belenzon et al.*, 2013] show that beyond 120–150 miles (approx. 190-240km), researchers practically never cite each other’s patents (although these are average distances), which means that they are neither in practice nor virtually collaborating. In Russia, we argue that the critical distance for inter-regional knowledge spillovers is lower because of lesser mobility and the closed (inward) nature of the various scientific schools.

Table 4. **Regression results from fixed effects model 1 (dependent variable: number of potentially commercializable patents)**

	Model					
	1	2	3	4	5	6
Constant	0.23 (0.26)	0.17 (0.24)	0.31 (0.24)	0.60** (0.24)	0.05 (0.24)	0.34 (0.24)
Number of economically active urban population with a higher education	0.56*** (0.05)	0.53*** (0.05)	0.49*** (0.05)	0.39*** (0.06)	0.34*** (0.06)	0.29*** (0.06)
Real internal spending on purchase of equipment	0.06*** (0.01)	–	0.05*** (0.01)	0.05*** (0.01)	0.04*** (0.01)	0.05*** (0.01)
Real internal spending on basic research	–	0.05*** (0.01)	0.05*** (0.01)	0.04*** (0.01)	0.03*** (0.01)	0.04*** (0.01)
Real internal spending on applied research	–	0.03*** (0.01)	0.02** (0.01)	0.02** (0.01)	0.02* (0.01)	0.01 (0.01)
Potential for interactions between researchers	–	–	–	–0.36*** (0.08)	–	–0.27*** (0.07)
Average patenting level in neighbouring regions	–	–	–	–	0.32*** (0.05)	0.27*** (0.05)
LSDV R^2	0.95	0.95	0.95	0.95	0.95	0.95
Akaike's Information Criterion (AIC)	462.86	459.39	437.72	417.71	398.30	316.06
Schwarz's Bayesian Criterion (BIC)	796.34	796.49	779.08	763.88	738.56	655.27
F-test for model specification. Null hypothesis: Pool versus FE (p-value)					35.36 (0.00)	
LM-criteria for model specification. Null hypothesis: Pool versus RE: Pool (p-value)					1843.61 (0.00)	
Hausman criteria for model specification. Null hypothesis: RE versus FE (p-value)					80.29 (0.00)	
Wald test for heteroskedasticity. Null hypothesis: observations have general dispersion of mistake (p-value)					6169.38 (0.00)	
Test for normal distribution of errors. Null hypothesis: errors are normally distributed (p-value)					958.72 (0.00)	

Note: As a result of the evaluation, we rejected the standard hypotheses about the nature of residual distribution in regressions. As the p-values show from the Wald test to check for heteroskedasticity and normality tests, there is non-uniform distribution in the model, and no Gaussian distribution. This should be considered when interpreting the results given the specificities of the sample (the presence of outliers). Significance of the coefficients in the regressions: * — 10%; ** — 5%; *** — 1%. Standard errors in brackets. Number of observations: 67i*15t=1005.

Source: compiled by the authors.

Results and discussion

Evaluating the factors of regional innovation

In our first model, the dependent variable is an indicator of the number of potentially commercializable patents. This indicator can also be described as innovation production as all commercialized patents will eventually be made into new products.[11] The primary rationale for using absolute values in the model is the concentration of production and employment in the regional capital cities of Russia [*Perret,* 2014].

The sample is quite diverse in terms of the absolute values of patents (Table 3). We see a big difference between the 'leading regions' of the cities of Moscow and St Petersburg, with their large concentrations of human capital and R&D funding, and the other regions. However, when we exclude Moscow and St Petersburg, the coefficient of variation decreases significantly. The particularities of the sample mean we need to carefully check for heteroskedasticity and construct scatter plots.

We then ran several models to test our hypotheses. Table 4 gives the final results of the regressions. All variables were logged according to the KPF and dependencies. Figure 5 shows the scatter plots of the key dependencies.

We find that the factor most positively and significantly associated with innovative production is human capital, which we operationalize as the number of economically active urban population with a higher education (*HC_ urb*). Other significant variables with positive effects are real internal spending on the purchase of equipment, and basic and applied research. Moreover, the purchase of equipment is the most important factor for innovation production, which testifies to the highly degraded state of equipment in research institutes and laboratories and to their need for upgrading.The insignificance of developmental R&D expenditures (*RnD_dev*) in contrast to the significance of spending on basic (*RnD_basic*) and applied research (*RnD_appl*) may indicate their low effectiveness in Russia and, consequently, the low returns on investment. However, this result may also be explained by the fact that patents are not the main way of registering the results of R&D.

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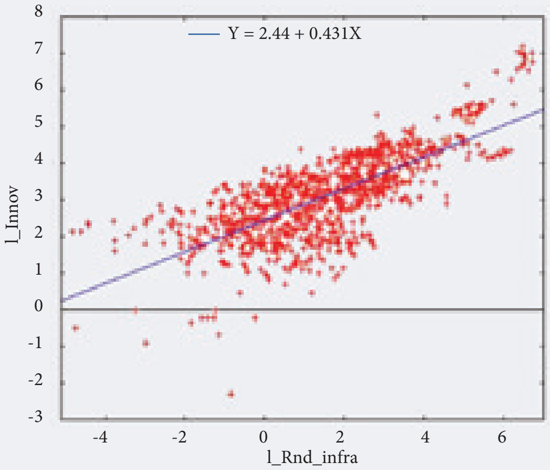
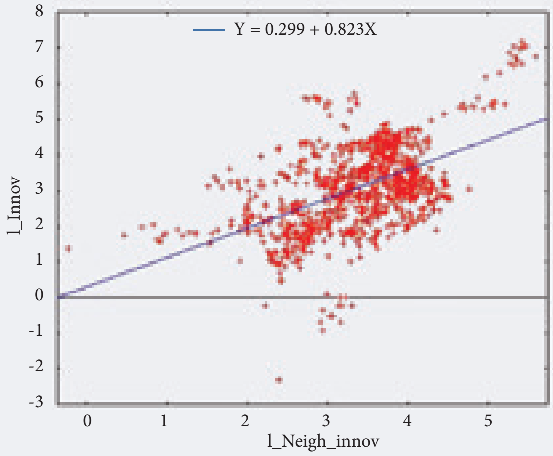
[11] Many commercialized patents do not have commodification potential and are far from centres of innovation production. For the 'leading patenting regions', the chance of converting patents into innovative products is in this regard higher because of their relatively large scale and well-developed innovation systems.

Figure 5. **Scatter plots showing the dependence of innovation production (*l_Innov*) on determinants (A, B, C)**

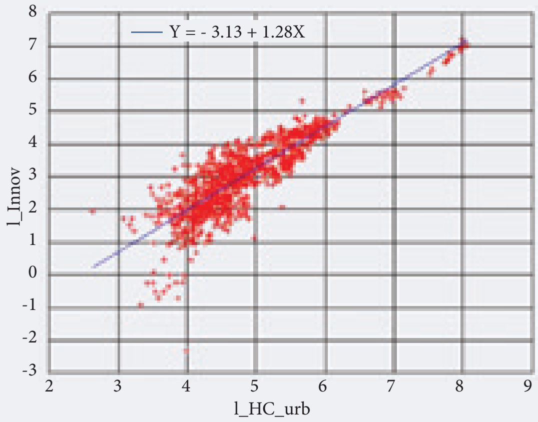
A — expenditures on acquisition of equipment (*l_Rnd_infra*)



B — average patenting levels in neighbouring regions (*l_Neigh_innov*)



C — number of economically active urban residents with higher education (*l_HC_urb*)



Source: compiled by the authors.

Our analysis found an unexpectedly significant and negative coefficient (-0.36 and -0.27 in columns 4 and 6 of Table 1 respectively, both significant at a 99% confidence level) for the inter-regional knowledge spillovers factor, expressed in terms of the interaction potential of researchers (*Pat_potential*). In other words, a one-unit increase in the potential for interactions between researchers had a small but very statistically significant, negative average effect on the number of potentially commercializable patents after controlling for fixed effects. This result contradicts our third hypothesis (H3) about the positive influence of inter-regional knowledge spillovers from neighbouring regions on innovation. Using the average patenting level in neighbouring regions as an indicator of knowledge transfer may lead to the opposite conclusion, which is evidence of the distribution of knowledge and trends to equal out the level of technological development. Russia's innovation system is characterized by a strong centre-periphery structure (Figure 3), which means that knowledge and highly skilled researchers tend to cluster in the 'leader regions' that have high scientific-technical potential and a developed innovation ecosystem. Thus, proximity of 'donor' regions to the innovative core areas has a negative effect on the levels of innovation in the former. Yet at the same time, given the fewer limitations on knowledge spillovers in the form of patents, proximity to the 'centre' can become a positive factor.

In line with our expectations, population density and the share of urban population did not have any effects in our model. This is consistent with the assumption about high concentrations of human capital and fixed assets in the regional capital cities (estimates of these models not given). Figure 6 shows a scatter plot of real and imputed indicators of regions' innovation activity.

We conclude that our model one is quite good at characterizing patenting outputs in regions of Russia between 1998 and 2011.

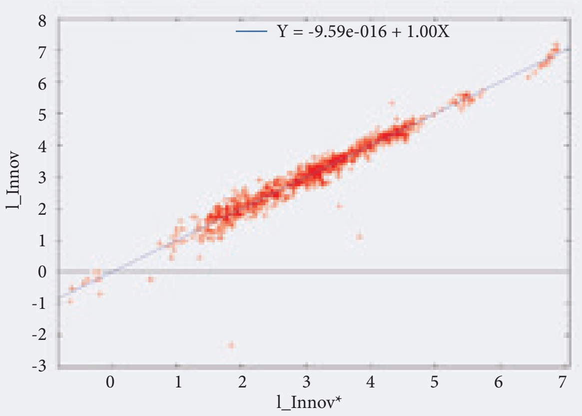
Evaluating the factors and the dynamics of regional innovation of economically active urban citizens

Our dependent variable here is the number of potentially commercializable patents in the region (*Innov*) per economically active urban citizen to understand what determines innovation activity of urban residents (Figure 4; Table 5).

We found that human capital — operationalized as the share of employed with higher education — had a large and statistically significant effect on innovation in regions. People who have graduated from a higher education institution and who thus have the necessary skills, are more likely to create innovative technologies or processes. Spending on basic and applied R&D also had small, positive, and statistically significant effects, as in the previous model (Table 4). Surprisingly, spending on researchers' salaries per economically active urban citizen was not statistically significant, although we expected this to stimulate the most likely innovators (researchers) to apply for patents. This may indicate the ineffectiveness of Russia's system of researchers' salaries , or that Russian researchers are not incentivized to apply for patents in light of the cumbersome application procedure.

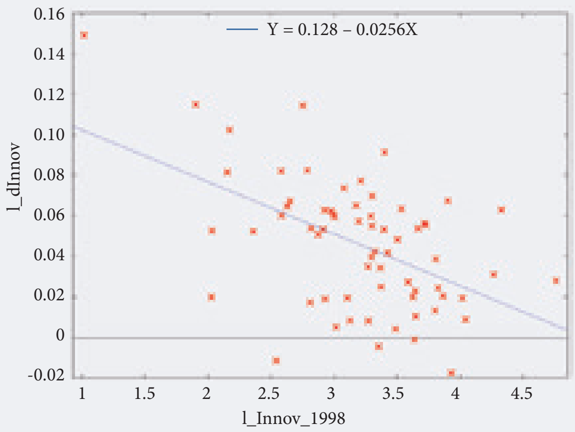
We observe a negative correlation between average geometrical growth rates of innovation in regions now and in 1998 (Figure 7). Overall, Russian regions tend to show a convergence of rates of innovation activity. This finding contradicts several other studies [for example, *Baburin, Zemtsov*, 2013], which found that innovation tended to concentrated in a handful of regions and that patenting was polarized. We should point out that the dependence was relatively weak in our model (R^2 of approx. 0.5), and hence

Figure 6. **Real and predicted values of patent activity in regions of Russia**



Source: compiled by the authors.

Figure 7. **Convergence in innovation activity in regions of Russia**



Source: compiled by the authors.

our finding about regional convergence is rather tenuous.

In relation to the unstable coefficient estimates over time that we identified above, we are particularly interested in the dynamics of the effects of human and physical capital. We can investigate this using the model of Mankiw-Romer-Weil [*Mankiw et al.*, 1992]:

$$\ln\left(\frac{Innov}{EAU}\right) = A + \frac{\alpha}{1-\alpha-\beta}\ln\left(High\_empl\right) + \frac{\beta}{1-\alpha-\beta}\ln\left(\frac{RnD\_\inf ra}{EAU}\right) - \frac{\alpha+\beta}{1-\alpha-\beta}\ln\left(n\right) + \varepsilon, \qquad (9)$$

Where:

EAU — economically active urban population (EAU);

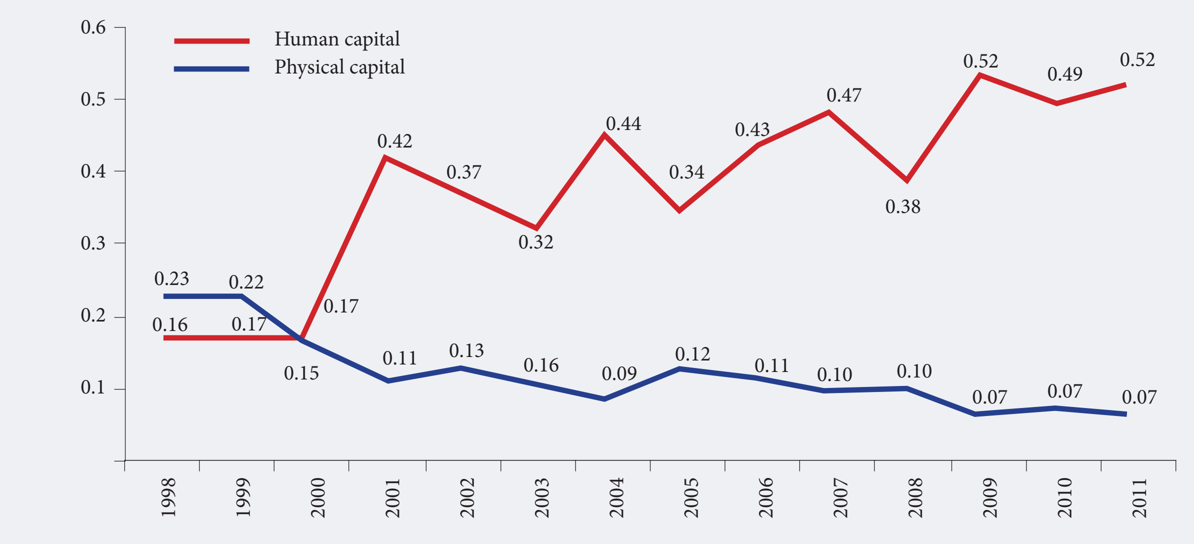
Table 5. **Results of regressions (fixed effects model 2) (dependent variable: number of potentially commercializable patents per economically active urban citizen)**

Regression equalization	1	2	3
Constant	1.86** (0.16)	1.77*** (0.16)	1.79** (0.16)
Share of employed with higher education	0.51*** (0.06)	0.48*** (0.06)	0.45*** (0.06)
Real internal spending on acquisition of equipment per economically active urban citizen	0.06*** (0.01)	–	0.05*** (0.01)
Real internal spending on basic research per economically active urban citizen	–	0.05*** (0.01)	0.05*** (0.01)
Real internal spending on applied research per economically active urban citizen	–	0.03*** (0.01)	0.03** (0.01)
LSDV R^2	0.84	0.85	0.85
Akaike's Information Criterion (AIC)	459.21	451.06	433.10
Schwarz's Bayesian Criterion (BIC)	792.47	788.15	774.23
F-test for model specification. Null hypothesis: Pool versus FE (p-value)			42.10 (0.00)
LM-criteria for model specification. Null hypothesis: Pool versus RE: Pool (p-value)			2805.04 (0.00)
Hausman criteria for model specification. Null hypothesis: RE versus FE (p-value)			25.78 (0.00)
Wald test for heteroskedasticity. Null hypothesis: observations have general error dispersion (p-value)			4989.95 (0.00)
Test for normal distribution of errors. Null hypothesis: errors are normally distributed (p-value)			581.95 (0.00)

Note: Checks for the influence of regional structures and temporary dynamics showed that the model accurately and effectively assesses the differences between regions, although only weakly takes temporary effects into account. The distribution over time is the same and normal for every region. A consequence of this is that when evaluating the between models, we can expect the standard suppositions about the distribution of residuals of the regression. Significance of the coefficients in the regressions: * — 10%; ** — 5%; *** — 1%. Standard errors in brackets. Number of observations: 67i*15t=1005.

Source: compiled by the authors.

Figure 8. **Dynamics of the elasticity of innovation performance by human and physical capital** (%)



Source: compiled by the authors.

High_ empl — the proportion of employees with a higher education;
Rnd_infra — spending on R&D;
n — the growth rate of the economically active urban population (EAU) in the region;[12]
α and β — the elasticity of innovation output by human and physical capital respectively.

A straightforward system of equalizations gives the following estimates for α and β:

$$\begin{cases} \alpha = \dfrac{\theta_1}{1+\theta_1+\theta_2} \\ \beta = \dfrac{\theta_2}{1+\theta_1+\theta_2} \end{cases} \quad (10)$$

Where:

θ_1 and θ_2 — the resulting regression coefficients using the logged values of the share of employees with a higher education and R&D spending per economically active urban resident (EAU), respectively.

We regressed the data for 14 years (1998–2011) using the ordinary least squares method to identify the dynamics per year (Figure 8).

From the start of the 2000s decade, we see that human capital has played an increasingly important role in innovation in Russia. In contrast, the role of physical capital (resources spent on equipment and materials for R&D) has slowly declined in the same period. This either indicates the ineffectiveness of R&D funding or the low priority attached to patenting by R&D expenditures. Moreover, in the first few years of this period, the role of spending on physical capital (equipment and R&D materials purchases) was higher than that on human capital. Then over the 2000s decade, patenting activity was increasingly concentrated in regions with a high level of human capital in a context of growing importance of human capital for innovation in Russia. These findings complement the results of other studies modelling economic growth in Russian regions [*Komarova, Pavshok*, 2007; *Komarova, Kritsyna*, 2012].

Conclusions

The database we have collected on social and economic indicators for regions of Russia between 1998 and 2011 enabled us to evaluate the effectiveness of various kinds of R&D spending and test our hypotheses. We were able to overcome data issues associated with the low quality of Russian patenting statistics and Russian patents themselves by developing a new indicator that incorporates both Russian and international patent applications. This indicator assesses the rate of commercialization of these patent applications. This new indicator enabled us to evaluate the real level of innovation performance as reliably as possible given the data limitations.

We argue that our indicator for human capital — the economically active urban population with higher education — is a substantial factor of innovation as it takes into account the significance of agglomeration

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[12] In the classical model of Mankiw-Romer-Vale, the value *n* presupposes growth in human capital as well as the writing-off of human and physical capital [*Mankiw et al.*, 1992].

effects. Our most significant finding here is that human capital is key for innovation, thus confirming Brenner and Broekel's hypotheses with empirical data from Russia. The economically active urban population with a higher education – the so-called 'creative class' or inhabitants of the 'first Russia' — has the potential to become the foundation of innovative development and economic diversification in Russia. Moreover, we found that human capital has become an increasingly significant factor of Russian innovation activity over the 2000s.

The process of creating regional innovation systems is a lengthy and cumulative process. Much time is thus needed for such systems to take root and for human capital to produce maximum returns. Our econometric analyses showed that a 1% increase in the quality and quantity of human capital leads to an average rise of innovation output of 0.5%. At the same time, a 1% increase of various kinds of R&D spending leads only to a 0.05% growth in innovation. Thus, greater spending on R&D in regions of Russia with weak human capital does not lead to a proportional increase in innovation.

This conclusion does not deny the fact that funding for various kinds of R&D does affect innovation performance. We found that spending on basic R&D (related to the most significant research in the Russian Academy of Sciences) and on acquiring new equipment (linked to the high rate of wear and tear of equipment in Russia) had the most positive and significant effects on innovation performance. Funding for researchers' salaries was insignificant. Although in contrast to much of economic theory, this result may suggest that the Russian system of researchers' salaries is ineffective. We found it hard to assess the effects of basic economic stimuli on R&D productivity and further research on the effects of different kinds of R&D funding is needed.

Our suggested new indicator for inter-regional knowledge spillovers — expressed by calculating the potential for researchers to interact — enables us to assess the importance of this factor for innovation in Russian regions. Our results confirm the presence of a strong centre-periphery structure of the Russian national innovation system [*Baburin, Zemtsov,* 2013]. Moreover, the observed 'brain drain' of researchers to more developed neighbouring regions leads to greater human capital in the largest scientific centres and contributes to a widening technological gap between the leading and 'donor' regions. Nevertheless, we do see a positive influence of patenting in neighbouring regions on innovation output in a given region. These two, seemingly contradictory, findings may be linked: consider the migratory nature of knowledge spillovers through which researchers go to the innovation leading regions, learn from them about advanced technologies, and then return to 'innovation lagging' regions and subsequently help to build up the technological potential of these regions. This trend could certainly be linked to various regional specializations, through which you witness the outflow of experts in one sector, and simultaneously the in-migration of other kinds of specialists who are more suitable for that region. This issue is ambiguous and merits further study.

Our paper confirms the conclusions of previous studies that in Russia, the market for innovation is insufficient, funding for innovation is ineffective, and the quality of registered applications of intellectual property (patents) remains low. Finding solutions to this situation may lie in creating favourable conditions for innovative entrepreneurship. It is also necessary to attract more private investment in R&D (including venture capital) alongside more effective state funding, and develop the market for intellectual property. As experiences in other countries beyond Russia have shown, these factors contribute to an innovation-friendly climate at the national level.

This study was implemented with the support of the National Research University Higher School of Economics' Basic Research Programme and the support of state subsidy funds allocated to support leading universities in the Russian Federation to increase their competitiveness among the leading global scientific research centres.

