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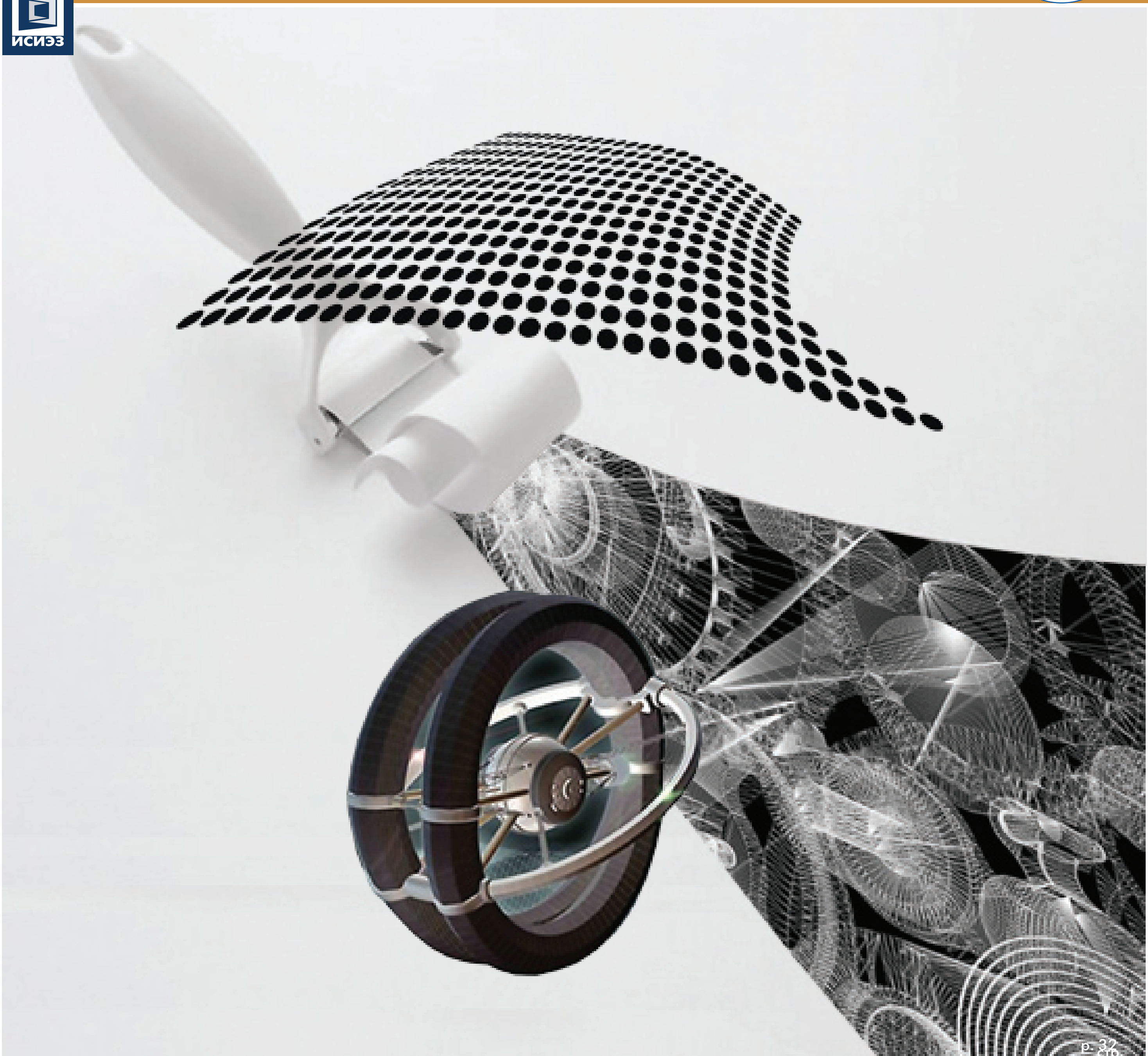

IN THIS ISSUE

Foresight-Russia

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About the journal

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.

TOPICAL COVERAGE:

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- Results of Foresight studies
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- State-of-the-art methods and best practices of S&T analysis and Foresight.

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Research scholars, university professors, policy-makers, businessmen, expert community, post-graduates, undergraduates and others who are interested in S&T and innovation analyses, Foresight and policy issues.

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Photo images – JPEG or TIFF format. Minimum resolution 300 dpi, image size not less than 1000x1000 pix

Charts, diagrams, line drawings- EXCEL or EPS format

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References to other publications must be in Harvard style and carefully checked for completeness, accuracy and consistency.

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Technological Landscape and Collaborations in Hybrid Vehicles Industry*

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Keywords

patent analysis; hybrid vehicles; collaborative research; hybrid electric vehicles (HEV); green car technology

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The production of hybrid vehicles has experienced intense growth in recent years. Carmakers invest significant resources into the development of advanced hybrid vehicles. The global prospects of this process can be estimated by systematically analyzing patents outlined in international patent databases.

The paper assesses the state-of-art and the future of the industry. Evidence from leaders in the development of hybrid vehicles demonstrates the productivity of the methodology for analyzing patent data developed by the authors.

The use of environmentally friendly energy sources represents a need that society must address. The fact that fossil fuels represent approximately 80% of overall fuel usage [*Sawin,* 2012] shows the extent to which society today depends on fossil fuels. Gas emissions have increased the effects of global warming, affecting the Earth and sea levels. Over the last 30 years, several hurricanes have occurred due to climate change, and the habitats of at least 279 species in the Arctic and Antarctic are threatened [*Márquez,* 2007].

The use of fossil fuels affects not only the air quality but also the quality of water, soil, flora, and fauna, causing environmental and social disasters [*Burns, Levings,* 1993]. Birds, fish, corals, and other marine wildlife are harmed by water pollution, often caused by oil spills. Fossil fuels produce chemicals and toxic compounds which alter the growth of plants and ultimately affect human health [*Marinescu et al.,* 2011].

These environmental problems require radical changes in the use of energy within the automotive sector. There have been extensive efforts to develop new technologies for hybrid vehicles in recent years to address these issues.

The US implemented important laws and policies focusing on zero emissions in the early 1990s (e.g. the Amendment to the Clean Air Act in 1990, the Energy Policy Act in 1992, and other regulations issued by the California Air Resources Board). Other initiatives for the development of hybrid vehicles were introduced in the early 21st century [US Department of Energy, 2005].

It is expected that the rise of emerging economies will lead to more demand for hybrid vehicles. The new opportunities for economic growth created in these

* We thank all of those who directly and indirectly provided academic support for the development of this research. In particular, we would like to thank the Advanced Manufacturing Research Group of Tecnológico de Monterrey. Additionally, we would like to thank Alejandro Palacios, Daniel Esquivel and Ana Marcela Hernández (Research Assistants) for their valuable time and support.

countries do, however, adversely affect the prospects for sustainable development. In this sense, hybrid electric vehicles (HEV) could play an important role, particularly in China, India, and in Western countries [*Porter et al.*, 2015].

The leaders in the automobile industry — namely, Toyota[1], Nissan, Honda and General Motors — have been creating new technologies in order to use renewable energy sources in their vehicles. According to Dijk and Yarime [*Dijk, Yarime,* 2010], the market for Hybrid Electric Vehicles (HEVs) became sustainable after 1995. Toyota introduced the Prius to the Japanese market in 1997, while Honda presented the Insight in California the following year. By 2002, the cumulaive HEV sales exceeded 100,000 vehicles and reached 1.5 million by 2008.

Since then, the major automotive companies have been increasingly involved in the development of ecological vehicles. More than 30 companies have emerged or expanded their efforts in the United States to provide pioneering solutions for vehicle pollution: Baker, Detroit Electric, GE, Studebaker, and Woods to name just a few [*Kraft,* 2012]. More than six million Toyota hybrid vehicles had been sold worldwide as of the end of 2013 [*Custommedia,* 2014a]. The *Nissan Leaf*, the first vehicle with zero emissions, achieved sales of 100,000 units and a presence in 35 countries between December 2012 and January 2014 [Custommedia, 2014b].