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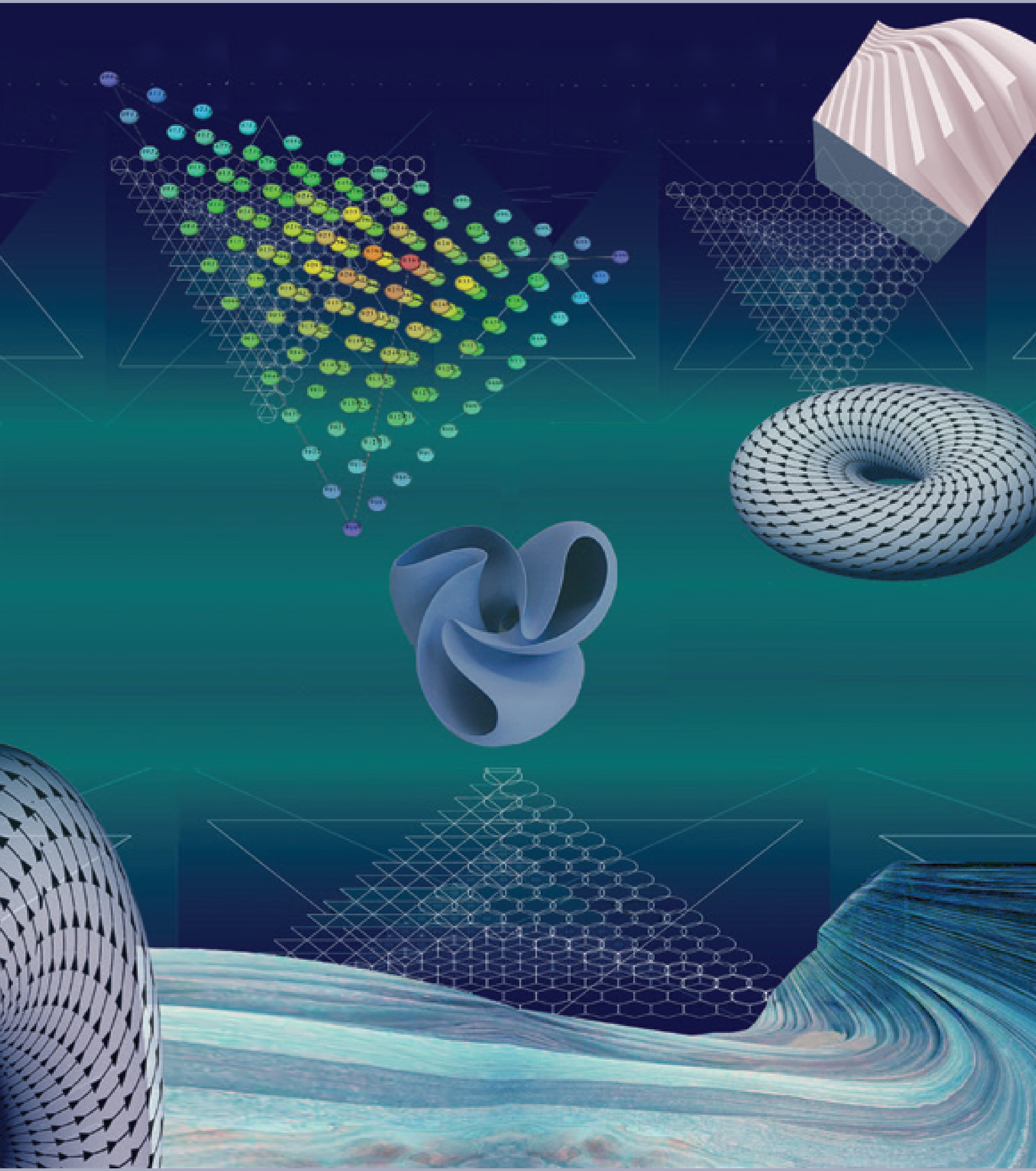

Determinants of Research Productivity: An Individual-level Lens

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Abstract

The continuous growth of investment in R&D in Russia and the world increases the demand for optimal allocation of public funds to support the most productive scientific performers. These are, however, hard to conceptualize and measure. First, we need to consider the nature of research activity itself and, second, we need to evaluate a number of factors that influence such activities at the national, institutional and individual levels. One of the key issues is motivation of academic personnel, who are considered the main producers of new knowledge. Therefore, it is necessary to analyse the employment characteristics of researchers, and develop adequate mechanisms to facilitate their scientific productivity.

This paper aims to examine determinants of publication activity among doctorate holders employed in the academic sector in Russia. Data for the analysis was derived from a survey on the labour market for highly qualified R&D personnel conducted in 2010 by the HSE, within the framework of the OECD / UNESCO Institute for Statistics / Eurostat international project on Careers of Doctorate Holders (CDH). With the use of regression analysis, we assess the effects of scientific capital, international cooperation, employment, and socio-demographic characteristics of researchers on their productivity, which is measured through their total publication output as well as through the number of papers in peer-reviewed academic journals.

The differences between factors were assessed for two generations of researchers – those under 40 years old, and above. It was shown that the quality of scientific capital, measured through diversity of research experience, has a stronger impact on research productivity, rather than the age or other socio-demographic characteristics of doctorate holders. It was also demonstrated that direct economic stimuli and actual research productivity of researchers are weakly correlated. Consequently, we identified that a potentially winning strategy for universities and research institutions that want to improve their performance indicators would be to provide younger scholars with wider opportunities for professional growth, including intense global cooperation in the professional community.

Keywords: performance-based payment; bibliometric indicators; Russian scholars; the productivity of science; human capital; scientific publications

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As one of the key drivers of growth and competitiveness in the economy, scientific knowledge is directly reflected in national science and technology development strategies and in the actual government spending figures of OECD member states [OECD, 2014]. Beginning in the 1960s, the governments of leading economies recognized the contribution of scientific research to economic development and began to provide higher levels of funding, while at the same time improving the statistical accounting system to monitor investment in knowledge production [*Godin*, 2013].

Following the development of methods to record resources accumulated in the research and development (R&D) sector, the question arose of effective use of allocated funds and approaches to measure the results of scientific and technological activity. This problem is particularly labour intensive on account of the creative and intellectual nature of scientific activities, as well as the need to consider multiple social, economic, political and other determinants affecting the development of a research culture at the national, institutional (organizational), and individual levels (cf. for example: [*Godin, Gingras*, 2000]). One of the most important conditions influencing the effectiveness of national science and technology systems is the support for and motivation of researchers, who are the key and direct producers of new knowledge.

Studying the factors influencing the individual productivity of researchers is of crucial importance if we want to analyse the working conditions of academics [*Gokhberg et al.*, 2011] and develop effective mechanisms to incentivize research activity [*Gershman, Kuznetsova*, 2013]. Criteria to assess these mechanisms and positive influences on related processes are of critical interest. This paper will also focus on the differences in publication activity between 'younger' and 'older' generations of academics, and their main determinants.

Literature review

Indicators of scientific productivity

In order to assess scientific productivity, we first need to define its place in the socio-economic system. Attempts to offer a more or less strict definition of the term 'science,' explain its distinguishing features, and arrive at a holistic view of scientific knowledge have been undertaken at various times by members of extremely diverse disciplines. In the 20th century, knowledge production expanded beyond the boundaries of universities and started to disperse among national laboratories, research centres, and business enterprises. In social disciplines, science has come to be seen as a public good [*Godin*, 2013] and institution [*Merton*, 1973] that produced 'certified' knowledge on the surrounding world, promoted progress, aided in the flourishing of society, and solved essential social problems. As for the state, it funded the work of academics, guaranteed their autonomy, and supported comfortable working conditions. The status quo was disrupted when formal criteria were introduced to assess researchers' output, and attempts to correlate output with actual spending. However, the tasks of conceptualizing and measuring R&D outputs have become one of the key challenges in statistics over roughly the last 80 years.

After the Second World War, science and technology underwent rapid growth and intensive integration into various spheres of social life. Consequently, governments in many countries desired to regulate the support for and development of R&D. One of the instruments used to control this was statistics, which set formal boundaries for the sector and defined methods of measuring financial and other resources absorbed by R&D [*Godin*, 2013; *Roud, Fursov,* 2011]. By the mid-1960s, the first conventional definition had been developed, covering the creation of new knowledge and the development of ways to make good use of this [*Godin*, 2009]. However, the overall direction in statistical development was aimed primarily at elaborating approaches to measure the scientific inputs rather than outputs. The assessment of scientific results is part of a different tradition, linked primarily to quantitative methods that are used to analyse publications, rarely patent and other forms of research activity. The assessment reflects not so much their productivity, but rather their presence and visibility in the international scientific community [*Godin*, 2006; *Garfield*, 2009; *Hicks et al.,* 2015; *Kirchik,* 2011].

Still, the number of publications in peer-reviewed academic journals, citations, and derivative indicators are recognized by most countries as key criteria of scientific productivity, including when deciding on funding for R&D [*Hicks,* 2012]. Some national jurisdictions [*Ancaiani et al.*, 2015] and organizations use individual productivity indicators. Despite the imperfection of this methodology and its multiple criticisms [*Bordons et al.,* 2002; *Weingart,* 2005; *Stephan,* 2012; *Hicks et al.,* 2015], publication activity together with several other approaches (primarily, professional expert assessments) remain the primary and most representative description of national and individual scientific contributions [*Ball*, 2005; *Moed*, 2009].

Russia is no exception: articles, monographs, conference papers, and other works are also viewed as evidence of significant scientific achievements. The 1996 Federal Law No. 127-FZ ('On Science and State Science and Technology Policy') defines performance results in this field as any product containing new knowledge or solutions which are recorded on a storage medium.[1] According to existing statistical

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[1] Federal Law No. 127-FZ 'On Science and State Science and Technology Policy' (version dated 22/12/2014 with amendments dated 20/04/2015), Article 2 (Accessible at http://www.consultant.ru/document/cons_doc_LAW_172547/, accessed 20.05.2015).

data, by the end of the period 2000–2010 Russian researchers published roughly 350,000 articles every year, but no more than 10% of these were included in the world's largest (Web of Science and Scopus) academic citation indices [HSE, 2011]. Despite growth in absolute figures, Russia's share of the global publication activity map on Web of Science in the period 2000 to 2014 shrank by almost twofold – from 3.2% to 2.1% [*Fursov*, 2015]. Over these years, Russia lost its position amongst the top ten international leaders in terms of number of published articles, falling six positions to the 15th place.

Russia's modest share of publications in international journals maybe attributed to the current 'national model' of scientific communication. English now serves as a *lingua franca* for global science as well as international communication in general. The scientific community is instilling a transnational model of knowledge exchange, where international academic publications are replacing traditional journals. This process was set in motion by the American academic Eugene Garfield[2] who set about developing a mechanism to prevent national isolation of the scientific community. Moreover, while the autarchic idea of 'national science' reigned globally up to the end of the 19th century, many European countries subsequently experienced a linguistic globalization in this sphere. Thus, in France from 1973 to 1988, the number of authors publishing in English rose by 45%. By the late 1990s, English became the universal language of scientific communication in developed European countries and Japan, and Anglo-American scientific publications assumed the position of global leaders [*Kirchik*, 2011]. The proportion of articles co-authored by Russian academics with international partners rose from 3% to nearly 30% from 1980 to 2014 [NRU HSE, 2011, p. 42; 2016, p. 286]. The highest numbers of joint articles are those co-authored by Russian academics in collaboration with researchers from Germany, USA, France, UK, Italy and Japan, which are the absolute global leaders for this figure. However, for various reasons, Russia has not yet managed to fully transition to the international communication model.

The growth in funding for research has been accompanied by an increased demand for research productivity, which needs to be analysed without taking into consideration long-term structural trends in the sector such as ageing personnel and deterioration of infrastructure and facilities [*Suslov*, 2010; *Kuznetsova et al.*, 2015]. The seriousness of these challenges calls into question the very possibility of guaranteeing growth in labour productivity in the sciences. In order to secure this, we need to examine the factors influencing productivity and the distinguishing features of 'productive' researchers' activities, Based on this, we can identify measures to encourage academics to publish research materials more actively in Russian as well as international journals.

Criteria to evaluate researcher productivity

Labour productivity and pay is directly dependent on the quality of human capital, i.e. the knowledge and skills of the worker. The term 'human capital', proposed by Theodore Schultz [*Schultz,* 1961], was later classified by Gary Becker into two types: general and specific. 'General human capital' refers to knowledge and skills employed to solve a wide range of tasks in different spheres, while 'specific' describes experience and competencies used in a relatively narrow sphere, which are ineffectual in others [*Becker*, 1964]. The latter category can include scientific capital as the individuals' accumulation of 'active properties' associated with the dissemination of academic power and recognition (as per the definition and mathematical operationalization proposed in [*Katchanov, Shmatko*, 2014; *Shmatko, Katchanov*, 2016, p. 181–182]). With a certain degree of conditionality, we can consider the notion of 'cumulative advantages' developed by Robert Merton to be encompassed by the notion of scientific capital; this refers to the social characteristics of an academic (in particular, professional status and recognition from colleagues), which facilitate the search for resources to conduct research [*Merton*, 1968b; 1988].

Socio-demographic and psychological factors can have a marked impact on academics' productivity – age, sex (work is a classic example of this [*Cole, Zuckerman*, 1984]), family, and material status [*Fox*, 2005]. According to Russian researchers, male teachers at higher education institutions are more inclined to research activity and publishing their results than women [*Roshchina, Yudkevich*, 2009], while older teachers are more active in this respect than younger. This age asymmetry confirms the existence of the so-called 'Matthew Effect' in science, reflected in the total number of citations – for example, in the Hirsch index, which is higher the older the author becomes.[3] This effect mirrors an imbalance characteristic of the scientific community: academics would rather support and promote the achievements of colleagues that have already become well-known thanks to their previous credentials and undervalue or refuse to recognize not so eminent young researchers.

Psychological factors can provisionally be broken down into personal, i.e. associated with the individual qualities of an academic, and organizational or environmental. From studying the first of these types, we can compile a relatively in-depth list of qualities we may find in researchers destined for success in their work: enterprise, emotional stability, openness to communication (applied to the community of

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[2] The founder of the first academic citation index, subsequently becoming one of the largest databases now owned by the company Thomson Reuters.

[3] The peculiarities of taking into account citation figures as the main factor influencing academic recognition, including temporal dynamics, have been described repeatedly in literature (cf. for example: [*De Bellis*, 2009, pp. 181–242]).

physicists, cf. for example: [*Hermanowicz*, 2006]), etc. The factors stimulating immersion in work and the productivity of researchers include not only the availability of resources and infrastructure [*Hesli, Lee*, 2011], but also the equal distribution of resources and infrastructure, including opportunities for independent work [*Silman*, 2014] and various forms of cooperation *[Lee, Bozeman,* 2005; *Carayol, Matt*, 2006]. These are the conditions on which job satisfaction and ultimately the performance of academics depend.

Methodology

This study defines and analyses the factors influencing publication activity among different generations of Russian academics. It relies on data from the Research Personnel Labour Market Monitoring survey conducted in 2010 by the HSE Institute for Statistical Studies and the Economics of Knowledge (ISSEK) as part of the OECD, Eurostat, and the UNESCO Institute for Statistics international project on 'Careers of Doctorate Holders' (CDH).[4] This comparative study uses a harmonized methodology and covers 25 participating countries [*Shmatko*, 2011; *Gokhberg et al.,* 2016]. The research population is made up of candidates and doctors of science (or Ph.D. holders) – employees at research institutions, higher education institutions, and business enterprises. The total sample numbers 3,451 people, i.e. roughly 1% of all doctorate holders in Russia. The data sample was compiled using a multi-stage stratified sample of respondents selected according to a specific quota based on the following criteria: academic level, sex, age, scientific field, territorial affiliation (Federal district). The data were collected during individual interviews at the place of work of each respondent.

For the purposes of our research, we imposed further restrictions: the final sample included only those who were employed at research organizations[5], even if this was one of several jobs. This reduced the final sample to 3,034 doctorate holders. However, only 2,633 respondents for whom data included dependent and independent variables in the regression models were selected for further analysis. Over half (58%) of those surveyed were men and the average age was 50 years, with a minimum of 23 and a maximum of 70 years old. In order to analyse generation-specific effects, the formulated sample was split into two groups according to age. The 'younger' cohort of academics included respondents up to the age of 40, including those who completed their higher education after 1991. Given that there has been a gradual reduction in the number of educational programmes, especially in the social sciences and humanities in line with global trends, the human capital of higher education institution graduates has significantly changed in its qualitative characteristics since 1991. New forms of mobility such as student exchanges and teacher training abroad have now become widespread. Foreign language study and work with foreign sources have taken pride of place in many programmes. The final sub-sample of younger researchers totalled 943 people, or 36% of the total number. Respondents aged 41 years or more, which accounted for 64% of the sample, were placed in a second cohort of 'older' academics.

The primary research hypothesis posits that the factors affecting the quality of the scientific capital have a stronger impact on publication activity than the socio-demographic characteristics of academics. The available empirical data allow us to use four indicators of researchers' publication activity over the three years preceding the survey:

1) total number of publications in Russia and abroad;
2) number of publications in foreign outlets;
3) number of publications in Russian outlets;
4) number of articles in peer-reviewed Russian and foreign academic journals.

Since the available data do not allow us to measure the number of publications by respondents and their types as indexed in the Russian Science Citation Index (RSCI), Scopus, or Web of Science databases, we will look at different groups of scientific works. The most representative sample when it comes to evaluating a researcher's level would appear to be the number of publications in scientific peer-reviewed journals – either in Russia or abroad (indicator 4). These works guarantee a certain level of specialization, high text quality, widespread coverage, and citations. However, publications in Russian and foreign journals have different statuses (indicators 2 and 3), as the latter require a command over a foreign language and compliance with international research standards. Using all four indicators allows us to examine different aspects of an academic's publication activity. These indicators will serve as dependent variables in the regression analysis using the Tobit model.[6] The model determinants are individual indicators of scientific capital such as work experience, and institutional and socio-demographic characteristics. Some of these variables were measured over the same time frame as the number of publications, which could lead to some endogeneity in the data. Each of the models was also applied to the samples of 'younger' and

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[4] For more on the project, see: https://www.hse.ru/monitoring/mnk/.

[5] The organizations covered by the study included RAS research organizations, research organizations in the higher education sector, research organizations run by state bodies, and industry research institutes.

[6] This model was chosen due to the presence of zero values in the dependent variables.

'older' academics. The possession of a doctorate degree, the number of foreign languages used in work, work experience or studies abroad, involvement in various forms of international collaboration, and professional development were all selected as criteria to evaluate individual scientific capital.

Results

Primary characteristics of researchers employed at research organizations

Respondents were asked to talk about all their jobs because multiple employment is common for S&T personnel in Russia. This study has established that roughly 71% of respondents are primarily employed at a research organization, 21% are employed by two research organizations, 4% enjoy a position at a research organization only as their secondary employment, and the remaining 4% hold jobs at three research organizations. We consider the most important characteristic of scientific capital to be the possession of a degree. All of those surveyed had defended a candidate of science dissertation, one quarter of respondents were doctors of science, and roughly 1% held PhDs. More than one third specialize in the natural sciences with the remaining almost equally distributed between the social sciences and engineering. A little over one quarter of respondents received their most recent qualification at a research institute and the remainder in a higher education institution. Almost a third of researchers are not involved in any way in international collaboration; however, over half have participated in conferences, seminars, and other research events taking place in Russia involving colleagues from abroad. A quarter of respondents had taken part in international programmes or conferences. Over two thirds (71%) of those surveyed actively use one foreign – predominantly English – language in their work, while 17% use two.

Efforts by academics to improve their knowledge continually, in some cases through further education, can help improve the quality of scientific capital. More than one third of respondents have attended courses, training sessions, or seminars either on their own or an adjoining specialization in the last three years; 14% of respondents have taken computer courses; and only 9% have studied foreign languages. While 78% of academics consider their primary employment to tie in with their specialization, 9% noted a significant shift in their research profile during their lifetime. In addition, the surveyed research personnel changed their place of employment 0.3 times on average over the last ten years and 8% had experienced unemployment. The results of the survey are shown in Table 1.

One fifth of respondents had no publications in the last three years (the average number of publications for all groups was 6.0) and 29% had publications in peer-reviewed journals (average – 4.4). A quarter of those surveyed had foreign publications (average – 1.0), while three quarters had Russian publications (on average, 4.2 publications per person). Thus, Russian academics publish on average roughly two works per year with only one foreign publication every three years. This confirms the prevalence of Russian academics publishing in Russian within the country, which reduces the chances of being noticed by foreign colleagues. It is also worth noting that one in five Russian academics has had no publications in the last three years.

Overall determinants of publication activity

The results of the regression analysis of the factors influencing the publication activity of Russian academics are presented in Table 2 (maximum effects are shown).

We will now look at the impact of variables reflecting scientific capital. We hypothesize that holders of a doctor of sciences degree show the highest levels of productivity both by total publication activity and the number of publications in peer-reviewed academic journals. The effect of this variable was the highest among all the determinants analysed. Surprisingly, holding a PhD does not have a significant impact on the number of foreign publications, but, as expected, it does have an influence on overall productivity. As a general rule, a degree in natural sciences points to higher performance compared with social sciences or humanities. Those academics actively using a foreign language in their work publish more articles than their monolingual colleagues. In other words, the more languages the researcher speaks, the higher the number of publications of all types he or she enjoys. This dependence can easily be explained: the requirement that the research has novelty value is much harder to achieve without access to recent findings and contemporary theories available in the original language. Thus, the ability to read and analyse foreign texts endows an academic with more advantages, in particular the ability to render their own text in a foreign language.

Of all the different forms of international collaboration, participation in foreign conferences reaps the most positive benefits. The impact of such participation on the number of foreign publications even exceeds that of having a doctorate. Other formats of research activity abroad are also significant: work on dissertations, participation in residential schools, forums and international stipendiary programmes, secondments, teaching foreign students, welcoming delegations from abroad, holding international conferences, and so on.[7] Giving lectures, joint projects, involvement in research work, and studying

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[7] The variants mentioned by respondents in an open question.