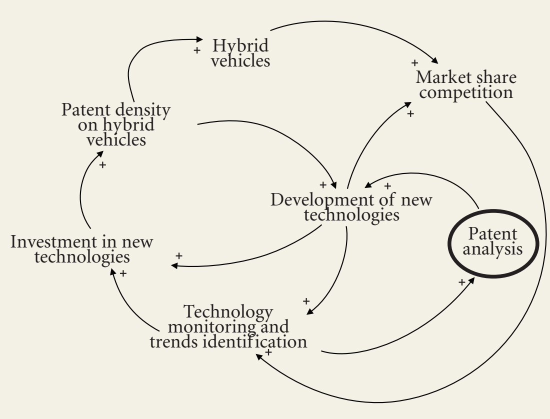
During the last few decades, automotive companies have increased collaboration to develop new technologies. Government initiatives play a key role. Japan planned to invest 21 billion yen (US$ 264 million) from 2009 to 2015. The 'Next Generation Vehicle Strategy' will support the development of new batteries used in electricity based vehicles. The US announced plans to invest US$136 billion in green energies (including green cars) from 2009 to 2018 through the Green New Deal initiative. The EU has invested 5 billion Euros (US$ 6.6 billion) to support the European Green Car Initiative announced in November 2008 [*Kwon, Jeong,* 2013].

Technological advances in the field of hybrid vehicles are clearly reflected in patents. Because of this, scientometric patent analysis is now often used to identify technological advances in the field.

This study complements patent analysis with the Systems Engineering approach to study hybrid vehicles patent activity. To implement this, we built a Causal Loop Diagram (CLD), which represents the elements of a system including its relationships and feedback dynamics [*Zemke,* 2001]. This method has been used for more than 30 years as a part of the Systems Thinking methodology [*Forrester,* 1961]. It envisions the organization as a system made up of individual elements, which creates a synergy effect. Using Vensim software [Ventana Systems Inc., 2006], we constructed a Causal Loop Diagram for hybrid vehicles as shown in Figure 1.

The greater the advances in hybrid vehicles, the higher the number of patents issued. Competition for market share will stimulate investments in new tech-

Fig. 1. **Causal loop diagram for hybrid vehicles**



Source: compiled by the authors using the Vensim software [Ventana Systems Inc., 2006].

[1] It should be mentioned that Toyota Motor Co. is the official English translation of the Japanese, Jidosha Kabushiki Kaisha [Toyota Motor Corporation, 2008]. Henceforth, in this paper we refer to this company by the English name.

nologies throughout the value chain — from leading companies to 'follower' companies. We will show below how collaborative efforts among companies in this field are key to succeed.

Patent analysis is a form of Competitive Technological Intelligence (CTI), which is applied to monitor the competitive and technological environment and to guide decisions regarding research, development and innovation activities.

In this paper, we develop a methodology for analysing patent activity which extends CTI and builds upon a previous study by the authors [*Rodríguez, Esquivel,* 2013]. The latter study revealed valuable insights about the technological advances protected by patents in the domain of hybrid vehicles. Additionally, it provides evidence that companies with a higher patent activity also have a strong focus on collaborative technology development.

The aim of this study is to support organizations in the field by identifying — in terms of patent density — the global research areas and emphasis of research categories (according to standard patent classifications), the top patenting organizations, the joint patents of the organizations with the highest patent activity, their technology collaboration efforts, patenting activity according to the type of hybrid vehicle and alternative energy sources, and finally, the most recent patents of top organizations regarding previous results.

The remainder of this paper is organized as follows. Section 2 reviews the literature on renewable energies, hybrid vehicles, and competitive technological intelligence. Section 3 describes the methodology used, and Section 4 presents the main findings. Finally, the conclusions, recommendations, and limitations of the study are presented in Section 5.

Literature Review

Renewable energy and hybrid vehicles

Energy problems caused by the exhaustion of fossil fuels have led to the advancement of green technologies, including mechanisms to be implemented in new vehicle systems.

Renewable energies

Renewable sources, such as wind power, geothermal heat, biomass, hydrothermal, and solar, are increasingly applied for industry and domestic purposes [*Rodríguez, Esquivel,* 2013] and their use in large and small-scale implementations is becoming increasingly important.