Table 1. **Average values of variables included in the regression analyses, for the three respondent samples**

Indicator	Total	'Younger'	'Older'
Total number of publications in last three years	6.0	4.7	6.5
Number of foreign publications in last three years	1.0	0.6	1.1
Number of Russian publications in last three years	4.2	3.3	4.6
Number of articles in peer-reviewed journals	4.4	3.3	4.8
Academic position only in primary employment	0.71	0.73	0.70
Academic position in primary employment and other employment (yes=1)	0.21	0.18	0.22
Academic position in all three places of employment (yes=1)	0.04	0.04	0.04
Academic position only in secondary employment (yes=1)	0.04	0.04	0.04
PhD degree	0.01	0.01	0.01
Doctor of Sciences degree	0.23	0.04	0.30
Degree in engineering (yes=1)	0.20	0.23	0.16
Degree in natural sciences (yes=1)	0.38	0.30	0.41
Degree in medical sciences (yes=1)	0.06	0.09	0.05
Degree in agricultural sciences (yes=1)	0.05	0.05	0.05
Degree in social sciences (yes=1)	0.19	0.26	0.16
Degree in humanities (yes=1)	0.07	0.10	0.06
Attended courses in own or adjoining specialization in last three years (yes=1)	0.39	0.46	0.36
Use one foreign language	0.71	0.74	0.70
Use two or more foreign languages	0.17	0.15	0.17
Foreign collaboration: delivered lectures (yes=1)	0.06	0.03	0.07
Foreign collaboration: studied (yes=1)	0.07	0.10	0.06
Foreign collaboration: worked abroad (yes=1)	0.07	0.05	0.07
Foreign collaboration: participated in joint projects (yes=1)	0.25	0.23	0.25
Foreign collaboration: participated in international conferences (yes=1)	0.28	0.24	0.29
Foreign collaboration: other (yes=1)	0.02	0.02	0.02
Directed research projects (yes=1)	0.50	0.35	0.55
Senior position at an educational organization (yes=1)	0.19	0.12	0.21
Senior position at a research organization (yes=1)	0.17	0.08	0.20
Number of times changed place of employment	0.27	0.44	0.22
Defended dissertation at research institute (yes=1)	0.28	0.21	0.30
Work in a higher education institution as primary employment (yes=1)	0.66	0.69	0.64
Permanent employment contract at primary employment (yes=1)	0.60	0.55	0.61
Complete match between primary employment and specialization (yes=1)	0.78	0.72	0.80
Changed research area (yes=1)	0.09	0.09	0.09
Have been unemployed at some time (yes=1)	0.08	0.09	0.07
Studied or worked abroad (yes=1)	0.16	0.14	0.17
Degree held by at least one parent (yes=1)	0.15	0.17	0.14
Age /10	5.04	3.30	5.68
Male (yes=1)	0.58	0.49	0.62
Married (registered or unregistered) (yes=1)	0.76	0.68	0.78
Number of observations	2633	1690	943

Source: authors' calculations.

abroad also help to increase publications, including foreign ones. In other words, any regular international activity by the researcher will raise both their overall productivity and the chances of successfully presenting research abroad.

Paradoxically, developing foreign language skills (by which we mean attending professional development courses) in one's own or adjoining specialization can have a negative impact on the number of publications in peer-reviewed scientific journals. This could be linked to the fact that attending language courses and training during a certain career period detracts researchers from direct work time as well as lowers the initial level of human capital of students on these courses. The skills acquired through such courses have a positive impact on the future level of publication activity, but in the short-term they do not help researchers to improve this indicator significantly.

Table 2. **Regression analysis of factors influencing publication activity for all respondents,** *df/dx*

Indicator	All publications	Foreign	Russian	Peer-reviewed
Academic position in primary employment and other employment (yes=1)		0.415	**0.488****	**0.613****
Academic position in all three places of employment (yes=1)	–0.464	–0.758	0.195	–0.285
Academic position only in secondary employment (yes=1)	**–1.362****	**–1.298***	–0.109	–0.421
PhD degree	**2.821***	1.988	**3.573****	**2.816****
Doctor of Sciences degree	**4.226*****	**2.186*****	**3.696*****	**3.892*****
Baseline – degree in engineering			0.202	
Degree in natural sciences (yes=1)	**0.672****	**1.177*****	0.155	**0.678****
Degree in medical sciences (yes=1)	0.439	0.374	0.884	0.523
Degree in agricultural sciences (yes=1)	–0.026	**–2.494*****	0.479	0.230
Degree in social sciences (yes=1)	0.641	**–2.852*****	–0.272	**–0.636***
Degree in humanities (yes=1)	0.606	**–2.386*****	–0.215	**–1.082****
Attended courses in own or adjoining specialization in last three years (yes=1)	–0.434	–0.121	**0.796*****	**–0.530****
Use one foreign language	**1.268*****	**2.443*****	**1.047*****	**1.170*****
Use two or more foreign languages	**1.859*****	**2.915*****	–0.326	**1.333*****
Foreign collaboration: delivered lectures (yes=1)	**1.598*****	**1.020***	0.427	0.119
Foreign collaboration: studied (yes=1)	0.509	**0.989***	–0.399	0.612
Foreign collaboration: worked abroad (yes=1)	–0.057	**1.317****	0.086	0.648
Foreign collaboration: participated in joint projects (yes=1)	**0.658***	**1.581*****	**0.733****	0.318
Foreign collaboration: participated in international conferences (yes=1)	**1.783*****	**2.741*****	0.558	**1.122*****
Foreign collaboration: other (yes=1)	**3.161*****	**2.338****	1.179	1.021
Directed research projects (yes=1)	**1.637*****	**0.618***	0.292	**1.328*****
Senior position at an educational organization (yes=1)	–0.003	–0.417	0.293	–0.132
Senior position at a research organization (yes=1)	0.393	–0.552	**–0.462*****	0.339
Number of times changed place of work	**–0.625*****	**–0.646****	0.526**	**–0.608*****
Defended dissertation at research institute (yes=1)	**0.626***	0.194	–0.350	**0.703****
Work in a higher education institution as primary employment (yes=1)	–0.565	**–1.663*****	**0.333***	**–0.760****
Permanent employment contract at primary employment (yes=1)	**0.590****	0.496	**0.919*****	0.377
Complete match between primary employment and specialization (yes=1)	**1.224*****	**0.768***	0.172	**1.160*****
Changed research area (yes=1)	0.235	0.207	–0.092	0.179
Have been unemployed at some time (yes=1)	0.233	0.259	–0.232	–0.140
Studied or worked abroad (yes=1)	0.309	**1.395*****	–0.071	0.388
Degree held by at least one parent (yes=1)	0.326	**0.737***	0.555	0.078
Age /10	1.424	0.897	–0.065	0.690
Age /10 (square function of)	**–0.160***	–0.059	**0.701*****	–0.094
Male (yes=1)	**0.984*****	0.344	–0.316	**0.825*****
Married (registered or unregistered) (yes=1)	–0.232	0.395	–1.159	–0.043
Number of observations	2633	2633	2633	2633
Number of uncensored observations	2141	626	629	1927
Pseudo-coefficient of determination (R Square)	0.04	0.14	0.04	0.05
Model significance (Prob> chi2)	0.000	0.000	0.0000	0.000

Coefficient significance: * — 10%, ** — 5%, *** — 1%.

Source: authors' calculations.

Those only employed by research organizations enjoy more publications in peer-reviewed academic journals than colleagues who work in such places for at least one of their jobs (even if this is their primary job). Primary employment in a non-academic sector, even with a secondary job in academia, has a negative impact on all research productivity indicators.

In the paper [*Gershman, Kuznetsova*, 2013], the authors describe the benefits of an 'effective contract,' which encourages researchers to increase their research performance. The pay principles bound up in this concept are actively used at foreign universities. It is also significant that having one's primary employment at a higher education institution can have a negative impact on publication activity in foreign journals. This seems to indicate that the relevant incentives are insufficient and demonstrate a weak dependence between teachers' incomes and their research effectiveness.

Out of all the socio-demographic characteristics, there is only a significant correlation for respondents' gender: males demonstrate a higher overall level of productivity and publish more frequently. Contrary to expectations, age does not appear to have a significant impact on this indicator in any of the models. However, the model for all samples (Table 2) showed that over a researcher's lifetime the total number of publications initially shows an upward trend and then declines. For older academics, publication in Russian outlets is the predominant trend. The models for this age cohort (Table 3) show that age has a negative impact on the number of peer-reviewed publications (10% significance), which can be explained partly by the tradition of publishing monographs over articles.

A one-way analysis of variance confirms that older academics publish more intensively on average than their younger colleagues (Table 4). However, since the dependence of publication in foreign outlets and peer-reviewed scientific journals on age is not significant in the regression analysis (Table 2), then,

Table 3. **Regression model of factors influencing publication activity among researchers in the older age cohort,** *df/dx*

Indicator	All publications	Foreign	Russian	Peer-reviewed
Academic position in primary employment and other employment (yes=1)	Peer-reviewed	0.723	0.437	**0.782****
Academic position in all three places of employment (yes=1)	–0.161	–0.285	0.387	–0.071
Academic position only in secondary employment (yes=1)	**–1.699***	–1.143	–0.365	–0.636
PhD degree	3.459	0.417	**4.755*****	2.954
Doctor of Sciences degree	**4.280*****	**2.144*****	**3.721*****	**3.942*****
Baseline – degree in engineering				
Degree in natural sciences (yes=1)	0.623	**1.165****	0.043	0.613
Degree in medical sciences (yes=1)	0.240	–0.043	0.114	0.327
Degree in agricultural sciences (yes=1)	–0.336	**–2.924*****	0.674	–0.311
Degree in social sciences (yes=1)	0.296	**–2.809*****	0.131	**–1.136****
Degree in humanities (yes=1)	–0.134	**–2.894*****	–0.417	**–1.585****
Attended courses in own or adjoining specialization in last three years (yes=1)	–0.451	0.190	–0.134	–0.540
Use one foreign language	**1.641*****	**2.389*****	**1.026****	**1.172****
Use two or more foreign languages	**2.150*****	**2.556*****	**1.663*****	**1.696*****
Foreign collaboration: delivered lectures (yes=1)	**1.262***	1.055	–0.021	0.208
Foreign collaboration: studied (yes=1)	**1.248***	**1.523****	0.836	**1.290****
Foreign collaboration: worked abroad (yes=1)	0.129	**1.459****	–0.499	0.603
Foreign collaboration: participated in joint projects (yes=1)	0.617	**1.694*****	0.084	0.387
Foreign collaboration: participated in international conferences (yes=1)	**1.879*****	**2.951*****	**0.772****	**1.141*****
Foreign collaboration: other (yes=1)	**3.012****	1.991	0.644	1.165
Directed research projects (yes=1)	**1.655*****	**0.791***	**1.319*****	**1.460*****
Senior position at an educational organization (yes=1)	0.269	–0.284	0.533	0.224
Senior position at a research organization (yes=1)	0.110	–0.557	0.066	0.247
Number of times changed place of employment	**–0.899*****	**–1.178*****	**–0.507****	**–0.742*****
Defended dissertation at research institute (yes=1)	0.348	–0.084	0.391	0.518
Work in a higher education institution as primary employment (yes=1)	**–0.851***	**–1.941*****	–0.636	**–1.003****
Permanent employment contract at primary employment (yes=1)	**0.654***	0.552	0.525	**0.632***
Complete match between primary employment and specialization (yes=1)	**1.022****	0.803	**0.843****	**1.121*****
Changed research area (yes=1)	0.087	0.601	–0.339	–0.469
Have been unemployed at some time (yes=1)	–0.004	–0.441	–0.106	–0.211
Studied or worked abroad (yes=1)	0.267	**1.526*****	–0.275	0.366
Degree held by at least one parent (yes=1)	0.269	**1.210****	–0.221	0.097
Age /10	–0.484	0.276	–0.218	**–0.432***
Male (yes=1)	0.573	0.005	**0.474***	0.509
Married (registered or unregistered) (yes=1)	0.361	0.816	–0.072	0.339
Number of observations	1690	1690	1690	1690
Number of uncensored observations	1387	442	409	0.05
Pseudo-coefficient of determination (R Square)	0.04	0.13	0.04	0.78
Model significance (Prob> chi2)	0.000	0.000	0.000	0.000

Source: authors' calculations.

Table 4. **Regression model of factors influencing publication activity among younger researchers,** *df/dx*

Indicator	All publications	Foreign	Russian	Peer-reviewed
Academic position in primary employment and other employment (yes=1)	0.358	–0.414	**0.643***	0.232
Academic position in all three places of employment (yes=1)	–1.107	**–2.294***	–0.213	–0.573
Academic position only in secondary employment (yes=1)	0.559	–0.740	0.751	0.442
PhD degree	2.644	**3.357****	**2.131***	**2.716****
Doctor of Sciences degree	**4.116*****	**2.446*****	**3.774*****	**3.715*****
Baseline – degree in engineering				
Degree in natural sciences (yes=1)	0.647	**1.117***	**0.643***	**0.786***
Degree in medical sciences (yes=1)	0.796	0.988	0.462	0.957
Degree in agricultural sciences (yes=1)	0.319	–1.169	**1.078***	1.073
Degree in social sciences (yes=1)	**1.332****	**–2.190*****	**1.126*****	0.334
Degree in humanities (yes=1)	**1.998****	–0.800	0.429	0.035
Attended courses in own or adjoining specialization in last three years (yes=1)	–0.362	**–0.914****	–0.263	–0.424
Use one foreign language	–0.164	**2.864****	0.097	0.794
Use two or more foreign languages	1.206	**4.355*****	–0.486	0.361
Foreign collaboration: delivered lectures (yes=1)	**2.989****	0.692	**–1.679****	–0.756
Foreign collaboration: studied (yes=1)	–1.369	–0.271	–0.164	–0.524
Foreign collaboration: worked abroad (yes=1)	0.516	**2.070****	0.072	**1.297***
Foreign collaboration: participated in joint projects (yes=1)	**0.963***	**1.060***	0.214	0.229
Foreign collaboration: participated in international conferences (yes=1)	**1.480*****	**1.914*****	**0.586***	**0.992*****
Foreign collaboration: other (yes=1)	**3.505****	**2.352***	**0.412**	0.472
Directed research projects (yes=1)	**1.460*****	0.041	**0.793*****	**0.982*****
Senior position at an educational organization (yes=1)	**–1.251***	**–1.387***	–0.566	–1.342
Senior position at a research organization (yes=1)	**2.500*****	–0.448	**1.205****	0.678
Number of times changed place of employment	–0.190	–0.008	**–0.374****	**–0.423****
Defended dissertation at research institute (yes=1)	**2.262*****	**1.168***	**1.217*****	**1.579*****
Work in a higher education institution as primary employment (yes=1)	0.675	–0.731	0.424	0.141
Permanent employment contract at primary employment (yes=1)	0.319	0.288	–0.075	–0.108
Complete match between primary employment and specialization (yes=1)	**1.886*****	0.696	**1.119*****	**1.207*****
Changed research area (yes=1)	0.717	–0.651	**1.388*****	**1.445*****
Have been unemployed at some time (yes=1)	0.673	**1.219****	**0.070**	0.307
Studied or worked abroad (yes=1)	0.498	1.072	0.126	0.676
Degree held by at least one parent (yes=1)	0.479	–0.562	0.146	–0.069
Age /10	–0.706	0.043	–0.328	–0.647
Male (yes=1)	**1.565*****	**0.783***	**1.080*****	**1.204*****
Married (registered or unregistered) (yes=1)	**–1.221*****	–0.122	**–0.568****	–0.451
Number of observations	943	943	943	943
Number of uncensored observations	762	184	220	695
Pseudo-coefficient of determination (R Square)	0.03	0.15	0.03	0.04
Model significance (Prob> chi2)	0.000	0.000	0.0000	0.000

Source: authors' calculations.

all things being equal (e.g. having a doctoral degree, international collaboration), the impact of age is negligible. In other words, the actual level of academics' publication activity is determined by the quality of their scientific capital. This hypothesis is also supported by the inclination among older researchers to publish in Russian, which (excluding the those in peer-reviewed journals) does not always guarantee high quality.

Factors influencing younger and older academics' publication activity

One of the hypotheses of this study is the disproportionate distribution of 'accumulated advantages' between academics (the 'Matthew Effect') , and their role on income received by colleagues from different generations (for a definition of these age categories, see section 'Methodology'). The data confirm the assumption that older academics demonstrate better performance level than their younger colleagues (Table 1) but do not allow for an unequivocal conclusion as to the higher relative productivity of the first group compared with the second. We will now look in more detail at how scientific capital, employment conditions, and socio-demographic characteristics can influence the publication activity of different generations of researchers.

The formal level of scientific capital among younger generation academics is still relatively low (Table 1). Although they often have a PhD that shows a positive effect on research productivity, the proportion of PhD holders among young researchers is not enough to influence greater publication activity. There is almost no difference in command of foreign languages between the two generations. The differences in their involvement in international collaborations are also negligible, although older researchers tend to give lectures, participate in joint projects, and go to conferences abroad slightly more often. Among younger academics, the proportion of those who have attended professional development courses in their own or related specialization is higher. Predictably, the older generations tend to hold senior positions in science and education and, as a general rule, work in their specialization on a permanent basis. Younger colleagues are more active in changing their place of work, often experience difficulty in finding work, and are typically affiliated with higher education institutions.

The regression analysis helps to identify the factors that help younger academics to overcome the 'Matthew Effect', secure additional advantages, and raise their productivity (Tables 3 and 4). Thus, a Doctor of Sciences degree (the highest doctorate award) is the most significant factor influencing publication activity for both generations of academics. A PhD has a significant impact on the number of journal publications (both Russian and foreign) by young researchers and on the total number of Russian publications by their older colleagues. This relationship can be explained by the fact that during their study on foreign doctoral programmes, younger academics acquire a significant store of up-to-date knowledge and a mastery of international article authoring standards.

Experience of research abroad helps to increase the publication activity of both generations. Various forms of academic mobility (business trips, residential schools, grants and scholarships from foreign higher education institutions) and international collaboration (student exchange, welcoming foreign delegations, conferences) can have a marked impact on growth in the number of articles published. However, participating in international conferences unlike giving lectures has a weak impact on the productivity of younger academics. Joint international projects have a moderate effect on the number of publications in foreign scientific journals of both age cohorts. Study or placements abroad only have a significant impact on overall performance and international publication activity for the older generation of academics. Management of research projects can increase both of these indicators for younger and older academics in equal measure; furthermore, older academics can increase their presence in foreign publications. Frequent changes in work place can have a serious adverse effect on publication indicators for older researchers, while for younger colleagues it can have significant negative as well as moderate consequences.

There is likely to be some connection between a researcher's working conditions and publication activity: low publication figures under an 'Effective Contract' mechanism can deter a research organization from hiring such an employee on a permanent contract. At a new place of work, an employee settles down to work on new projects, often discarding previously initiated projects; this is corroborated by the growth in publication activity – both overall and in peer-reviewed journals – among the older generation of researchers who work under permanent employment contracts.

The match between the researcher's primary employment and specialization also has a positive impact on overall publication activity and the number of articles in peer-reviewed journals for both generations. However, for younger researchers the opposite dependence is more accurate: a fundamental shift in research area can lead to growth in peer reviewed journal publications. The same dependence is true of unemployment among this age cohort, which can increase the number of foreign publications. This can likely be explained by the fact that periods of formal unemployment often bring about an intensification of the academic process or foreign travel. Predictably, foreign educational programmes improve the corresponding indicators of the older generations, and are higher among those holding engineering or medical degrees in comparison to other specializations. There are no such differences in foreign publications of younger academics; only those with a degree in social sciences are less published abroad compared with members of engineering disciplines, while those with engineering degrees have less of a presence in Russian publications.

Relationship between publication activity and job satisfaction

Another hypothesis posited by this study was the relationship between academics' publication activity and their motivation and job satisfaction. Due to significant institutional differences between the academic and non-academic spheres, in this study we only selected those respondents who were employed primarily at research or educational organizations and who responded to questions about satisfaction with working conditions.

Researchers were most satisfied with the length of leave (average of 3.5 on a four-point scale), job security (3.2), social importance (3.2), and the geographic location (3.0) of their work, as well as the opportunity for creative expression (3.1) and the responsibility entrusted to them (3.1). Academics were least satisfied

Table 5. **Factor analysis of academics' satisfaction with working conditions**

Satisfaction at primary employment	Factor loadings		
	1	2	3
Opportunity for creative expression	0.756	0.079	0.186
Opportunities for professional development	0.716	0.254	0.119
Level of responsibility	0.652	0.069	0.293
Degree of freedom/level of independence	0.646	0.028	0.274
Social importance of work	0.642	0.110	0.155
Prestige of work	0.625	0.272	0.060
Availability of the required S&T information	0.601	0.287	0.152
Opportunities for international collaboration	0.581	0.225	–0.013
Primary wage	0.229	0.811	0.005
Bonuses, allowances	0.224	0.820	0.47
Benefits	0.111	0.698	0.275
Availability of modern devices and equipment	0.509	0.446	0.053
Length of leave	0.208	–0.065	0.786
Proximity to home	0.054	0.144	0.596
Job security	0.366	0.228	0.587

Source: authors' calculations.

with payment-related issues: wages (2.2), bonuses (2.2), and benefits (2.5). The results largely confirm the theory regarding internal motivations of research personnel taking precedence over external ones [*Volodarskaya, Kiseleva*, 2012]. To reduce the dimensions and determine the internal structure of the attribute space, we applied a factor analysis model (principal component analysis, Varimax rotation). The results identified three factors, explaining 53% of the overall dispersion (Table 5).

The *first factor* can be described as satisfaction with opportunities for creative work and professional development. Research allows academics to manage their schedule, which is not administratively regulated, as the outcome depends on the individual rhythm of an employee's creative activity. Professional development and social importance are additional elements of the subjective satisfaction of research personnel, driven not only by curiosity, but also a need to have the fruits of their labour approved by the professional community.

The *second factor* is linked to satisfaction with material incentives (pay and benefits). While internal motivation dominates, a worthy wage and social protection are both important conditions underpinning academics' professional activities. Low primary income forces academics to search for additional sources of earnings, resort to fundraising, and participate in commercial projects. Arguably, the main incentive for academics with set-ups such as this is the system of internal competition or additional payments at the primary place of employment.

The *third factor* can be characterized as satisfaction with working conditions, expressed through indicators such as proximity to home, job security, and length of leave. These intangible incentives, together with the creative nature of research and direct material rewards, are most frequently used by universities and research institutes.

The existence of relationships between these factors and key productivity indicators was verified using a correlation analysis. A significant dependence but sparse correlation, was established only for the first and third factors. In particular, satisfaction with opportunities for creative expression is positively correlated with researchers' publication activity. Thus, in order to achieve the very best productivity indicators, academics need a certain degree of academic freedom. The negative correlation between number of foreign publications and job satisfaction could indicate academics' willingness to forego comfort for the sake of achieving a significant outcome. However, the reasons for this dependence require further study. Importantly, in our view, the lack of significant correlation between satisfaction with income and the level of publication activity can likely be explained by the fact that material incentives are essential for research personnel, but inadequate when it comes to working conditions.

Conclusion

According to our findings, academics who have their primary employment at research organizations publish on average six scientific works every three years (Table 1). Researchers with no employment elsewhere are less productive compared to those who combine research assignments with employment in other sectors of the economy (but do research work as their primary activity). The majority of texts are published in Russian: only one in six articles published over a three-year period were issued abroad.

Table 6. **Comparison of publication activity and pay in the older and younger age cohorts of academics**

Group	Average number of publications				Average income at primary place of employment (thousands of roubles)	
	All publications	Foreign	Russian	Peer-reviewed	Research organizations	Other organizations
Older (41–70 years)	6.53	0.98	4.34	4.78	269.2	448.5
Younger (23–40 years)	4.82	0.56	3.20	3.38	242.7	363.1

Source: authors' calculations.

Generally, older academics are more productive and publish one to two articles more than their younger colleagues. Younger academics, in turn, are more active when it comes to foreign publications.

Academics' satisfaction with their primary employment at research organizations, namely opportunities for creative expression and development, has a positive correlation with productivity. However, no significant relationship between the amount of material remuneration and publication activity was identified (Table 6), which points to the secondary nature of financial incentives in relation to other factors. Academics' publication activity can be buoyed not only by a high level of pay, but also stimulating working conditions that include opportunities for creative expression and a certain degree of academic freedom.

The regression analysis allowed us to identify the key determinants of publication activity. The greatest impact on academic productivity came from various characteristics of scientific capital, (or 'accumulated advantages'). Primarily, these include a highest doctorate level, experience in international collaboration, and management of research projects. On the other hand, academic career characteristics such as a senior position in an educational institution can play a negative role. Ultimately, a positive factor influencing publication activity among Russian researchers is working within one's specialization and subscribing to the notion of a research career as a long-term life choice.

Older generations of academics exhibit higher levels of publication activity. However, the field of specialization in which the researcher obtained their degree can affect both age cohorts in different ways. Among the older generations, those specialized in the medical sciences and engineering have an advantage, while among younger academics, these differences are negligible; a more perceptible effect comes from having a PhD and engagement in international collaboration, primarily conference participation. Finally, success in the publications market comes more from the quality of scientific capital (for example, mastery of foreign languages, a doctoral degree, management and involvement in international projects and various programmes) than from age and other socio-demographic characteristics. Against this backdrop, the more successful strategies are expected at those universities and research centres that are able to provide their younger employees with the necessary conditions for professional development by offering material incentives as well as the possibility of integration into a global professional community.

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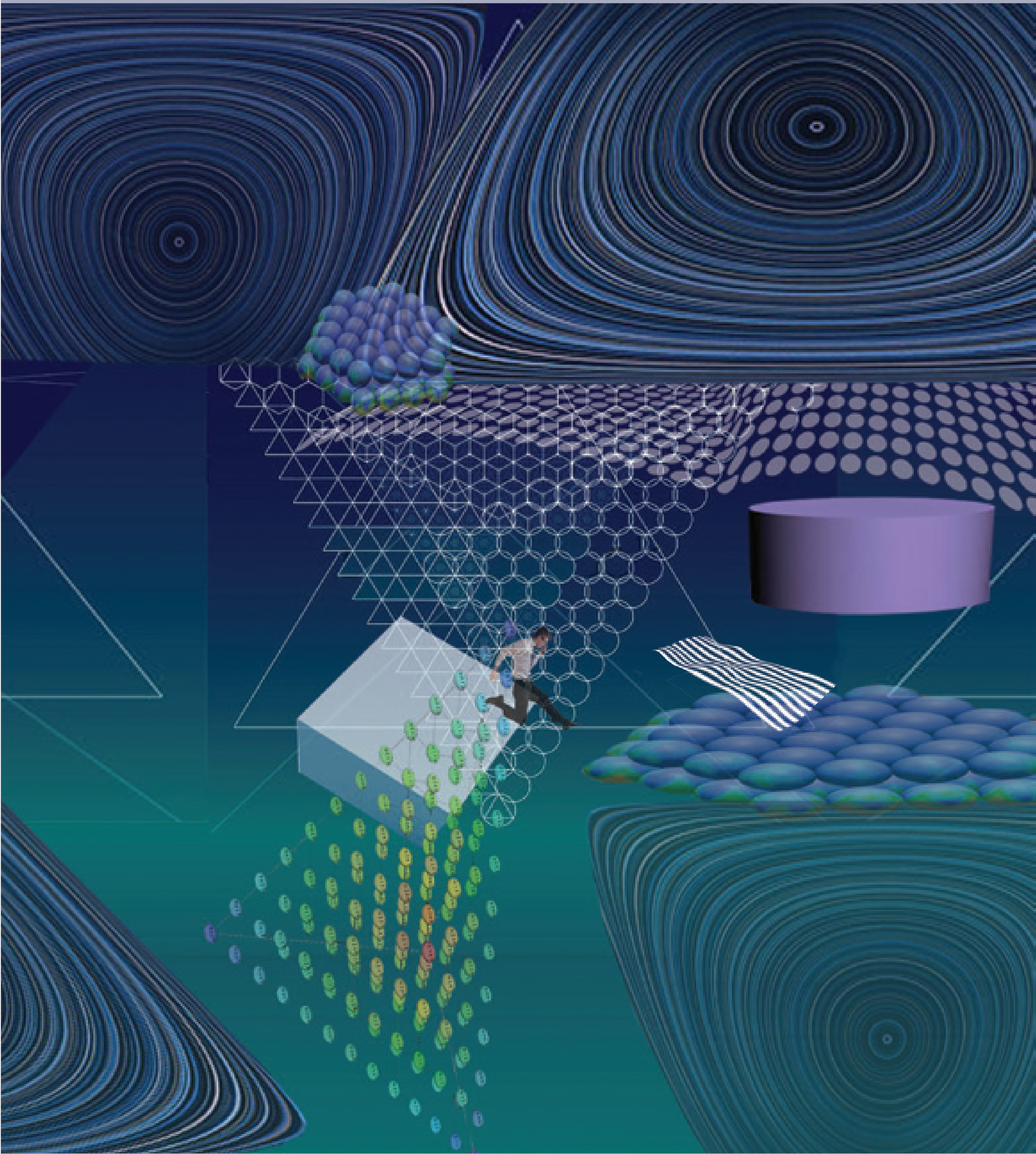
MASTER CLASS



Social and Business Innovations: Are Common Measurement Approaches Possible?

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Abstract

This article reviews various approaches to measuring business innovation with the aim of drawing lessons for measuring social innovations, and offers several methodological and policy conclusions. First, Innovation Union Scoreboard (IUS) indicators, in principle, could be useful in settings where the dominant mode of innovation is based on R&D activities. In practice, however, both R&D and non-R&D-based modes of innovation are important. IUS, therefore, only provides a partial picture. Social innovations can rely on R&D-based technological innovations; their essence, however, tends to be organizational, managerial, and behavioural changes. The IUS indicators do not capture these types of changes. Second, an assessment of the 81 indicators used to compile the Global Innovation Index reveals that it would not be fruitful to rely on such indicators to capture social innovations. Third, given the diversity among innovation systems, a poor performance signalled by a composite indicator does not automatically identify the area(s) necessitating the most urgent policy actions; only tailored, thorough comparative analyses can do so. Finally, analysts and policy makers need to be aware of the differences between measuring (i) social innovation activities (or efforts); (ii) the framework for social innovations (pre-requisites, available inputs, skills, norms, values, behavioural patterns, etc.); and (iii) the economic, societal, and environmental impacts of social innovations.

Keywords: Evolutionary economics of innovation; business innovation; social innovation; measurement of innovation; composite indicators; scoreboards; league tables; unit of analysis
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The basic objective of this article is to review established approaches to capturing and measuring various types of innovations from the angle of measuring social innovations. Social innovation is defined by the Creating Economic Space for Social Innovation (CrESSI) project as follows: "The development and delivery of new ideas (products, services, models, markets, processes) at different socio-structural levels that intentionally seek to improve human capabilities, social relations, and the processes in which these solutions are carried out." [*Budd et al.,* 2015].

It is important to clarify at the outset that this article considers all sorts of business (or, profit-oriented) innovations on the one hand, and social (socially-oriented or societal) innovations, on the other. In other words, we should take into account not only technological (product, service, and process) innovations when discussing profit-oriented innovations, but organizational and marketing innovations as well.[1]

Innovation studies also show that it is more of an exception than a rule to introduce technological innovations without organizational innovations and, in many cases, marketing and market innovations as well. Moreover, the latter are vital for the success of the former [*Pavitt,* 1999; *Tidd et al.,* 1997]. In particular, radical innovations often create new markets and that is, by definition, a market innovation also.

In a similar vein, technological innovations, aimed at tackling societal challenges, should not be neglected when considering social innovations. Most likely certain organizational and marketing innovations are useful — or even indispensable — to achieve societal goals. In sum, we should keep in mind a distinction between the nature of innovation (technological, organizational, and marketing) and the goals of innovation efforts (business versus societal purposes).

Significant progress has been achieved in measuring R&D and innovation activities since the 1960s with the intention to provide comparable data sets as a solid basis for assessing R&D and innovation performance and thereby guiding policy makers in devising appropriate policies [*Grupp,* 1998; *Grupp, Schubert,* 2010; *Smith,* 2005].[2]

Although there are widely used guidelines to collect data on R&D and innovation — the Frascati and Oslo Manuals [OECD, 2002, 2005] — it is not straightforward to find the most appropriate way to assess R&D and innovation performance. To start with, R&D is such a complex, multifaceted process that it cannot be sufficiently characterized by two or three indicators, and that applies to innovation *a fortiori*. Hence, there is always a need to select a certain set of indicators to depict innovation processes, and in particular to analyse and assess innovation performance. The choice of indicators is, therefore, an important decision reflecting the mind-set of the decision makers. These figures are 'subjective' in that respect, but as they are expressed in numbers, most people perceive indicators as being 'objective' by definition.

For this and other reasons, it is important to review how innovation is understood in particular models of innovations and analysed by various schools of economics. Based on this, the paper focuses on an in-depth assessment of two major measurement endeavours, namely the Innovation Union Scoreboard (IUS) and the Global Innovation Index (GII), and discusses further methodological issues.

Models and economic theories of innovation

Besides Schumpeter, only a few economists had perceived innovation as a relevant research topic in the first half of the 20th century.[3] At that time, however, natural scientists, managers of firms' R&D laboratories, and policy advisors had formulated the first models of innovations, stressing the importance of scientific research, and these ideas are still highly influential.[4] Since the late 1950s, more and more economists have shown interest in studying innovation, leading to new models of innovation, as well as making explicit mention of innovation in various economics paradigms. The role of innovation in economic

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[1] These three types of innovations are defined by the Oslo Manual [OECD, 2005], aimed at providing guidelines to interpret and measure innovations introduced by businesses. Interestingly, market innovations, that is, entering new markets to purchase inputs or sell outputs (not to be confused with marketing innovations) are not mentioned by the Manual (although these are parts of the classic description of innovation by Schumpeter, and important ones, indeed). Perhaps it would be almost impossible to measure these crucial innovations. Further financial innovations are not mentioned either as a separate category. Certain types of financial innovations can be interpreted as service innovations (e.g. new financial 'products'), while others (e.g. e- and m-banking) as new business practices, that is, organizational innovations using the definitions presented in the Manual.

[2] "The Innovation Union Scoreboard 2013 gives a comparative assessment of the innovation performance of the EU27 Member States and the relative strengths and weaknesses of their research and innovation systems." [European Commission, 2013a, p. 4].

[3] This section draws heavily on Section 2 in [*Havas*, 2015a].

[4] For further details, see, e.g. [*Fagerberg et al.,* 2011, p. 898] and [*Godin,* 2008, pp. 64–66].

development, however, is analysed by various schools of economics in diametrically different ways.[5] The underlying assumptions and key notions of these paradigms lead to diverse policy implications.

Models of innovation and policy implications[6]

Natural scientists and practitioners had devised the first models of innovation before economists showed a serious interest in these issues. The idea that basic research is the main source of innovation had already been proposed at the beginning of the 20th century, gradually leading to what is known today as the science-push model of innovation, forcefully advocated by Bush [*Bush,* 1945].

It is worth recalling some of the main building blocks of Bush's reasoning:

> *"We will not get ahead in international trade unless we offer new and more attractive and cheaper products. Where will these new products come from? How will we find ways to make better products at lower cost? The answer is clear. There must be a stream of new scientific knowledge to turn the wheels of private and public enterprise. There must be plenty of men and women trained in science and technology for upon them depend both the creation of new knowledge and its application to practical purposes. (…)*
>
> *New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science.*
>
> *Today, it is truer than ever that basic research is the pacemaker of technological progress. In the nineteenth century, Yankee mechanical ingenuity, building largely upon the basic discoveries of European scientists, could greatly advance the technical arts. Now the situation is different.*
>
> *A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill."* [*Bush,* 1945, chapter 3].

By the second half of the 1960s, the so-called market-pull model contested that reasoning, portraying demand as *the* driving force of innovation. Then a long-lasting and detailed discussion started to establish which of these two types of models is correct, that is, whether R&D results or market demand are the most important information sources of innovations.[7]

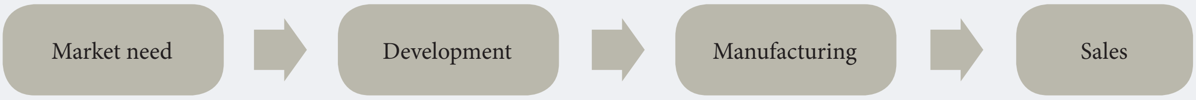
Both the science-push and the market-pull models portray innovation processes as linear ones (Figure 1).

In contrast, the chain-linked model of innovation, suggested by Kline and Rosenberg [Kline, Rosenberg, 1986], stresses the non-linear properties of innovation processes, the variety of information sources, as well as the importance of various feedback loops (Figure 2).

Figure 1. **Linear models of innovation**

a) Science-push model

b) Market pull model



Sources: [*Dodgson, Rothwell,* 1994, p. 41 (figures 4.3 and 4.4)].

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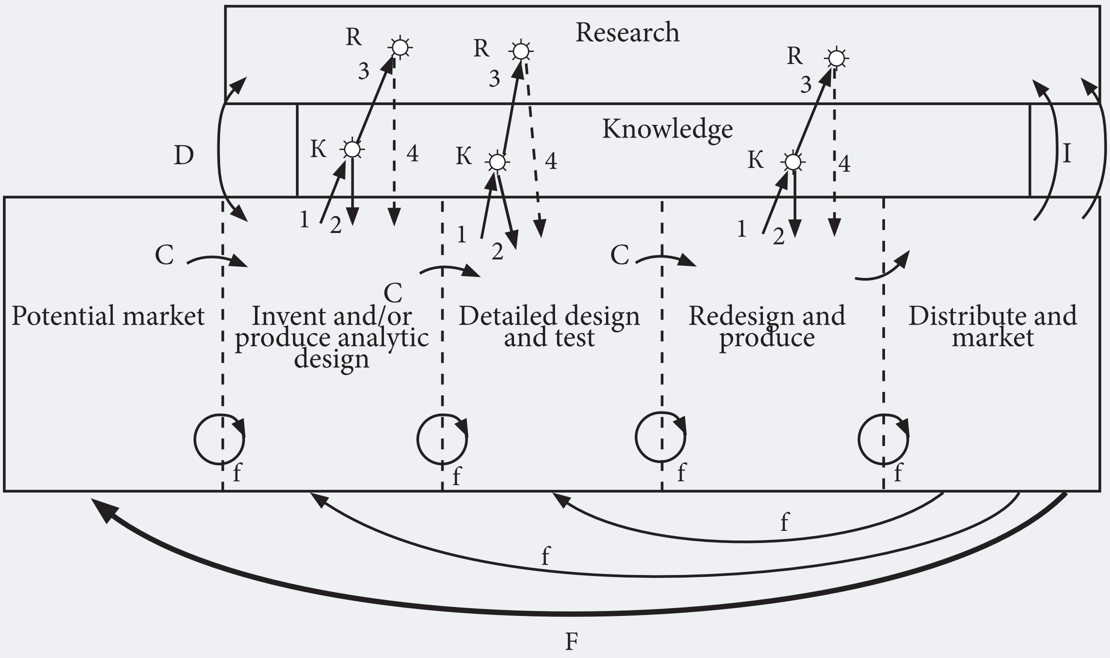
[5] The ensuing overview can only be brief, and thus somewhat simplified. More detailed and nuanced accounts, major achievements and synthesizing pieces of work include [*Baumol,* 2002; *Baumol et al.,* 2007; *Castellacci,* 2008a; *Dodgson, Rothwell,* 1994; *Dodgson et al.,* 2014; *Dosi,* 1988a, 1988b; *Dosi et al.,* 1988; *Edquist,* 1997; *Ergas,* 1986, 1987; *Fagerberg et al.,* 2005; *Fagerberg et al.,* 2012; *Freeman,* 1994; *Freeman, Soete,* 1997; *Grupp,* 1998; *Hall, Rosenberg,* 2010; *Klevorick et al.,* 1995; *Laestadious et al.,* 2005; *Lazonick,* 2013; *Lundvall,* 1992; *Lundvall, Borrás,* 1999; *Martin,* 2012; *Metcalfe,* 1998; *Mowery, Nelson,* 1999; *Nelson,* 1993, 1995; OECD, 1992, 1998; *Pavitt,* 1999; *Smith,* 2000; *von Tunzelmann,* 1995].

[6] This brief account can only list the most influential models; for detailed discussions on their emergence, properties, and use for analytical and policy-making purposes see [*Balconi et al.,* 2010; *Caraça et al.,* 2009; *Dodgson, Rothwell,* 1994; *Godin,* 2006].

[7] It is telling that a recent review of this discussion by [*Di Stefano et al.,* 2012] draws on 100 papers.

Figure 2. **The chain-linked model of innovation**



Chain-linked model showing flow paths of information and cooperation.

Symbols on arrows: C — central-chain-of-innovation, f — feedbak loops, F — particularly important feedback.

K–R — links through knowledge to research and return paths. If problems solved at node K, link 3 to R not activated. Return from research (link 4) is problematic — therefore dashed line.

D — direct link to and from research from problems in invention and design.

I — support of scientific research by instruments, machines, tools, and procedures of technology.

S — support of research in sciences underlying product ares to gain information directly and by monitoring outside work. The information obtained may apply anywhere along the chain.

Source: [*Kline, Rosenberg,* 1986].

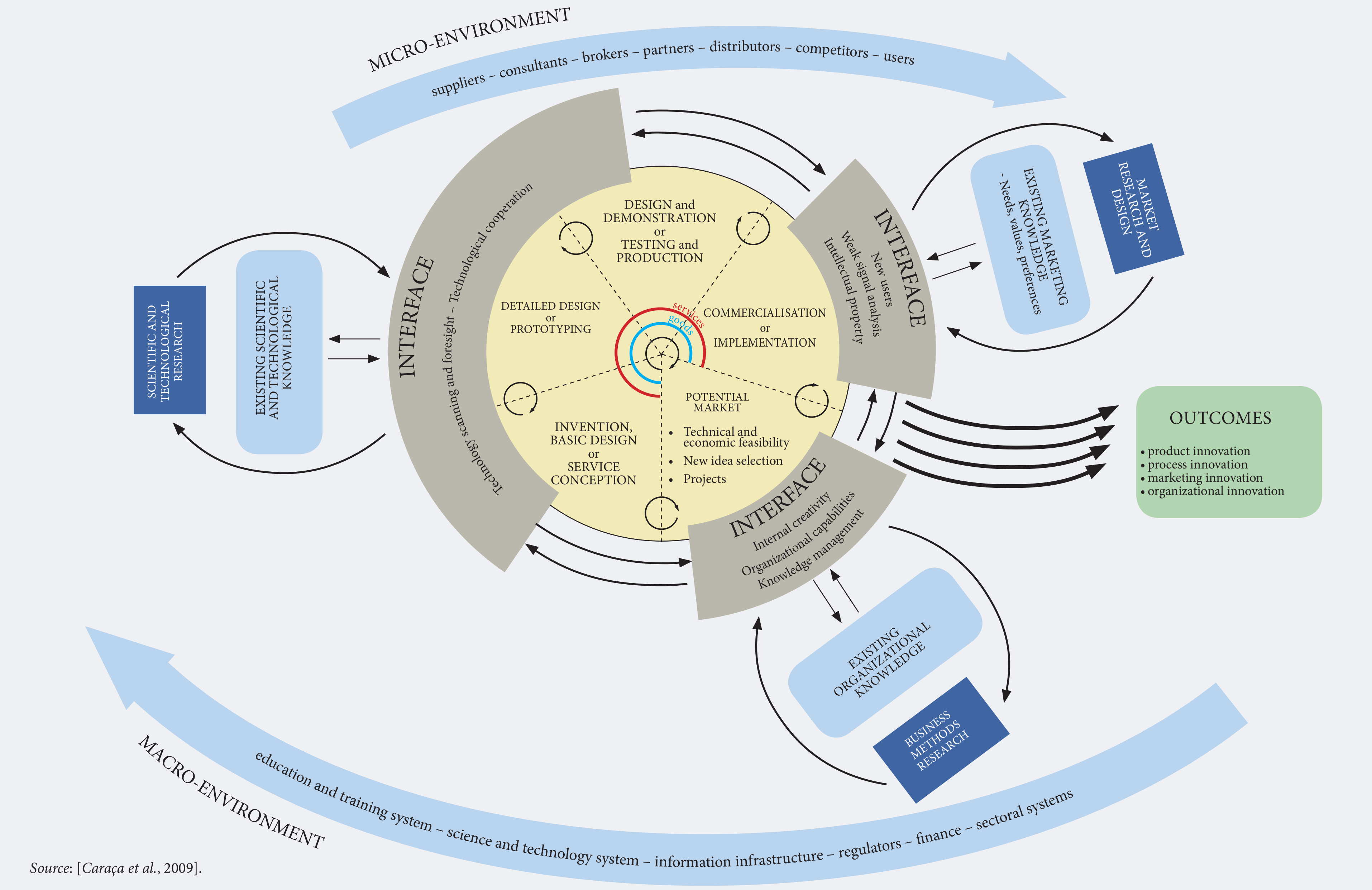
The chain-link model has then been extended into the networked model of innovation. Its recent, highly sophisticated version is called the multi-channel, interactive learning model (Figure 3).

> *“[This model] has representational purposes and not representative ones, i.e.* it does not assume that all factors have to be in place *for innovation to be realised and successful. Rather, it tries to provide a stylised representation of the main classes of variables, and their interrelationships, which are involved in the innovation process taking place in a wide array of industries. (...)*
>
> *Thus, the model is an analytical grid that describes and contextualises elements, but it also provides a set of flexible generalisations upon which to base our thinking when trying to explain the sources and stages of the innovation process. It points to the* ubiquitous experience-based learning processes *taking place within firms, as well as at the interfaces with users, suppliers and competitors.”* [*Caraça et al.,* 2009, pp. 864–866*;* emphasis added, footnotes removed from the original].

Innovation in economics paradigms

Technological, organizational, managerial changes and the opening up of new markets had been major themes in classical economics — without using the term innovation [*Havas,* 2015b]. Later, neo-classical economics essentially abandoned research questions concerned with dynamics, and instead focused on static allocative efficiency. Optimization was the key issue for this school that assumed homogenous products, diminishing returns to scale, technologies accessible to all producers at zero cost, perfectly informed economic agents, perfect competition, and thus zero profit. Technological changes were treated as exogenous to the economic system, while other types of innovations were not considered at all. Given the empirical findings and theoretical work on firm behaviour and the operation of markets, mainstream industrial economics and organizational theory has relaxed the most unrealistic assumptions, especially perfect information, deterministic environments, perfect competition, and constant or diminishing returns. Yet, “this literature has not addressed institutional issues, it has a very narrow concept of

Figure. 3. **The multi-channel, interactive learning model of innovation**



Source: [*Caraça et al.*, 2009].

uncertainty, it has no adequate theory of the creation of technological knowledge and technological interdependence amongst firms, and it has no real analysis of the role of government" [*Smith,* 2000, p. 75].

Evolutionary economics of innovation rests on radically different postulates compared to mainstream economics.[8] The latter assumes rational agents, who can optimize by calculating *risks* and taking appropriate actions, while the former stresses that "innovation involves a fundamental element of *uncertainty*, which is not simply the lack of all the relevant information about the occurrence of known events, but more fundamentally, entails also (a) the existence of techno-economic problems whose solution procedures are unknown, and (b) the impossibility of precisely tracing consequences to actions" [*Dosi,* 1988a, p. 222, emphasis added]. Thus, *optimization* is impossible on theoretical grounds.

Availability of *information* (symmetry vs. asymmetry among agents in this respect) has been the central issue in mainstream economics until recently. Evolutionary economics, in contrast, has stressed since its beginnings that the success of firms depends on their accumulated *knowledge* — both codified and tacit, *skills*, as well as *learning capabilities*. Information can be purchased (e.g. as a manual, blueprint, or licence), and hence can be accommodated in mainstream economics as a special good relatively easily and comfortably. Yet, knowledge — in particular, the types of knowledge required for innovation such as tacit knowledge, skills, and competences in pulling together and exploiting available pieces of information — cannot be bought and used instantaneously. A learning process cannot be avoided if one is to acquire knowledge and skills, and that not only takes time, but the costs of *trial and error* need to be incurred as well.[9] Thus, the uncertain, cumulative, and path-dependent nature of innovation is reinforced.

Cumulativeness, path-dependence, and learning lead to *heterogeneity* among firms, as well as other organizations. On top of that, sectors also differ in terms of major properties and patterns of their innovation processes [*Castellacci,* 2008b; *Malerba,* 2002; *Pavitt,* 1984; *Peneder,* 2010].

Innovators are not lonely champions of new ideas. While talented individuals may develop radically new, brilliant scientific or technological concepts, successful innovations require various types and forms of knowledge that are rarely possessed by a single organization. Close collaboration among firms, universities, public and private research organizations, and specialized service-providers is, therefore, a prerequisite for major innovations, which can take various forms – from informal communications to highly sophisticated R&D contracts, alliances, and joint ventures [*Freeman,* 1991, 1994, 1995; *Lundvall, Borrás,* 1999; OECD, 2001; *Smith,* 2000, 2002; *Tidd et al.,* 1997]. In other words, 'open innovation' is not a new phenomenon at all [*Mowery,* 2009].

Policy rationales derived from economic theories

Different policy rationales can be used from competing schools of economic thought. Mainstream economics is primarily concerned with market failures: the unpredictability of knowledge outputs from inputs, the inability to appropriate full economic benefits of private investment in knowledge creation, and the indivisibility in knowledge production lead to a 'suboptimal' level of business R&D efforts. Policy interventions, therefore, are justified if they aim at (a) creating incentives to boost private R&D expenditures by ways of subsidies and protection of intellectual property rights, or (b) funding for public R&D activities.

The evolutionary economics of innovation school investigates the role of knowledge creation and exploitation in economic processes; that is, it does not focus exclusively on R&D. This paradigm considers

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[8] The so-called new or endogenous growth theory is not discussed here separately because its major implicit assumptions on knowledge are very similar to those of mainstream economics [*Lazonick,* 2013; *Smith,* 2000]. Moreover, knowledge in new growth models is reduced to codified scientific knowledge, in sharp contrast to the much richer understanding of knowledge in evolutionary economics of innovation. When summarising the "evolution of science policy and innovation studies" (SPIS), Martin also considers this school as part of mainstream economics: "Endogenous growth theory is perhaps better seen not so much as a contribution to SPIS but rather as a response by mainstream economists to the challenge posed by evolutionary economics" [*Martin,* 2012, p. 1230].

[9] Arrow [*Arrow,* 1962] was already discussing "The Economic Implications of Learning by Doing," and Rosenberg [*Rosenberg,* 1982] stressed the importance of learning by using. Recently, learning has become a more regular subject in mainstream economics, most notably in game theory. For instance, while "learning" only appeared twice in the title of NBER working papers in 1996, it occurred 5 times in 1999, 6 times in 2002, 13 times in 2008, 10 times in 2013, and 12 times in 2014. The expressions used include "learning by doing", "learning from experience", and "learning from exporting" — but also "learning from state longitudinal data systems" and "learning millennial-style." It should be added that at least 15–20 NBER working papers are published a week. Taking the titles and abstracts of articles published in the American Economic Review, "learning" occurred first in 1999, then 2–3 times a year in 2002–2006; 4 times in 2008, 2011, and 2012; 5 times in 2013; 6 times in 2007, 2010, and 2014; and 7 times in 2009. These articles discuss a wide variety of research themes — e.g. behaviour of firms and other organizations, business cycles, stock exchange transactions, forecasting of economic growth, mortgage, art auctions, game theory, behavioural economics, energy, health, labour market — and modes of learning. Thus, not all these articles are relevant from the point of analysing innovation processes (e.g. "learning [one's] HIV status" is not part of an innovation process). Further, in several cases knowledge is narrowed down to patents, which is clearly a misconception. Yet, a detailed analysis of the substance of these articles is beyond the scope of this paper.

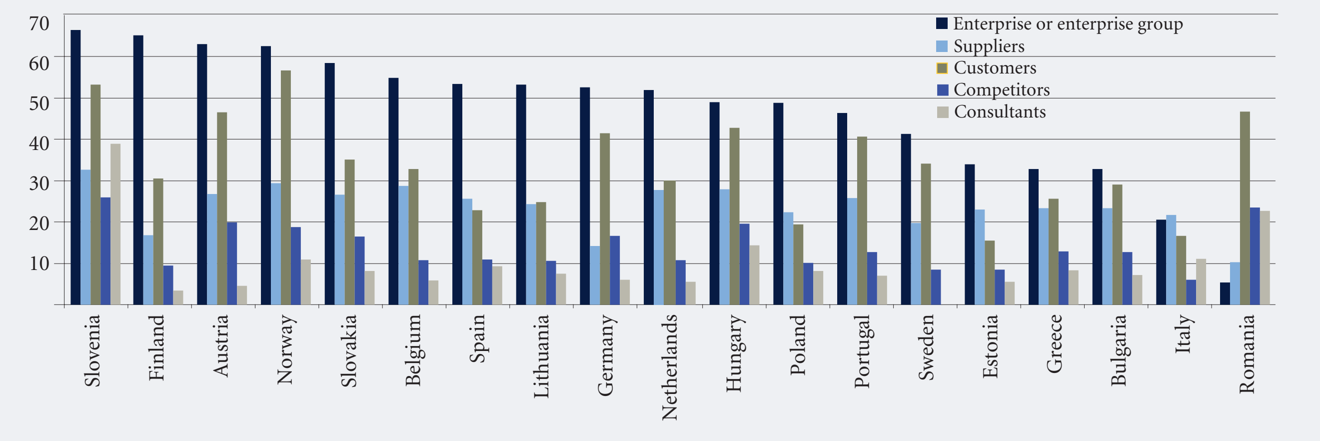
various types and forms of knowledge, including practical or experience-based knowledge acquired via learning by doing, using, and interacting. As these are *all* relevant to innovation, scientific knowledge is far from being the only type of knowledge required for successfully introducing new products, processes or services, let alone non-technological innovations. R&D is undoubtedly among the vital sources of knowledge. Besides in-house R&D projects, however, results of other R&D projects are also widely utilized during the innovation process: extramural projects conducted in the same or other sectors, at public or private research establishments, home or abroad. More importantly, there are a number of other sources of knowledge that are also essential for innovations, including design, scaling up, testing, tooling-up, trouble-shooting, and other engineering activities, ideas from suppliers and users, inventors' concepts and practical experiments [*Hirsch-Kreinsen et al.,* 2005; *Klevorick et al.,* 1995; *Lundvall,* 1992; *Lundvall, Borrás,* 1999; *Rosenberg,* 1986, 1998; *von Hippel,* 1988]. Collaborations among engineers, designers, artists, and other creative 'geeks' are also significant sources of knowledge. Further, innovative firms also utilize knowledge embodied in advanced materials and other inputs, equipment, and software.

The Community Innovation Survey (CIS) defines its own set of categories as highly important sources of information for product and process innovation. These include the enterprise or the enterprise group; suppliers of equipment, materials, components or software; clients or customers; competitors or other enterprises from the same sector; consultants, commercial labs or private R&D institutes; universities or other higher education institutes; public research institutes; conferences, trade fairs, exhibitions; scientific journals and trade/ technical publications; and professional and industry associations. All rounds of CIS clearly and consistently show that firms regard a wide variety of information sources as highly important ones for innovation. This paper, however, given space limits, only presents the 2010–2012 data in Figures 4–5.[10]

The wide variety of knowledge drawn on in innovation processes is a crucial point to bear in mind as the OECD classification of industries only takes into account expenditures on formal R&D activities, carried out within the boundaries of a given sector.[11] In other words, a number of highly successful, innovative firms, exploiting advanced knowledge created externally in distributed knowledge bases [*Smith,* 2002] and internally by non-R&D processes, are classified as medium-low-tech or low-tech, because their R&D expenditures are below the threshold set by the OECD.

In sum, evolutionary economics of innovation posits that the success of firms is largely determined by their abilities to exploit various types of knowledge, generated by both R&D and non-R&D activities. Knowledge generation and exploitation takes place in, and is fostered by, various forms of internal and external interactions. The quality and frequency of the latter is largely determined by the properties of a given innovation system, in which these interactions take place. STI policies, therefore, should aim at strengthening the respective innovation system and improving its performance by tackling *systemic*

Figure 4. **Highly important 'business' sources of information for product and process innovation, selected EU members, 2010–2012** (share of respondents selecting each response out of total respondents by country, %)



Source: [*Eurostat*, 2012].

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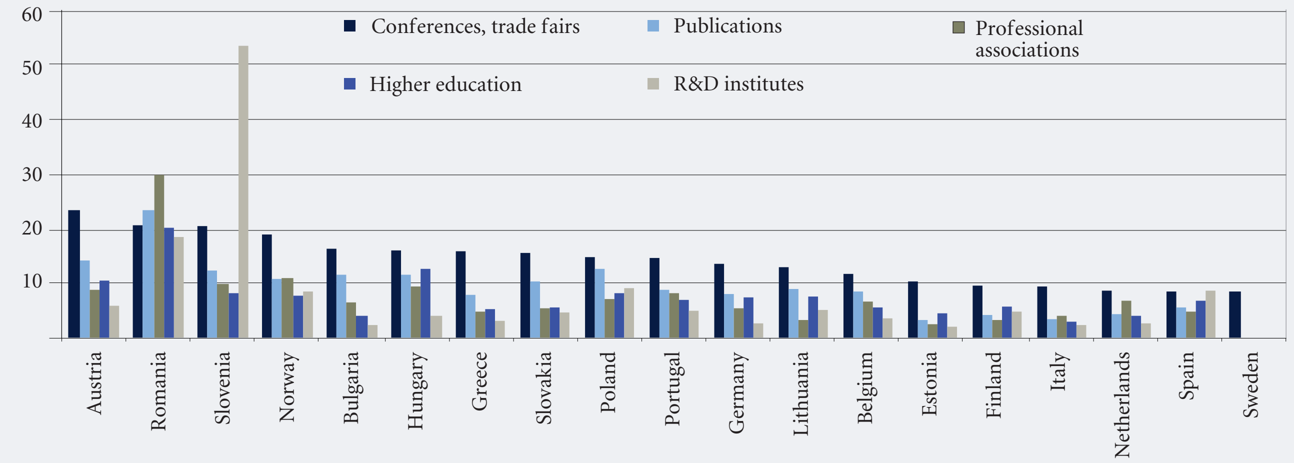
[10] Data for the 2006–2008 and 2008–2010 periods are presented in [*Havas,* 2015c].

[11] The so-called indirect R&D intensity has been also calculated as R&D expenditures embodied in intermediates and capital goods purchased on the domestic market or imported. Yet, it has been concluded that indirect R&D intensities would not influence the classification of sectors [*Hatzichronoglou,* 1997, p. 5].

Figure 5. **Highly important 'scientific' sources of information for product and process innovation, selected EU members, 2010–2012** (share of respondents selecting each response out of total respondents by country, %)



Source: [*Eurostat*, 2012].

failures hampering the generation, diffusion, and utilisation of any type of knowledge required for successful innovation.[12] To put it in another way, conscious, co-ordinated policy efforts are needed to promote knowledge-intensive activities in all sectors.

The Innovation Union Scoreboard

As shown above, firms exploit various types of knowledge for their innovation activities. Applying this general observation to the Danish case, and relying on the DISKO survey, Jensen et al. [*Jensen et al.*, 2007] made an elementary distinction between two modes of innovation: (a) one based on the production and use of codified scientific and technical knowledge (in brief, the ST[I] mode), and (b) another one relying on informal processes of learning and experience-based know-how (called DUI: learning by Doing, Using and Interacting).

Following this distinction, the indicators used in the various editions of the Innovation Union Scoreboard[13] are characterized below, using a rudimentary classification. An indicator can be relevant to reflect:

- only R&D-based innovations
- mainly R&D-based innovations
- only non-R&D-based innovations
- mainly non-R&D-based innovations
- both types of innovations

This rudimentary classification reveals a bias towards R&D-based innovations in the first edition of the EIS: 10 indicators were only relevant for R&D-based innovations; 8 could be relevant for both types of innovations; and none focused on non-R&D-based innovations (Table 1).[14]

The 2014 and 2015 editions of the IUS use 25 indicators, grouped by 8 innovation dimensions [European Commission, 2014, 2015]. Repeating the same exercise shows that the bias towards R&D-based innovations has been retained: ten of the most recent IUS indicators[15] are *only* relevant for, and a further

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[12] In an attempt to systematically compare the market and systemic failure policy rationales, Bleda and del Río [*Bleda, del Río*, 2013] introduce the notion of evolutionary market failures, and reinterpret "the neoclassic market failures" as particular cases of evolutionary market failures, relying on the crucial distinction between knowledge and information.

[13] The Innovation Union Scoreboard was originally called the European Innovation Scoreboard (EIS). The EIS and IUS indicators have been revised several times since the first edition of the scoreboard of EIS 2002 [European Commission, 2002]. The current name of the scoreboard was introduced in 2010.

[14] A fairly detailed, partly technical, partly substantive discussion would be needed to refine this simple classification.

[15] There was only a slight change introduced in 2015: the indicator called "Contribution of medium and high-tech product exports to the trade balance" was replaced by "Exports of medium and high-technology products as a share of total product exports." This change had no effect on the nature of the indicators, and thus the 2014 edition of the IUS is not reproduced here.

four *mainly* capture, R&D-based innovations; seven could be relevant for both types of innovations; and a mere four focus on non-R&D-based innovations (Table 2).

A fairly detailed discussion, both technical and substantive, would be needed to refine this simple classification, particularly concerning the following issues:

- To what extent upper secondary education, venture capital, employment in knowledge-intensive activities, and knowledge-intensive services exports are relevant indicators to capture non-R&D-based innovations?
- How much are non-R&D-based innovation activities needed for successful R&D-based innovations?

To give an overview of the evolution of the EIS and IUS indicators, results are summarized in Table 3.[16] Overall, the bias towards R&D-based innovations has been rather persistent, although there has been some fluctuation.

Table 1. **The 2002 European Innovation Scoreboard indicators**

	Relevance for R&D- based innovation	**Relevance for non-R&D- based innovation**
1 Human resources		
New S&E graduates (ISCED 5a and above) per 1000 population aged 20–29	X	
Population with tertiary education (% of 25–64 years age class)	b	b
Participation in life-long learning (% of 25–64 years age class)	b	b
Employment in medium-high and high-tech manufacturing (% of total workforce)	X	
Employment in high-tech services (% of total workforce)	X	
2 Knowledge creation		
Public R&D expenditures (GERD – BERD) (% of GDP)	X	
Business expenditures on R&D (BERD) (% of GDP)	X	
EPO high-tech patent applications (per million population)	X	
USPTO high-tech patent applications (per million population)	X	
3 Transmission and application of knowledge		
SMEs innovating in-house (% of manufacturing SMEs)	b	b
SMEs involved in innovation co-operation (% of manufacturing SMEs)	b	b
Innovation expenditures (% of all turnover in manufacturing)	b	b
4 Innovation finance, output and markets		
High technology venture capital investment (% of GDP)	X	
Capital raised on parallel markets plus by new firms on main markets (% of GDP)*	X	
Sales of 'new to market' products (% of all turnover in manufacturing)	b	b
Home internet access (% of all households)	b	b
ICT expenditures (% of GDP)	b	b
Share of manufacturing value-added in high-tech	X	

Legend:

X: only relevant

x: mainly relevant

b: relevant for both types

Notes: Public R&D expenditures do not equal to GERD – BERD; rather, it should be the sum of government-funded parts of BERD, GOVERD, and HERD.

Three indicators, namely EPO patent applications (per million population), Home internet access (per 100 population), and Inward FDI stock (% of GDP) were only used for candidate countries.

* "Parallel stock exchanges focus on high technology sectors." [European Commission, 2002, p. 31].

Source: own compilation, drawing on the detailed definition of indicators [European Commission, 2002].

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[16] The indicators used in the previous editions of the EIS and IUS are characterized in detail in [*Havas,* 2015c].

Table 2. **The 2015 Innovation Union Scoreboard indicators**

	Relevance for R&D-based innovation	Relevance for non-R&D-based innovation
Human resources		
New doctorate graduates (ISCED 6) per 1000 population aged 25–34	X	
Percentage population aged 30–34 having completed tertiary education	b	b
Percentage youth aged 20–24 having attained at least upper secondary level education	b	b
Open, excellent and attractive research systems		
International scientific co-publications per million population	X	
Scientific publications among the top 10% most cited publications worldwide as % of total scientific publications of the country	X	
Non-EU doctorate students* as a % of all doctorate students	X	
Finance and support		
R&D expenditure in the public sector as % of GDP	X	
Venture capital investment as % of GDP	x	
Firm investments		
R&D expenditure in the business sector as % of GDP	X	
Non-R&D innovation expenditures as % of turnover		X
Linkages & entrepreneurship		
SMEs innovating in-house as % of SMEs	b	b
Innovative SMEs collaborating with others as % of SMEs	b	b
Public-private co-publications per million population	X	
Intellectual assets		
PCT patents applications per billion GDP (in PPS€)	X	
PCT patent applications in societal challenges per billion GDP (in PPS€) (environment-related technologies; health)	X	
Community trademarks per billion GDP (in PPS€)		X
Community designs per billion GDP (in PPS€)		X
Innovators		
SMEs introducing product or process innovations as % of SMEs	b	b
SMEs introducing marketing or organizational innovations as % of SMEs		X
Economic effects		
Employment in fast-growing enterprises in innovative sectors (% of total employment)	b	b
Employment in knowledge-intensive activities (manufacturing and services) as % of total employment	x	
Exports of medium and high-technology products as a share of total product exports	x	
Knowledge-intensive services exports as % total service exports	x	
Sales of new to market and new to firm innovations as % of turnover	b	b
License and patent revenues from abroad as % of GDP	X	

Legend:
X: only relevant
x: mainly relevant
b: relevant for both types
* It is a somewhat strict definition of openness, which only takes into account non-EU doctorate students.
Source: own compilation.

Table 3. **The evolution of the EIS and IUS indicators, 2002–2014**

	EIS 2002	EIS 2003	EIS 2004	EIS 2005-2006	EIS 2007	EIS 2008	EIS 2009	IUS 2010-2013	IUS 2014-2015
Indicators reflecting:									
only R&D-based innovations	10	9	9	8	7	8	8	10	10
mainly R&D-based innovations	–	3	3	5	5	4	4	4	4
both types	8	9	9	12	12	15	16	6	7
only non-R&D-based innovations	–	–	–	–	–	1	1	4	4
mainly non-R&D-based innovations	–	–	1	1	1	1	1	–	–
Number of indicators	18	21	22	26	25	29	30	24	25

Source: own compilation.

Several conclusions can be drawn from the above considerations for analysing social innovation.

First, while the number and definitions of indicators used to compile the various editions of EIS and IUS have changed considerably since 2002, these indicators consistently focus on measuring R&D activities (inputs and outputs) and R&D-based innovation activities. In other words, they can be relevant in settings characterized predominantly by the so-called ST mode of innovation, but are significantly less useful in other settings that are characterized by other types of innovation activities. In other words, using the EIS or IUS indicators would not help find out whether a certain system is characterized by a low level of innovation activities altogether or a low level of R&D-based innovation activities. Yet, that is an important distinction from an analytical as well as a practical (policy) point of view: these two systems (settings) are fundamentally different.

Several analysts and policy makers tend to believe that (a) advanced economies can be sufficiently characterized by focusing on the ST mode of innovation, and (b) less advanced economies should attempt to change the sectoral composition of their economy by increasing the weight of the so-called high-tech (HT) sectors. These views, however, cannot be corroborated by empirical evidence.

Any simple statistical analysis reveals that the so-called high-tech sectors that are supposed to be drivers of economic development, due their intense ST mode of innovation activities, have a fairly low weight either in output or employment. Innovation studies have shown that technological innovations can hardly be introduced without organizational and managerial innovations. Moreover, the latter ones — together with marketing innovations — are vital for the success of the former[17] [*Pavitt,* 1999; *Tidd et al.,* 1997]. In fact, those companies that consciously combine the ST and DUI modes of innovation are the most successful ones [*Jensen et al.,* 2007].

Yet, the high-tech myth is so powerful that even researchers who base their work on thorough analyses of facts are surprised when the facts are at odds with the widespread obsession with high-tech. A telling example is Peneder's excellent study on the 'Austrian paradox':

> *"On the one hand, macroeconomic indicators on productivity, growth, employment and foreign direct investment indicate that overall performance is stable and highly competitive. On the other hand, an international comparison of industrial structures reveals a severe gap in the most technologically advanced branches of manufacturing, suggesting that Austria is having problems establishing a foothold in the dynamic markets of the future"* [*Peneder,* 1999, p. 239].

In contrast, evolutionary economics of innovation claims that any firm — belonging to either a low- and medium-technology (LMT) or a HT sector — can become competitive in 'the dynamic markets of the future' if it successfully combines its own firm-specific innovative capabilities with 'extra-mural' knowledge available in distributed knowledge bases. In other words, Austrian policy makers need not be concerned with the observed 'paradox' as long as they help firms sustain their learning capabilities, and thereby maintain their innovativeness. That would lead to good economic performance irrespective of the share of LMT industries in the Austrian economy.

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[17] Although it goes without saying that not all technological innovations are based on R&D results, people tend to forget this basic fact. Certain organizational, managerial, marketing, and financial innovations, in turn, draw on R&D results (but usually not stemming from R&D activities conducted or financed by firms). For these two reasons, it would be a mistake to equate technological innovations with R&D-based innovations.

From a different angle, while the bulk of innovation activities in the LMT sectors are not based on intramural R&D efforts, these sectors also improve their performance by various types of innovations. These firms are usually engaged in the DUI mode of innovation, but also draw on advanced S&T results available through the so-called distributed knowledge bases [*Robertson, Smith,* 2008; *Smith,* 2002], as well as advanced materials, production equipment, software and various other inputs (e.g. electronics components and sub-systems) supplied by HT industries [*Bender et al.,* 2005; *Hirsch-Kreinsen et al.,* 2005; *Hirsch-Kreinsen, Jacobson,* 2008; *Hirsch-Kreinsen, Schwinge,* 2014; *Jensen et al.,* 2007; *Kaloudis et al.,* 2005; *Mendonça,* 2009; *Sandven et al.,* 2005; *von Tunzelmann, Acha,* 2005]. Thus, demand by the LMT sectors constitutes major market opportunities for HT firms, and provides strong incentives and ideas for their RTDI activities [*Robertson et al.,* 2009].

It is worth recalling that the 2003 EIS report also stressed the importance of the LMT sectors, as well as the significance of their innovation activities:

> *„The EIS has been designed with a strong focus on innovation in high-tech sectors. Although these sectors are very important engines of technological innovation, they are only a relatively small part of the economy as measured in their contribution to GDP and total employment. The larger share of low and medium-tech sectors in the economy and the fact that these sectors are important users of new technologies merits a closer look at their innovation performance. This could help national policy makers with focusing their innovation strategies on existing strength and overcome areas of weakness"* [European Commission, 2003a, p. 20].

Since then, however, these ideas have been given less prominence. It would be an interesting research question to investigate this development, but that is beyond the scope of this paper. More recently, another European Commission (EC) document, namely the 2013 EU Competitiveness Report, gives 'mixed' messages on these issues. At certain points, it reinforces these adverse effects:

> *„The EU has comparative advantages in most manufacturing sectors (15 out of 23) accounting for about three quarters of EU manufacturing output. (…) Of the 15 sectors with comparative advantages mentioned above, about two-thirds are in the low-tech and medium-low tech manufacturing groups.* On a positive note though, *even in those sectors EU competitiveness is based on high-end innovative products"* [EC, 2013b, pp. 3–4, emphasis added].

Is it a negative phenomenon, then, that around 10 EU LMT sectors are internationally competitive? A more balanced view is also offered:

> *"The policy priority attached to key enabling technologies which lead to new materials and products in all manufacturing sectors has a strong potential to upgrade EU competitiveness not only in the high-tech sectors but also in the traditional industries"* [*Ibid.,* p. 5].

To sum up the first conclusion, analysts and policy makers dealing with innovation should pay attention to both R&D-based and non-R&D-based innovations.

Second, while social innovations can indeed utilize R&D-based technological innovations, their essence tends to be organizational, managerial, and behavioural changes. The EIS and IUS indicators, in turn, do not capture these types of changes.

The Global Innovation Index

Compared to the IUS, the Global Innovation Index (GII) has a significantly broader coverage— in two respects: it covers well over 100 countries, and considers 81 indicators, arranged in 7 "pillars" each with 3 sub-pillars (Table 4, Figure 6).

To assess the relevance of these 81 indicators, and especially the 'match' between the themes (or headings) captured by the 7 pillars, is beyond the scope of this paper. In other words, the GII indicators are characterized in a somewhat simplified way here.[18] It should be stressed that most elements are indices themselves i.e. not 'stand-alone' indicators. In other words, several methodological weaknesses are likely to remain hidden.

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[18] For some more detailed comments, see Appendix 3 in [*Havas,* 2015c].

Table 4. **Distribution of GII 2014 indicators by pillars**

Name of the pillar	Number of indicators
Institutions	9
Human Capital and Research	11
Infrastructure	10
Market Sophistication	10
Business Sophistication	14
Knowledge and Technology Outputs	14
Creative Outputs	13

Source: own compilation.

Pillar 1: Institutions

The first sub-pillar — political environment — incorporates three indices with the intention to reflect the following aspects: "perceptions of the likelihood that a government might be destabilized; the quality of public and civil services, policy formulation, and implementation; and perceptions of violations to press freedom".

The second sub-pillar, called regulatory environment, is comprised of two indices to capture "perceptions on the ability of the government to formulate and implement cohesive policies that promote the development of the private sector and at evaluating the extent to which the rule of law prevails (in aspects such as contract enforcement, property rights, the police, and the courts)." A third indicator is meant to evaluate "the cost of redundancy dismissal as the sum, in salary weeks, of the cost of advance notice requirements added to severance payments due when terminating a redundant worker."

The third sub-pillar — business environment — is aimed at summarizing three aspects directly affecting private entrepreneurial endeavours. It uses the World Bank indices "on the ease of starting a business; the ease of resolving insolvency (based on the recovery rate recorded as the cents on the dollar recouped by creditors through reorganization, liquidation, or debt enforcement/foreclosure proceedings); and the ease of paying taxes" [Cornell University et al., 2014, pp. 45–46].

Not all the above elements are institutions ("rules of the game"), and not all are directly related to innovation processes and performance. However, it can be argued that the aspects captured by these indices may help characterize the political, regulatory, and business environment for innovation. The important missing elements include legislation on competition[19] as well as the entrepreneurial culture in a given country.

Pillar 2: Human capital and research

Sub-pillar 2.1 is composed of several of indicators with the intention to capture achievements at the first two levels of education, namely elementary and secondary education. Education expenditure and school life expectancy are taken as "good proxies for coverage." Government expenditure per pupil at secondary level is meant to indicate "the level of priority given to secondary education by the state." The quality of education is measured via (a) PISA (OECD Programme for International Student Assessment) results indicating 15-year-old students' performances in reading, mathematics, science, and computing, as well as (b) the pupil-teacher ratio.

Sub-pillar 2.2 on tertiary education is designed to measure coverage at this level of education. "[P]riority is given to the sectors traditionally associated with innovation (with a series on the percentage of tertiary graduates in science and engineering, manufacturing, and construction); and the inbound mobility of tertiary students, which plays a crucial role in the exchange of ideas and skills necessary for innovation."

Sub-pillar 2.3 on R&D is meant to indicate the level and quality of R&D activities by using the number of researchers (headcounts, per million of population), gross expenditures on R&D as percentage of GDP, and the quality of scientific and research organizations proxied by the average score of the top three universities in the QS World University Ranking as of 2013. "[T]his indicator aims at capturing the availability of at least three higher education institutions of quality within each economy (i.e., included in the global top 700), and is not aimed at assessing the average level of all institutions within a particular economy" [Cornell University et al., 2014, pp. 46–47].

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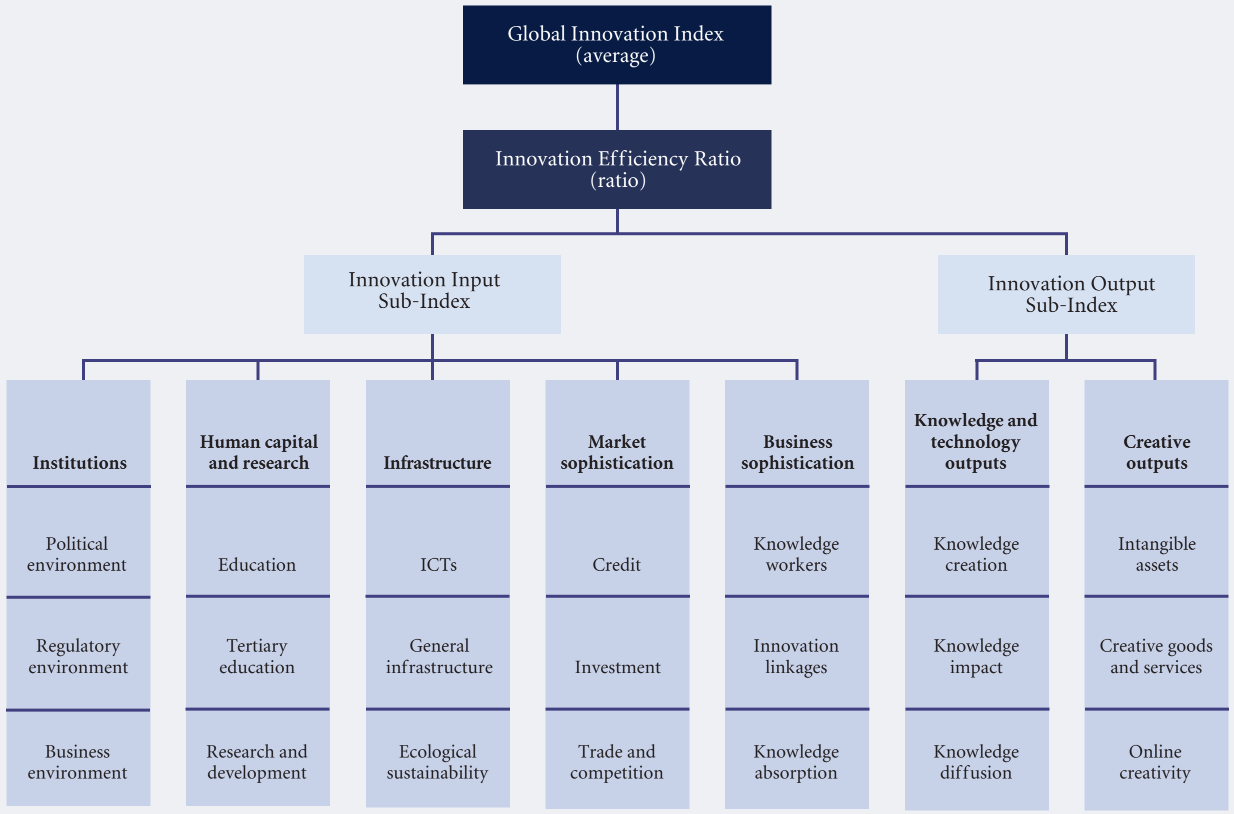
[19] The intensity of competition is included in Pillar 4.

Figure 6. **Framework of the Global Innovation Index 2014**



Source: [Cornell University et al., 2014].

Formal education is undoubtedly a crucial factor determining the quality of human capital but life-long learning and other informal modes of learning are also important. Research is conducted outside universities, too, both by publicly financed research organizations and businesses. Moreover, the quality of research conducted by these latter types of organizations is not necessarily lower than that at universities. Moreover, university rankings themselves suffer from several major methodological weaknesses. Thus, the name of this pillar is more 'ambitious' than its actual content.

Pillar 3: Infrastructure

Three sub-pillars form the third pillar of infrastructure: information and communication technologies (ICT), general infrastructure, and ecological sustainability. Sub-pillar 3.1 on ICT is computed by using four indices developed by international organizations on ICT access, ICT use, online service by governments and participation of citizens. Sub-pillar 3.2 on general infrastructure is composed of "the average of electricity output in kWh per capita; a composite indicator on logistics performance; and gross capital formation, which consists of outlays on additions to the fixed assets and net inventories of the economy, including land improvements (fences, ditches, drains); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings." Sub-pillar 3.3 on ecological sustainability is constructed by using three indicators: "GDP per unit of energy use (a measure of efficiency in the use of energy), the Environmental Performance Index of Yale and Columbia Universities, and the number of certificates of conformity with standard ISO 14001 on environmental management systems issued" [Cornell University et al., 2014, p. 47].

Ecological sustainability is certainly an important issue, but it is difficult to grasp why it is part of the "infrastructure" pillar, especially when it is measured by the above three components. These are more pertinent to environmental challenges that require innovation efforts or to the outcome of previous eco-innovation efforts. In other words, there is a certain mismatch between the name of this pillar and its actual content.

Pillar 4: Market sophistication

The fourth pillar integrates three sub-pillars "structured around market conditions and the total level of transactions." Sub-pillar 4.1 on credit intends to reflect, "the ease of getting credit aimed at measuring the degree to which collateral and bankruptcy laws facilitate lending by protecting the rights of borrowers and lenders, as well as the rules and practices affecting the coverage, scope, and accessibility of credit information." Transactions are measured by the total value of domestic credit to the private sector (as a percentage of GDP) as well as by the gross loan portfolio of microfinance institutions (as a percentage of GDP) with the intention to make the method applicable to emerging markets, too.

Sub-pillar 4.2 on investment is composed of the ease of protecting investors index and three indicators on the level of transactions. Besides stock market capitalization, the total value of shares traded (as percentage of GDP) is also taken into account to show if market size is matched by market dynamism. Data on venture capital deals (a total of 18,860 deals in 71 countries in 2013) are also used.

Sub-pillar 4.3 considers trade and competition. The market conditions for trade are measured by two indicators: the average tariff rate weighted by import shares, and a metric on the conditions of non-agricultural foreign market access (five major export markets weighted actual applied tariffs for non-agricultural exports). The last indicator, that is, the intensity of competition in local markets, is taken from a survey as: "Efforts made at finding hard data on competition have so far proved unsuccessful" [Cornell University et al., 2014, p. 48].

Pillar 5: Business sophistication

The fifth pillar is intended to capture the level of business sophistication to assess "how conducive firms are to innovation activity". Sub-pillar 5.1 on knowledge workers is composed of four indicators: employment in knowledge-intensive services; the availability of formal training at the firm level; R&D performed by business enterprise (BERD) as a percentage of GDP; and the percentage of gross expenditures of R&D (GERD) financed by businesses. Further, it includes an indicator taken from the Graduate Management Admission Test (GMAT): "The total number of GMAT test takers (scaled by population aged 20 to 34 years old) [was] taken as a proxy for the entrepreneurial mind-set of young graduates."

Sub-pillar 5.2 on innovation linkages exploits data on business-university R&D collaborations, "the prevalence of well-developed and deep clusters," the ratio of GERD financed from abroad, and "the number of deals on joint ventures and strategic alliances. The latter covers 2,978 deals announced in 2013, with firms headquartered in 127 participating economies. In addition, the total number of Patent Cooperation Treaty (PCT) and national office published patent family applications filed by residents in at least three offices is included this year to proxy for international linkages."

"The rationale behind sub-pillars 5.3 on knowledge absorption (an enabler) and 6.3 on knowledge diffusion (a result) — two sub-pillars designed to be mirror images of each other — is precisely that together they will reveal how good countries are at absorbing and diffusing knowledge. Sub-pillar 5.3 includes four statistical indicators that are linked to sectors with high-tech content or are key to innovation. These include royalty and license fees payments as a percentage of total trade; high-tech imports (net of re-imports) as a percentage of total imports; imports of communication, computer and information services as a percentage of total trade; and net inflows of foreign direct investment (FDI) as a percentage of GDP" [Cornell University et al., 2014, pp. 48–49; some obvious mistakes, e.g. mentioning GERD instead of BERD, have been corrected by the author].

The name of this pillar is not explained, although it does not seem to be self-explanatory. It is not clear either, why firms should be conducive to innovation activity. Usually analyses have a different logic: market and regulatory conditions, which are external to the firms, can be conducive for – or alternatively hamper – innovation activities performed by businesses. Further, it is difficult to accept the ratio of GMAT test takers "as a proxy for the entrepreneurial mind-set of young graduates." The name of sub-pillar 5.2 (innovation linkages) only partially matches its components, of which two concern R&D activities, and a third (on patents) is more relevant to R&D than innovation activities. Data on high-tech imports can only partially reflect knowledge absorption.

Pillar 6: Knowledge and technology outputs

Sub-pillar 6.1 on knowledge creation "includes five indicators that are the result of inventive and innovative activities: patent applications filed by residents both at the national patent office and at the international level through PCT; utility model applications filed by residents at the national office; scientific and technical published articles in peer-reviewed journals; and an economy's number of articles (H) that have received at least H citations."

Sub-pillar 6.2 on knowledge impact is meant to measure "the impact of innovation activities at the micro- and macro-economic level or related proxies: increases in labour productivity, the entry density of new firms, spending on computer software, and the number of certificates of conformity with standard ISO 9001 on quality management systems issued." The indicator on the share of high- and medium-high-tech industrial output in total manufacturing output features for the first time in this edition of the GII.

Sub-pillar 6.3 on knowledge diffusion "is the mirror image of the knowledge absorption sub-pillar of Pillar 5. It includes four statistics all linked to sectors with high-tech content or those that are key to innovation: royalty and license fees receipts as a percentage of total trade; high-tech exports (net of re-exports) as a percentage of total exports (net of re-exports); exports of communication, computer and information services as a percentage of total trade; and net outflows of FDI as a percentage of GDP" [Cornell University et al., 2014, pp. 49–50].

The first sub-pillar comprises indicators on "the result of inventive and innovative activities." Yet, most of these indicators are relevant to characterize R&D (and not innovation) activities. As for the knowledge impact sub-pillar, only one of the five components is related to knowledge impacts, and even that one is only partially: reflecting the impact of certain types of knowledge. As for the knowledge diffusion sub-pillar, all its four components can indicate knowledge diffusion outside a given country (with certain limitations), and thus none seems to be a relevant indicator of knowledge diffusion inside a given country.

Pillar 7: Creative outputs

The first sub-pillar on intangible assets includes data on trademark applications by residents at the national office; trademark applications under the Madrid System by country of origin; and results obtained via two survey questions on the use of ICTs by businesses.

Sub-pillar 7.2 on creative goods and services aims to capture creativity and an economy's creative outputs by using five indicators: i) cultural and creative services exports, including information services, advertising, market research and public opinion polling, and other personal, cultural, and recreational services, as a percentage of total trade; ii) national feature films produced in a given country per capita; iii) global entertainment and media output per capita; iv) printing and publishing output, as a percentage of total manufacturing output; and v) creative goods exports, as a percentage of total trade.

Sub-pillar 7.3 on online creativity is composed of four indicators among population aged 15–69 years: generic (biz, info, org, net, and com) and country-code top level domains, average monthly edits to Wikipedia, and video uploads on YouTube. "Attempts made to strengthen this sub-pillar with indicators in areas such as blog posting, online gaming, the development of applications, and have so far proved unsuccessful" [Cornell University et al., 2014, pp. 50–51].

It is not clear why "the use of ICTs in business and organizational models" is an output indicator. Only a small fraction of printing and publishing output is a creative output, with the bulk being revenues to cover printing costs (paper, other raw materials, and labour). It would be rather costly to establish what portion of video uploads on YouTube constitutes creative output.

In sum, the GII is a remarkable effort both in terms of its geographic and thematic coverage, but it suffers from severe weaknesses concerning business innovation activities. In several cases, there is a non-negligible mismatch between the 'headline' notions (pillars and their sub-pillars) and the actual components (indices or indicators) selected. Just as in the case of the EIS and IUS indicators, there is a bias towards R&D-based (ST mode) innovations, and thus the DUI mode is eclipsed. It is even worse when R&D and innovation are conflated. When it comes to describing and assessing social innovations, none of the 81 GII indicators are really fit for purpose.

Further methodological considerations

Degree of novelty, unit of analysis

A standard question in innovation surveys relates to the degree of novelty. A given innovation can be new to the firm, to the market (in a given country) or to the world. For pragmatic reasons, the Community Innovation Survey (CIS) uses only the first two categories: it would be too difficult to judge by the respondents — and subsequently get it checked by experts — if a given innovation is new to the market in a given country or the world. Of course, in rare instances such as the introduction of the first digital camera, mobile phone, or tablet, it would be easier to establish novelty; however, even in these exceptional cases there could be some difficulties to establish which product variation (by which company) has been introduced first — and which successfully.

This issue is related closely to the classification of innovations. In qualitative analyses the following categories can be used. New goods (that is, products or services) might represent an incremental or a radical change (innovation). If we consider further units (levels) of analysis, we can also think of innovations at the level of technology systems. This would include a set of technologically and economically interconnected goods and processes affecting several companies or an entire sector at the same time, occasionally leading to the emergence of new industries (e.g. canals, gas and electric light systems, plastic goods, electric household devices). Dissatisfied with the notion of 'long waves' used in analysing business cycles (mainly by Kondratiev and Schumpeter), Freeman and Perez elaborated on the notion of techno-economic paradigms:

> *"The set of the most successful and profitable practices in terms of choice of inputs, methods and technologies, and in terms of organisational structures, business models and strategies. These mutually compatible practices, which turn into implicit principles and criteria for decision-making, develop in the process of using the new technologies, overcoming obstacles and finding more adequate procedures, routines and structures. The emerging heuristic routines and approaches are gradually internalised by engineers and managers, investors and bankers, sales and advertising people, entrepreneurs and consumers. In time, a shared logic is established; a new 'common sense' is accepted for investment decisions as well as for consumer choice. The old ideas are unlearned and the new ones become 'normal'"* [*Perez*, 2010, p. 194].

As an illustration, the examples of such paradigmatic changes are the (first) industrial revolution; the age of steam and railways; the age of steel, electricity, and heavy engineering; the age of oil, automobile, and mass production; and more recently, the age of info-communications.

Some of these considerations might be useful when analysing social innovations in a qualitative way. Yet, compared to technological innovations, it is likely to be even more difficult to establish the degree of novelty of a given social innovation. The degree of novelty, however, seems to be of lesser importance in these cases: usually intellectual property rights are not an issue for social innovators. Of course, prestige — being inventive and obtaining acknowledgments for that — might play a role: it could give some impetus to be involved in certain social innovation projects. It is an empirical question to establish the role of prestige in these endeavours.

What seems to be perhaps more relevant but probably even more difficult than in the case of technological innovations is identifying whether a given social innovation is an 'isolated' new solution or a part of a new 'social system.' In other words, whether it is part of a set of socially, institutionally, organizationally, and economically interconnected social innovations that affect several groups of people or an entire community (a neighbourhood, village, town or city) at the same time. Occasionally, a new 'social system' can also lead to the emergence of new social structures, norms, institutions, behaviour, value systems and practices at a higher level of aggregation (e.g. sub-national regions, nations or even supra-national regions, for example, the European Union).

Some aspects of the notion of techno-economic paradigms are contested among economists and economic historians dealing with technological innovations, on the one hand, and this notion is probably too complex, too demanding – too far-fetched – to be applied to analyse social innovations, on the other. However, one of its features could be considered as a useful guiding principle when analysing social innovations, namely the interconnectedness of technological, organizational, and business model innovations, together with the emergence of a new, widely accepted 'common sense.'

Most of the indicators and indices used to compile the Summary Innovation Index (EIS, IUS), the Global Innovation Index, and the Technology Achievement Index [UNDP, 2001] reflect the macro level. These components are calculated by aggregating micro level data (e.g. economic indicators at the firm level, and education indicators at the level of individuals). In contrast, social innovations are usually monitored (observed) at a project level. It is hardly possible to aggregate these data (observations) in a meaningful way to arrive at the macro level.

Innovation activities, their framework conditions and impacts

Despite the relatively long-established tradition in measuring business innovations and the significant efforts devoted to advance and standardize methods, there is a considerable lack of clarity on whether a certain measurement or monitoring exercise (a set of indicators, data collection, measurement and analytical methods) aims to characterize: (a) innovation activities (efforts) themselves; (b) the framework conditions (e.g. pre-requisites, available inputs, skills) of being innovative (or successful in innovation efforts); or (c) the economic, societal, or environmental impacts of innovations. Given the complexity of innovation processes themselves, as well as that of economic, societal or environmental developments, it is certainly a major difficulty to attribute a certain economic, societal or environmental phenomenon as a direct (or major) effect of a given innovation project (or a set of them at an aggregated level).

These fundamental methodological difficulties certainly apply to social innovations, too, perhaps even *a fortiori*. Again, a noteworthy issue is the lack of conscious efforts to distinguish between measuring (a) social innovation activities (efforts) themselves; (b) the framework conditions (e.g. pre-requisites, available inputs, skills, norms, values, behavioural patterns) of being socially innovative; and (c) the economic, societal or environmental impacts of social innovations.

Composite indicators

There is a strong, often explicit, pressure to devise so-called composite indicators to compress information into a single figure in order to compile eye-catching, easy-to-digest scoreboards. A major source of complication is choosing an appropriate weight for assigning to each component. By conducting sensitivity analyses of the 2005 European Innovation Scoreboard (EIS) [European Commission, 2005], Grupp and Schubert [*Grupp, Schubert,* 2010, p. 72] have shown how changing weights de-stabilizes the rank configuration. Besides assigning weights, three other ranking methods are also widely used, namely: unweighted averages, Benefit of the Doubt (BoD), and principal component analysis. Comparing these ranking methods, the authors conclude: "Not only utilizing the rankings highly sensitive to weighting (…), but even using accepted approaches like BoD or factor analysis may result in drastically changing rankings" [*Ibid.,* p. 74]. Hence, they propose using multidimensional representations, e.g. spider charts to reflect the multidimensional character of innovation processes and performance. That would enable analysts and policy makers to identify strengths and weaknesses, and thus pinpoint more precise targets for policy actions.

Other researchers also emphasize the need for sufficiently detailed characterizations of innovation processes. For example, a family of five indicators — R&D, design, technological, skill, and innovation intensities — offers a more diversified picture on innovativeness than the Summary Innovation Index of the EIS [*Laestadius et al.,* 2005]. Using Norwegian data, they demonstrate that the suggested method can capture variety in knowledge formation and innovativeness both within and between sectors. Thus, it supports a more accurate understanding of creativity and innovativeness and directs policy makers' attention across various sectors, and directs policy makers' attention to this diversity (suppressed by the OECD classification of sectors).This suggested method, therefore, can better serve policy design.

These considerations could also be applicable to social innovations.

Conclusions

This paper has reviewed business innovation indicators from theoretical and policy perspectives. It has discussed two widely used sets of innovation indicators, their context and shortcomings, and considered whether they can be followed as a 'model' when designing social innovation indicators.

The main findings can be summarized as follows. Various economics paradigms treat (business) innovation in diametrically dissimilar ways: they consider different notions as crucial ones (e.g. risk vs. uncertainty, information vs. various forms, types and sources of knowledge, skills and learning capabilities and processes); offer diverse justifications (policy rationales) for state interventions; and interpret the significance of various types of inputs, efforts, and results differently. Thus, they implicitly identify different 'targets' for measurement, monitoring, and analytical purposes (what phenomena, inputs, capacities, processes, outcomes and impacts are to be measured and assessed).

The science-push model of innovation, reinforced by the sophisticated — and thus appealing and compelling — models of mainstream economics emphasizes the economic impacts of R&D-based innovation efforts, and advances the market failure argument and the concomitant set of policy advice. Hence, it focuses the attention of decision makers and analysts on the so-called ST mode of innovation. Measurement and monitoring systems influenced by this way of thinking — most notably the Innovation Union Scoreboard of the European Commission, the Global Innovation Index and the Technology Achievement Index [UNDP, 2011] – tend to pay attention mainly to the ST mode of innovation at the expense of the so-called DUI mode of innovation. It is a major concern, however, as the latter also plays an important role in enhancing productivity, creating jobs, and improving competitiveness.

In contrast, the evolutionary economics of innovation – in line with the networked model of innovation – stresses the systemic nature of innovation and thus advocates rectifying any systemic failure that hinders the generation, circulation, and exploitation of any type of knowledge required for successful innovation processes. This way of thinking has influenced the measurement and monitoring practices of the European Commission or the OECD to a significantly lesser extent than mainstream economics.

The IUS indicators could in principle be useful where the dominant mode of innovation is the ST mode. In practice, however, both the ST and DUI modes of innovation are important [*Jensen et al.,* 2007]. Moreover, the so-called Summary Innovation Index – calculated from the IUS indicators – does not provide sufficient information to assess a given innovation system: its low value could reflect either an overall low level of innovation activities or a low level of R&D-based innovation activities (while other types of innovations are abundant). Nevertheless, that is an important distinction from an analytical as well as a practical (policy) point of view: these two innovation systems are fundamentally different, necessitating bespoke policy actions. Analysts and policy makers dealing with innovation, therefore, should pay attention to both R&D-based (ST) and non-R&D-based (DUI) innovations.

Furthermore, while social innovations can certainly rely on R&D-based technological innovations, their essence tends to be organizational, managerial, and behavioural changes. The IUS indicators do not capture these types of changes. More generally, analysts and decision makers should be aware of the diversity of social innovations too in terms of their nature, drivers, objectives, actors, and process characteristics.

An assessment of the 81 indicators used to compile the Global Innovation Index has shown that it would not be fruitful to rely on any of the indicators to describe and characterize social innovations.

The Technology Achievement Index, presented in the 2001 edition of the Human Development Report [UNDP, 2001], has not been discussed in this paper, but it is worth recalling that it does not offer a promising approach as it is not a comprehensive measure: it considers only certain types of technological achievements and not those that are the most relevant from the point of view of human development [*Chiappero-Martinetti,* 2015; *Desai et al.,* 2002].

Some more general methodological lessons, however, can be distilled from the efforts devoted to measure business innovations. The first one concerns the use of composite indicators. Scoreboards and league tables compiled following the science-push logic, based on a composite indicator to establish rankings, and published by supranational organizations, can easily lead to 'lock-in' situations. National policy makers – and particularly politicians – are likely to pay much more attention to their country's position on a scoreboard than to nuanced assessments or policy recommendations in lengthy documents, and hence this inapt logic is 'diffused' and strengthened at the national level, too, preventing policy learning and devising appropriate policies. Despite the original intention to broaden the horizon of decision makers by offering internationally comparable data, these scoreboards and league tables strengthen a narrow-minded, simplifying approach.

In other words, given the diversity among innovation systems, one should be very careful when trying to draw policy lessons from the 'rank' of a country as 'measured' by a composite indicator. A scoreboard can only be constructed by using the same set of indicators across all countries, and by applying an identical method to calculate the composite index. Yet, it is important to realise that poor performance signalled by a composite indicator, and leading to a low rank on a certain scoreboard, does not automatically identify the area(s) necessitating the most urgent policy actions.

In contrast, a high rank on a scoreboard – such as Sweden's first place on the 2013 Innovation Union Scoreboard – does not necessarily reflect a satisfactory performance [European Commission, 2013a]. By taking into account the input and output nature of various IUS indicators, Edquist and Zabala-Iturriagagoitia [*Edquist, Zabala-Iturriagagoitia,* 2015] calculated the productivity of national innovation systems covered by the IUS. Using this assessment, which is undoubtedly highly relevant from a policy point of view, Sweden ranks a mere 24.

Analysts and policy makers, therefore, need to avoid the trap of paying too much attention to simplifying ranking exercises. Instead, it is of utmost importance to conduct detailed, thorough comparative analyses. It is crucial to identify the reasons for disappointing performance, as well as the sources of – and opportunities for — balanced, and sustainable, socio-economic development.

Second, the degree of novelty and the unit of analysis are interrelated issues when business innovations are surveyed. It seems a difficult task to establish the degree of novelty of a given social innovation. Actually, this issue seems to be of lesser importance in these cases: intellectual property rights are seldom an issue for social innovators. However, prestige – obtained by being acknowledged as a creative social innovator – might play a role. It could be perceived as an incentive to initiate social innovation projects. No doubt, it is an empirical question to establish the role of prestige in these endeavours.

It could be also an interesting and demanding research question to identify whether a given social innovation is a stand-alone new solution or (using the analogy of technology systems) a part of a new 'social system.' A 'social system' could be a set of socially, institutionally, organizationally, and economically interconnected social innovations that affect several groups of people or an entire community (a neighbourhood, village, town or city) at the same time. Occasionally, a 'social system' leads to the emergence of new social structures, norms, institutions, behaviour, value systems and practices at a higher level of aggregation such as at the level of sub-national regions, nations, or even supra-national regions (for example, the European Union).

Efforts aimed at measuring social innovation cannot rely on as long a tradition as those capturing technological innovation. The EC-funded 'Theoretical, Empirical and Policy Foundations for Social Innovation in Europe' (TEPSIE) project has contributed significantly to this goal. Although the proposed TEPSIE framework for measuring social innovation [*Bund et al.,* 2013] has not been analysed here, it should be noted that its first pillar ('entrepreneurial activity') is not specific to social innovation. It also somewhat neglects non-entrepreneurial social innovation activities. Its second pillar ('field-specific output and outcomes') offers useful recommendations; yet we are faced by the usual attribution problem in the case of social innovations. The third pillar is concerned with framework conditions. The structure of the TEPSIE indicators prompts a more general caveat: analysts and policy makers need to be aware of the differences between measuring: (a) social innovation activities (or efforts) themselves; (b) the framework for social innovations (pre-requisites, available inputs, skills, norms, values, behavioural patterns, etc.); and (c) the economic, societal, or environmental impacts of social innovations.

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Electronic ‘Knowledge Factories’ versus Micro-environment of Innovation: Who Will Win?

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Abstract

The end of the 20th century was marked by several studies that revealed the collective mechanisms of the knowledge development as a joint activity in working teams. Thus, the idea that acquiring knowledge was an unproblematic transfer of what is already available and can be unilaterally transferred and assimilated was rejected [*Lave, Wenger,* 1991]. The aim of this paper is to study the opportunities persented by electronic network platforms for using the collective nature of knowledge in the interests of further developing knowledge and innovation through online communication of professionals.

Based on a literature review on the development of knowledge, the paper compares the basic principles of knowledge application in formulating new decisions during real joint activity and during online communication within specialized platforms for ‘knowledge exchange’. The author argues that electronic networking platforms contribute to the fragmentation of knowledge representation of participants, eluding a common sense and purpose. Thus, such platforms blur the boundary between knowledge and information. The article indicates that the desire to increase the effectiveness of collective creativity via online communication risks not developing competencies, discretion, and exploration of others’ experiences. Instead, this desire leads to strengthening external control and separation of functions into primary routine operations when an individual participant is valued not for his/ her knowledge and previous experience, but for his/ her communicative capabilities. The produced effect is akin to the industrial revolution of the machine era; when this effect is widespread, there are risks that knowledge workers will be turned into easily replaceable, piecemeal workers. To avoid this, electronic platforms should either learn to recreate the conditions of offline micro-environments of innovation, or not claim to fulfil the role of knowledge production.

Keywords: knowledge; innovation; joint activity; electronic platforms; communities of practice; communication; connection; working team; social interaction
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Innovation as a Process of Social Interaction

Researchers in the field of science and innovation have focused mainly on questions of science and technology policy for a long time, with social interaction in groups of workers being left 'on the back burner.' As a result, many scholars argue that innovations, as a joint activity, are something of a 'black box' [*Brown, Duguid,* 2001; *Howaldt, Schwartz,* 2010], and that 'after Schumpeter innovations were reduced to technical innovations' [*Howalt, Schwartz,* 2010; *Rammert*, 1997].

In many ways, the difficulties faced by innovation researchers can be explained by the lack of clarity surrounding knowledge, the latent nature of the collective mechanism for knowledge assimilation and development, and the close connection between innovation and the specific conditions in which it takes place. The situation is further complicated by the simplistic and rationalist identification of knowledge with academic books, guidelines, and data. The end of the 20th century was marked by a number of studies leading to a change in views on the collective nature of knowledge and its practical orientation. This was dubbed the 'practice turn' in social sciences [*Schatzki et al.*, 2001]. Theories such as Jean Lave and Etienne Wenger's 'communities of practice' [*Lave, Wenger*, 1991], actor-network theory [*Latour*, 2005] and organizational knowledge started to gain popularity. The notion of organizational knowledge was developed by Ikujiro Nonaka and Hirotaka Takeuchi based on their experience of Japanese corporations [*Nonaka, Takeuchi*, 1995]. Despite these differences of approach, the notion that knowledge development is an 'unproblematic process of transferring what is already available' – able to be unilaterally transferred from person to person and automatically assimilated – has been firmly refuted [*Lave, Wenger*, 1991]. Researchers have described this shift in social theory as a 'silent revolution' [*Gherardi, Nicolini,* 2000]. However, the spread of technologies allowing network-based electronic interaction between specialists, which has been recognized as giving fresh impetus to the development of collective knowledge, does not entirely justify these expectations and even at times leads to the results of previous studies on knowledge being rejected. The wide dispersion of participants, ease of initiating and ending virtual communications, textual form of expression, advantages of short communications and their dilution with hyperlinks and visual effects effectively promote the fragmentation of knowledge, the illusion of common sense, and the blurring of boundaries between knowledge and information. The question arises as to 'What can this lead to?' and 'How are we to overcome the 'growing pains' so that electronic knowledge development platforms can reproduce and increase the value of the social micro-environment of innovation?'

Many factors reflecting the social micro-environment of innovation can explain the development of collective knowledge theories in the 1990s. First, knowledge, its diffusion in a group and development within an individual can be latent [*Polanyi,* 1967; *Teece,* 1998; *Nonaka, Takeuchi,* 1995]. According to some empirical studies, knowledge is particularly important in the acquisition of new skills and development of innovations in organizations [*Nonaka, Takeuchi*, 1995].

Second, knowledge can be viewed as a 'dynamic human process of justifying personal belief toward the truth' [*Nonaka, Takeuchi,* 1995, p. 58]. This entails some effort on the part of the individual to set goals and engage in mental or real interaction with other people or the environment to guarantee the truth of a judgment. We can, therefore, view knowledge in a similar way to capital in Marx's theory as a self-expanding value, to counterbalance information, which is inert in nature. However, justifying the truth of knowledge takes place in combination with 'social learning systems' [*Wenger*, 2000], which enables non-specialist individuals in neighbouring fields to act in line with their achievements, thereby developing their knowledge as opposed to 're-inventing the wheel.'

Third, knowledge is 'situated,' that is, shaped by the empirical or experimental situation. Therefore, the notion of 'situated knowledge' or 'communities of practice' can be applied to any instance of knowledge development [*Lave, Wenger*, 1991; *Wenger*, 1998]. Regional innovation clusters have now exemplified the special conditionality of knowledge, particularly in relation to local or regional specifics [*Brown, Duguid,* 2000; *Porter*, 1998; *Batheld et al.*, 2004]. At the same time, the conditionality associated with a specific place is a special case of the properties and specificity of knowledge.

Fourth, knowledge is collective. According to J. Lave and E. Wenger, any assimilation and development of knowledge can be viewed as a joint activity between the initiator and more experienced specialists in the corresponding field. This applies equally to physical and intellectual activity, including science [*Brown, Duguid*, 2001; *Ryle*, 1949]. J. Lave and E. Wenger provided the simplest outline of the bilateral knowledge assimilation process – the newcomer is an active party in this process and therefore, the knowledge of all participants is refined and reformulated.[1]

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[1] At the same time, viewing knowledge from the position of group dynamics is important not only in sociology, but also in science, technology and innovation research, where the static approach is extremely widespread. For example, it can be seen through the undervaluation of the innovative potential of technological borrowing in developing countries. In this case, the fact that assimilation of any new technology assumes a simultaneous assimilation of knowledge and a change in the system within which the new technology is integrated is ignored.

Fifth, the collective nature of knowledge assumes 'engaged participation' rather than individuals with appropriate experience or general specialization [*Lave, Wenger*, 1991]. For there to be insight, participants need to be involved in solving a problem collaboratively [*Brown, Duguid,* 2001; *von Hippel*, 2009]. This is different to specific social connectedness (fleeting or more stable – which depends on the problem-solving conditions), which can be likened to an electrical circuit in physics, or to special attachment in social science. In fact, researchers use a different metaphor – 'prudent' or 'mindful participation', which combines joint efforts and a common focus on searching for solutions [*Hargadon, Bechky,* 2006].[2]

The Micro-Process of Knowledge Creation: The Story of Machinery Repairs

To illustrate this position, we will use the example described by Julian Orr [*Orr*, 1990] and analysed by John Brown and Paul Duguid [*Brown, Duguid*, 1991]. If there is an unexpected breakdown in an important piece of equipment, a worker will turn to a technical repairs specialist to repair it. The specialist does not have a ready-made solution; the solution emerges as a result of the interaction consisting primarily of an exchange of 'stories' of similar repairs and solutions in the past [*Brown, Duguid*, 1991; *Orr*, 1990].

The interaction between two workers with differing experience, one of whom cannot solve a new problem independently or is not aware of their problem-solving aptitude, can arguably be viewed as the unit or 'cell' of knowledge development. In this example, knowledge development and problem-solving actually emerges from dialogue between two people, which is comparable with the situation of professional communications on an electronic network[3]. How does this take place?

Narratives – the stories told by participants – occupy a central position in the dialogue. They serve as both a graphic and verbal form of making sense of the situation. At first glance, these are discrete examples from the past, but they are 'flexible universals', allowing a certain common sequence to be formulated from the components of the stories. Storytelling is simpler than looking at the situation analytically; but, of course, for this you would need to select an approach and the cause of the fault is unclear to the participants. In addition, a narrative provides holistic 'pieces' of experience which are richer than any analytical 'fall-out' could be, as a narrative is inscribed with subconscious elements of latent knowledge. The process of searching for a solution is akin to Freud's theory, where recalling past episodes and identifying hidden connections under the guidance of a psychoanalyst will reveal a patient's unconscious [*Freud*, 1920]. Similarly, in our example, by using imagination and latent knowledge of the two participants, stories of past breakdowns and repairs are 'patched together' into a new solution.

In theory, each participant could recall stories independently as a means to bring latent knowledge to bear on a new situation. But interaction speeds up the search for a solution. Contact with an experienced colleague:

- causes a partial *verbalization of the latent knowledge* held by each participant through narration;
- expands the variety of examples subtly *linked* to the current breakdown;[4]
- increases the intensity and emotional impact of memories;
- ensures the *continuity* of memories through mutual additions to the narrative and *gap-filling* in each other's experience.

An important condition of productive interaction between previously unacquainted workers with different specialisms is *a separate general sense* of what is going on (each participant has their own experience of repairing machinery breakdowns, which frame the scope of their interaction). Even less competent repair workers have their own unique experience, which allows for mutual understanding and dialogue. This would not have been the case in the other example presented by Orr, where the technician was the only professional among unskilled onlookers [*Orr*, 1998]. According to Orr the specialist's understanding of repairs is 'tacit,' since he is working alone. When a sociologist, as an uninformed outsider, asks the specialist questions, the responses will seem awkward. The technician would be forced to choose words which characterize his knowledge as 'tacit understanding.' The existence of a boundary object combining the experience of two participants, rather than the actual presence of people engaged in the work of the machinery, serves as the necessary precondition for joint progress towards a new solution [*Tsoukas*, 2009; *Bruni et al.*, 2007; *Bechky*, 2003].

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[2] Failure to comprehend the importance of connection in this context can lead to misinterpretation and misidentification of communities of practice from the presence of group attachment, personal relationships, etc. to the point of resembling a community [*Lindqvist,* 2005]. The gap between newcomers and experienced practitioners is perceived as a threat to the stability of the community [*Handley et al.,* 2006]. A group of innovators is a social group, but the relations between members are not the result of a community of self-identification and personal relations, but rather a common cause and joint knowledge.

[3] The ethnographic work of J. Orr and his best known book 'Talking About Machines' [*Orr*, 1996] highlights the importance of talking about work to develop knowledge. The forms these conversations take is the subject of this paragraph.

[4] The first two features tie in with I. Nonaka and H. Takeuchi's processes of knowledge 'externalization' (moving from tacit to explicit knowledge) and knowledge 'socialization' (moving from the tacit knowledge of one person to the tacit knowledge of another) [*Nonaka, Takeuchi*, 1995].

Networked Electronic Mediation for Knowledge Development

We will now turn to the current situation of electronic professional networks. Numerous justifications in social sciences as well as in innovation research have recognized the collective nature of knowledge and innovation.[5] In contrast, the value of collective interaction to develop knowledge and innovation in collaboration involving information and communication technologies (ICT) is almost undisputed. This is due to the aforementioned 20th century studies and, in part, the visible presence of multiple people on a single platform serving as documented proof of communications: blogs, chats, photographs, links, visitor statistics, 'friends' lists, 'followers', and page visitors. Such platforms are often larger than many conferences in terms of participant and contact numbers; further, the textual form of communications makes it possible to document the contribution of each participant.

In this respect, can we speak of a new stage in the successful assimilation of knowledge resources and the acceleration of innovation? To answer this, we need to understand what happens during professional dialogues using electronic resources and then compare the results with observations regarding face-to-face interaction.

Recent literature abounds in materials on virtual 'knowledge exchange and sharing' platforms. But the blemishes and failures can be explained by the fact that this experience is new, carrying natural defects in design or formulation of tasks by customers.

In discussions of the workings of electronic platforms, several key subjects tend to be examined:

- the creation of professional or thematic platforms bringing together professionals with a particular profile irrespective of their affiliation with organizations [*Pan et al.,* 2015; *de Kraker et al.,* 2013; *Phang et al.,* 2009; *Chen,* 2007; *Chiu et al.,* 2006];
- the use of corporate electronic resources for professional exchange between employees of a company [*Murphy, Salomon,* 2013; *Salminen-Karlsson,* 2014; *Gray et al.,* 2011, *Tiwana, Bush,* 2005];
- the use of social media for 'open user-driven innovation,' where non-professional consumers play a role in the development of new products initiated by companies [*Mount, Martinez,* 2014; *Füller et al.,* 2014; *Martinez-Torres,* 2014].

The variety of subjects partly reflects the myriad uses of electronic platforms. Thematic platforms are geared towards the integration of professionals and are almost closer to the idea of developing professional knowledge in and of itself. This mainly applies to corporate platforms, especially, in the way they are tied to the working conditions of a specific organization and the continuity of working processes in real life. Ultimately, the advantage of open innovation platforms is that innovation based on the contributions of users is both the primary aim and end result; and where there is innovation, there is knowledge development. We will now look at each variant in more detail.

Thematic Platforms

These platforms bring together professionals with a particular profile or specialty who are not connected through an organization. The literature identifies several common traits of these platforms.

First, platforms are categorized in terms of satisfying an individual's need for knowledge and their willingness to share this knowledge. The situation is often described as being similar to market supply and demand: at one end, there are individual demands for certain knowledge, and at the other, there are those who have the corresponding knowledge and are willing to share it. To describe this situation, we use terms characteristic of commodity markets, where the platform stands in place of the circulation of money. The most common word combinations are knowledge exchange, knowledge sharing, knowledge transfer, knowledge flows, knowledge providers, and knowledge contribution. Researchers see the task of developers as balancing these opposing movements: between knowledge seeking and knowledge contribution, knowledge demand and knowledge supply, knowledge sharing and knowledge seeking behaviour.

To establish a social quasi-market for knowledge, where everyone offers what they have and takes what they need, we need a larger number of participants on board and arrive at a platform of competent specialists. The development of knowledge management systems is considered essential to this process as they allow knowledge to be collected, accumulated and exchanged [*Pan et al.*, 2015].

There is a general consensus that for electronic knowledge exchange platforms to work successfully, we need to encourage the space for inquiries and opinions on such platforms. This confirms the fact that an electronic platform is not always used to develop knowledge or obtain information on a specific topic, even when the platform is thematic and the participants belong to a particular professional group. We

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[5] Innovation studies tend to study social process through the prism of the technical characteristics of the social capital.

also need external controls to check the match between inquiries received on the platform and industry specialization. It may have a content structure and team of experts and moderators who encourage creative content and reject irrelevant themes [*Pan et al.*, 2015].

As early as the late 1990s it was noted that searching for information is not the only or primary aim of participants in networked communities. Living in an information environment has become the natural form of passing time for people today. The literature uses various metaphors for this: 'information neighbourhood' [*Savolainen*, 1995; *Burnett*, 2000] and 'berrypicking' [*Bates*, 1989]. As a form of life and leisure, such activities can hardly be considered work or creative and have little in common with consulting a reference book. Characteristic forms of such activities include neutral behaviour (exchanging compliments and gossip), playful behaviour (jokes, word games) and emotional support. In turn, the search for information can also take on various forms: posting announcements, information inquiries, requests for business consultations, and work by managed project groups [*Burnett*, 2000].

The fact that the closest interaction in 'virtual communities of practice' is in pairs, where participants maintain each other's attention on common tasks, attracts particular attention. Moreover, the connection is stronger when the virtual communication is reinforced with contact in real life [*Pan et al.*, 2015], which points to the limitations of online communications. The capabilities of video links do not disprove this observation, but also serve as a necessary stand-in for face-to-face communication. Even group video links between working groups are mostly based on dialogues between two participants [*Salminen-Karlsson*, 2014].

According to developers of professional logistics networks [*Pan et al.*, 2015], giving an electronic platform all the properties of a social network (the ability to manage profiles and lists of friends, which is absent in forums) forms 'transactive memory' and social capital in participants [*Pan et al.*, 2015]. However, accumulating social capital is not the same as knowledge development. Some might point to the case of new virtual acquaintances whom we consult for information, help or even invite to solve a creative task, but this only implies that the main interaction does not take place on the platform. This is in fact more an example of service functions such as posting announcements and information inquiries. With a large number of participants, we can add candidate screening to this list, when searching for partners or consumers for offered services. In this way, new ideas can be tested, although this would primarily involve first impression assessments. More thorough testing and especially joint development of ideas through electronic discussions is unlikely due to the inability to check mutual engagement, participant competence, and a number of other conditions that will be examined in the following section.

Corporate Platforms

The natural precondition for the creation of corporate electronic platforms is a common subject-matter and common interests among the participants. Theoretically, it could provide the foundation for greater integration between participants than in thematic platforms, where contributors have no organizational ties to one another. Some of the most successful examples explored in the literature come from major corporations: Lockheed Martin (an aerospace company) and Pfizer (a pharmaceutical company) [*Murphy, Salomon*, 2013]. In the first case, platforms were developed in a top-down manner, and in the second, from the bottom-up. Researchers agree that both cases have recorded positive results from developing tools to externalize tacit knowledge. To achieve these results, an internal social network was set up that allowed specialized blogs, organized thematic discussions, and e-broadcasting. In addition, there was also the opportunity to directly share tacit knowledge through joint use of electronic bookmarks and collaborative development of specialized wiktionaries [*Murphy, Salomon*, 2013].

In both cases, the successes are linked to the fairly complex design of the platform. At Lockheed Martin, the platform was initially developed to solve corporate problems, and some of the internal platforms had access restrictions and anonymity was forbidden. The task was to overcome the problem of probable loss of knowledge once the groups of specialists working in geographically disconnected subdivisions retired. The inability to form such an archive would cause the company to lose all the experience it had accumulated over the years [*Murphy, Salomon,* 2013].

In turn, Pfizer solved the problem from the bottom-up: its platform was developed in several stages, implementing changes to its design and technical characteristics. Thus, the company gradually struck a balance between its staff's demand to share and integrate experience, and the managers' interest in improving worker and customer loyalty. Eventually, some of the content was made accessible to external participants. An 'exo-environment' was set up between company employees and stakeholders upholding professional concern for clients that increased client confidence. Thus, employees' knowledge development was tied in with stakeholder management.

These examples open up a new chapter in marketing, personnel management, and the strategic development of business organization as a whole. The experience of platforms can also be used at multi-national corporations to uphold common standards and working conditions in divisions located in different regions, particularly when businesses are based in countries with a different work and management culture.

At the same time, even these examples of best corporate practices raise a number of questions from the perspective of direct contribution to knowledge development. It is well-known that pricing specialists have turned to electronic platforms and have started to write blogs. However, what remains unclear is what knowledge has been exchanged, by whom, and how it has been learned. The corporate platforms themselves are innovations undoubtedly, but these innovations fall more within the realm of management than employees' knowledge development. The development of corporate wiktionaries does not appear to be a significant innovative contribution to employees' knowledge development at a micro-level. We can however be more certain of the increased level of awareness of the workings of different divisions or employees. At the same time, other researchers have shown that indirect contact and spatial dispersion between participants complicates active professional collaboration, even if the latter is a requirement of the work process [*Salminen-Karlsson*, 2014; *Batheld et al.*, 2004].

These examples suggest that mutual motivation on the part of workers to participate in professional exchanges of experience is important for corporate and non-corporate platforms in equal measure. However, companies have their own problems that need to be solved before the problem of employees' knowledge development is raised. If a company does not recognize the interests of its employees and underestimates the potential commonality between those interests in real life, developing platforms as a means to exchange experience and enhance communication between personnel can prove futile [*Venters, Wood*, 2007]. In addition, companies are interested in staff integration only to the extent that it satisfies their economic interests. They have little motivation to encourage the integration of employees and their knowledge, since this may pose a threat to the degree of control it has over both staff and knowledge [*Burton-Jones*, 2014; *Zuboff*, 1988]. In this regard, some researchers believe that diffusing the discourse of knowledge development can help to intensify the impact of managers and extract knowledge from employees 'carrying' the knowledge [*Adelstein*, 2007]. In view of these reservations, corporate electronic platforms can be a double-edged sword in knowledge management and, depending on the management's aims, be used to integrate and disintegrate workers' knowledge.

Platforms for Open User-Driven Innovations

Compared with the forms of electronic platform examined above, the workings of platforms for open innovations developed by users are more coherent, focusing on one subject and emphasizing effectiveness in terms of the platform's contribution to innovation. As opposed to abstract 'knowledge exchange,' innovation is the end goal and finite result of platform participants in the form of a developed product. Thus, researchers describe the interaction among participants in user-driven innovation as a 'powerful source of knowledge', 'knowledge synergy', 'crowd collaboration', 'collective intelligence' [*Mount, Martinez*, 2014] and 'aggregate knowledge' [*Füller et al.,* 2014]. At the same time, the recent experience of collective product development shows that it can be a vulnerable pursuit, unlike the collaboration of specialists both in real life and online.

Above all else, it is important to note that the participants involved in the collaboration are not professionals. Therefore, the effectiveness of user-driven innovations is highly dependent on the number of participants, the representativeness of the target groups of consumers, and their level of activity. The 'collective intelligence' of user-driven innovations is in a certain sense opposed to the professional approach. An individual's contribution has little value, and in fact is an example of 'e-tribalism' [*Kozinets*, 1999]. According to this view, the functional roles of participants increase: with 'tourists', 'socialites' or 'followers'; 'newcomers' – 'denizens' – 'elders'; 'lurkers', 'opponents', and 'developers'. [*Füller et al.,* 2014; *Kim,* 2000; *Kozinets,* 1999].

Another difference is that means of communication are the main attraction of consumer electronic platforms. 'Creativity' as such is demanded of some 'developers,' while the task of the end-user is simply to be a member of the group, to review, support or choose from different variants. The differentiation in functional roles muddies the picture somewhat, but the demands of the platform are not fundamentally different. Other studies on the workings of innovative teams using electronic resources also point to the higher importance of communication skills and greater number of contacts compared to the qualitative characteristics of partners [*Gloor et al.*, 2008].

Yet there are serious doubts as to whether such platforms increase the knowledge of participants since each participant is only a 'cog' in the collective process, and the end result is estranged from the participant in the same way as it is in one of Marx's capitalist factories. But the point is not whether this activity is without remuneration, but rather that each participant performs elementary actions that requires neither professional experience nor great intellectual effort, which is extremely removed from the vision of the overall development process for a new product. Therefore, we can hardly expect any qualitative increase in a participant's knowledge.[6] The increase in knowledge and the resulting innovation, as in the case with electronic corporate platforms, are in fact the management's: the management's knowledge and innovation [*Paton*, 2012]. Even an ardent propagandist of crowdsourcing such as Jeff Howe recognizes that given the poor ability of a 'crowd' to organize itself and apply its energy, knowledge, or economic resources, in user-driven innovations it is only effective if it is managed from the outside, as a crowd is unable to organize itself in crowdsourcing [*Howe*, 2008].

This does not reduce the value of user-driven innovation in any way. On the contrary, it allows companies to save resources, helps to increase labour productivity and satisfy client needs. The question is more of how this relates to knowledge. In crowdsourcing, users stand in place of professionals, as the carriers of specialist knowledge. In fact, this is another example of the common situation arising when the introduction of a new technology leads to reduced demand for qualified specialists in a particular field (say, marketing specialists or sociologists) and increases their demand in another field (e.g. managers or programmers). The roles of marketing specialists and sociologists converge or become routine, and consequently the demand for their knowledge falls.[7]

Despite the differences in the three types of electronic resources examined above, there are some common traits inherent in them all:

- Increasing the number of participants and the number of interactions between them are a common goal of electronic platforms and a criterion for their success (although perhaps not the only ones);
- Managers play a deciding role in ensuring that the platform operates effectively;
- External controls by the management are often tacit and anonymous in nature, and are implemented through the structure, design and variety of capabilities. For the user, in contrast, it appears as if they are given the freedom and tools to aid their creativity. More noticeable forms of control, including direct moderation and rejecting irrelevant content, become more necessary when external conditions interfere with managerial authority;
- In most cases, potential participants of platforms have no direct need for electronic or regular cooperation. As a result, updating and using the interests and real needs of people (for example, overcoming social and work-related isolation, a need for recognition of work achievements, satisfying consumer preferences, seeking out helpful acquaintances, or keeping in touch with colleagues and acquaintances offline) usually guarantee the success of electronic platforms;
- Joining a network and being a member is a primarily individualistic act, based on personal interests and individual choice. The subsequent creation of groups is mediated by the platform, and any integrated involvement is restricted by the conditions imposed by the platform;
- Textual communications tend to dominate the social interaction between participants.

Differences Between Professional Discussions Online and Offline: The Contribution to Understanding Knowledge

Examples from studies so far on electronic platforms only enable us to analyse comparable situations to a certain extent. The initiators behind the creation of platforms are pursuing differing aims; their declared and actual intentions may differ; and finally, we do not have all of the empirical evidence on the workings of electronic platforms. In this section, therefore, we will analyse the more common properties of professionals' interaction online and offline (provided that both situations have the ultimate goal of knowledge development). Needless to say, this analysis is not exhaustive.

Comparing stories of machine repairs (face-to-face interaction from within a work situation) with discussions of professional problems on specialized electronic platforms reveals a number of differences (Table 1).

While they are similar in many respects, strictly speaking, real and virtual communications differ greatly. The key differences in virtual communications are linked to the ease of switching to another commentator, hyperlinks, changing the subject and participant, time gaps, and the high role of chance, including the chance of being involved in the discussion itself. This often makes the communication and

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[6] Winners of competitions which demand serious creativity and extremely active communicators are exceptions to this rule. But any new knowledge held by these is linked not to the substance of any innovations developed through concerted efforts, but is attributed instead to the development of personal communications and team-working skills [*Martinez-Torres*, 2014].

[7] The displacement and/or deskilling of workers as a result of technological shifts is a serious topic for discussion, relating both to the machine era [*Braverman*, 1974] and modern conditions [*Paton*, 2012; *Bakhshi, Windsor*, 2015]. An example of possible displaced professions is given here for clarity. To understand precisely which types of profession can be displaced or affected in terms of their rights and to forecast professional shifts, we need to look at specific examples of technological substitution.

Table 1. **Main elements of professional communication: differences between online and offline forms**

Characteristic	Type of communication	
	Offline	**Online**
Externalization of tacit knowledge	Takes place directly through sharing stories that are directly linked to the work process	Some of the author's tacit knowledge may be revealed in the wording of a professional blog. Asymmetry in sharing knowledge between the blogger and commenters, reduce the mutual potential for knowledge development. Success depends on the purpose and design of the platform and the professional level of visitors. Bloggers and commentators are not connected by a common work process
Continuity over time	Yes	Possible, but not guaranteed. Barriers to continuity include pauses in between responses; discrepancies over time in the involvement of the necessary and competent specialists; the need to be on the platform at the right time and low chances of the blog being read on time.
Focus on a common subject	Strong, as participants are absorbed in the context of what is going on, which is easily controlled by all participants	Unstable and unequal for different participants, as they are outside the context of the subject being discussed[I], may not have experience in the field in question, even if they share the specialization. Without direct contact and the shared context, it is difficult to control attention
Mutual understanding	Visual, emotional, and verbal affirmation	Predominantly textual affirmation. It may be deferred over time, which can limit control of the participants' content by the blogger and reduce the level of devotion to the group's work. The presence of special symbols, graphic and sound effects to express emotions confirms the lack of emotional contact
Assessing the competence of a partner	Complex – based on practical actions, including joint activity, based on verbal contact and visual signs (outward attributes of the profession, reputation, indirect confirmation from third parties, artefacts)	Based on textual evidence: formal self-presentation of platform participants, content of blogs, involvement in discussions. Takes longer than offline. Depending on the extent to which the authenticity of the information provided by participants and competence and specialization of said participants is controlled by the platform, assessing the competence of a partner can be more or less reliable than offline. In the absence of strict controls by the platform, it is difficult to control or check the competence upon 'entrance'[II]. The most accessible methods of control by participants – friendships and closed groups – are relatively reliable.
Common goal of participants	Takes on a certain nature – to do, to solve, to repair, etc. Set specific work conditions, time constraints, and criteria for the result	Unclear or absent. Even overlapping common goals do not have to be linked to joint activities. Motivation is varied, and may go beyond the scope of professional activities, as well as significantly differ between the blogger's and commentator.
Involvement in joint activity	Clear in real conditions, with the possibility of exchanging tacit knowledge	Weak or absent. Specialist instruments (videos demonstrating skills and knowledge in real conditions, joint drafting of documents) make up for this shortcoming only partly, as this is not full-fledged work, but rather a demonstration of what has been done or could be done offline[III]
Nature of participation	'Engaged' [*Lave, Wenger*, 1991] or 'mindful' [*Hargadon, Bechky*, 2006]	Dispersed, characterized by a lack of engagement and attention. Discussants may not intend to profit from the experience under consideration, subsequently developing it online or offline
Participant make-up	Complete and known, which reinforces mutual help and responsibility	Not always known and can change, and the level of responsibility and mutual help is unpredictable

[I] This is true if the blog author and commentators do not work together offline. But we are looking at the standard case of online communication, when participants are generally not acquainted and interact remotely.

[II] In the Lockheed Martin example, for certain thematic areas, there are restrictions on participants accessing the discussions, as they are controlled by the platform conditions. The selection of relevant commentators increases the effectiveness of online communication, which is a rare practice as it requires special forms of control. The key reason for the restrictions imposed by Lockheed Martin is information secrecy [*Murphy, Salomon,* 2013].

[III] This is not related to the types of work that are initially carried out online or require remote work. These include, for example, website development and administration, electronic database processing and exchange, network analytics, preparing and running remote learning courses and hacking.

Source: compiled by the author.

the knowledge arising discontinuous and fragmented. As a result, online dialogues can bring benefits to business, while interim results – in the form of changing the direction of discussions or uncovering previously unknown properties – do not take the form of new knowledge and innovations. When it comes to the best professional practices online, such as developing knowledge and innovations, this is a significant drawback of electronic platforms.

Many researchers, including those who believe that this problem will be resolved in future, have remarked upon the important role played by contextual absorption and a continuous discourse. Key differences and problems lie in the fact that the unity of participants in online interaction is imposed from outside by the conditions of and conditions over the platform. Offline unity, in contrast, is set from within the work process – by the business or context shared by the participants in which they are situated as well as by physical objects, standards of work relations, and many other tacit circumstances. This is a component of the 'tacit knowledge' described by J. Orr.

There are two consequences of this. First, there is a contradiction between creative freedom and external control. Research on communities of practice has shown that rigid structuring from outside harms the development of knowledge in real life. To be successful there needs to be professional autonomy and discretion [*Thompson*, 2005; *Brown, Duguid*, 1991]. In online discussions, the external controls offset the lack of internal connection, meaning that they cannot be ruled out. Second, the general context of an online discussion is not a prerequisite but rather a result of said discussion, which calls into question the possibility of obtaining a full-fledged creative product from it.

The main distinction between online communications (in 'isolation' from the work situation) and direct offline dialogue that is 'immersed' in the context, lies in the loss of common sense and common goals. The exceptions are cases when people who work together use the same virtual platform: in which case they simply bring their work online. To discuss a complex work situation on a virtual platform, all of the circumstances surrounding the work need to be 'carried over', which in many cases is either not possible or not advisable.[8]

The move to a virtual environment partly causes a gap in natural relations between facts, events, and objects. These relations are present in artificial speech and narratives, so it is possible to share them online. However, on a blog or chat – the most widespread forms of online discussion – reproducing whole stories, let alone exchanging them, could be problematic. Disjointed comments can only poorly replicate real relations for others; the chain of discussion forms relations, but they do not fully reflect the experience of each of the participants. These are chance relations between commentators, which arise spontaneously during the course of the discussion. They are linked only by the theme of the blog, and are at times only linked to the utterances of certain participants who have 'digressed' onto new topics. Together they may have no sense of unity and are entirely abstract in nature.

Giving virtual platforms set up to exchange professional information the role of a 'knowledge exchange' instrument arguably constitutes a step backwards compared with 20th century groundbreaking studies on knowledge development done by Polanyi, Lave and Wenger, and Nonaka and Takeuchi. In essence, we are now seeing a repeat of the misunderstandings of the earlier period of social research on knowledge: no distinction is being made between information and knowledge. Knowledge transfer is equated with textual communications and the amount of knowledge received with the quantity of participants in a discussion or simply recipients of communications sent through the 'share' function.

When we study electronic platforms to understand knowledge, what stands out is an abstract rationalist side and the depersonalization of the personal contribution that was noted at the beginning of the mass computerization era [*Burton-Jones*, 2014; *Zuboff*, 1988; *Orr*, 2006]. With the emergence of electronic platforms, the collectivity and interpersonal connection between people are starting to take on a formal and abstract form. An electronic platform can perform the role of a quasi-market for knowledge, but knowledge itself is an easily broken down, alienable substance which can be 'transferred' or 'exchanged.'

If we follow the vector of this development into the future, we see the intellectual worker as a producer of creative eclecticism derived from unconnected fragments of other people's knowledge. Sources of knowledge can be likened to a 'second-hand goods market' for information, while electronic platforms are akin to 'knowledge factories.' Similar to the 'part-time worker' at a factory, a part-time knowledge worker in this imaginary world will produce memes and choose between developers offered by a computer. This 'knowledge work' is a call for the individual mastery and conversion power of innovative micro-groups. Small innovative groups are hardly likely to disappear even if circumstances develop in this way; however, they will start to behave like elite laboratories employing a small fraction of the skilled population. Whether this prospect will become reality, or whether small creative laboratories will serve as a micro-environment for innovation for an ever growing number of people deserting mass production, only the future will tell. Nevertheless, to increase the likelihood of this second scenario, electronic platforms should learn to recreate the conditions of innovative micro-environments existing offline, or they should not lay claim to the role of producing knowledge.

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[8] Lockheed Martin's corporate platform was intended to solve similar problems - the disclosure of knowledge by experienced engineers whose were locked in narrow working groups – 'silos' – due to the way in which work was divided or for the sake of secrecy. They assessed the effectiveness of the platform based on the number of workers over 40 years of age who had been invited to keep blogs [*Murphy, Salomon*, 2013]. At the same time, knowledge development assumes interaction, a return from listeners or blog readers, which should form a part of a blogger's virtual communities of practice, i.e. be able to reproduce what he or she has shared on the blog. This aspect of knowledge work has still not been studied.

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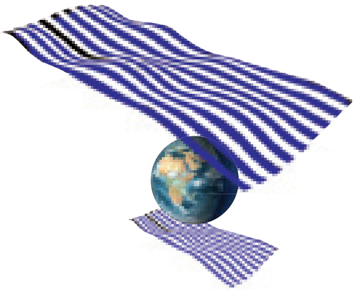

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