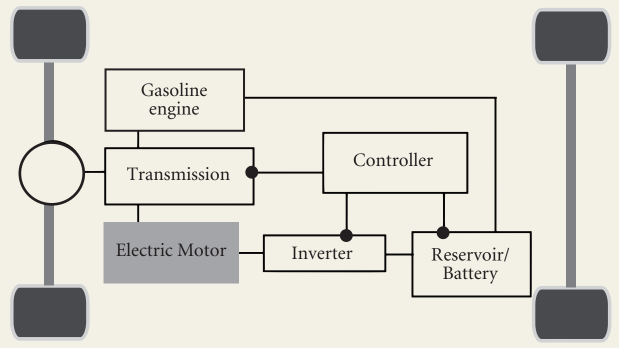
There is a clear need to develop intelligent power management systems to optimize the use of energy and reduce energy consumption. These systems are needed to control many applications, including electric systems in vehicles and hybrid vehicles [*Zhou et al.,* 2014]. According to Sewe and León [*Sewe, León,* 2010], the most popular alternative energy sources are: solar, wind, biomass, geothermal, and hydraulic. To reduce the negative impact of vehicle emissions, hydrogen, natural gas, ethanol, methanol, biogas, and gasoil energy sources can be used [*Momoh, Omoigui,* 2009]. Additionally, solar energy represents an important possibility for the propulsion of hybrid vehicles [*Khan,* 1994]. These elements were considered during the analysis. As we show later, the results obtained indicate that hydrogen and solar energy have the highest activity in patents. In light of this, we undertook a special analysis to identify the patent applicants working with different types of alternative fuels.

Hybrid vehicles and hybrid electric vehicles (HEV)

This section delineates the main characteristics of hybrid vehicles, including electric ones. Hybrid vehicles are vehicles with two sources of propulsion. The primary source is the combustion engine, while the secondary source is the high-voltage battery. The latter is typically an electric motor, although it can be any other renewable source [*Urdiales, Limón,* 2009]. The use of hybrid propulsion methods means that carbon emissions can be reduced. The most successful hybrid vehicle configuration is the hybrid electric vehicle which combines the internal combustion engine with an electric motor.

Hybrid vehicles are an increasingly important factor for protecting the environment. The evidence for this has been discussed for more than a decade [*Boesel,* 2013]. As pointed out above, one major trend in this market is the increase in research and development (R&D) due to new state initiatives for hybrid vehicles [TechNavio 2014].

Fig. 2. **Parallel hybrid system**



Source: [*Emadi*, 2005, p. 23].

Three types of hybrid vehicles can be identified, as described below [*Sewe, León*, 2010; *Emadi*, 2005]:

(1) Parallel hybrid (Fig. 2). These vehicles are the most economical and popular on the market. Their architecture is widely used because the propulsion architecture is similar to a conventional vehicle. The hybrid system serves as a kind of add-on structure [*Emadi*, 2005].

(2) Series Hybrid (Fig. 3). As Emadi [*Emadi*, 2005] highlights, the series hybrid propulsion system has yet to find acceptance in gasoline and diesel electric passenger sedans and light trucks. This may be partly because the architecture here is heavier and more expensive than its parallel and combination architecture alternatives.

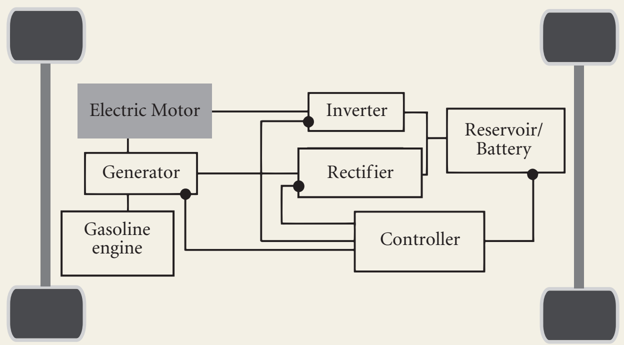
(3) Series-Parallel Hybrid (Fig. 4). Emadi [*Emadi*, 2005] states that the primary three advantages of this architecture are: i) the relatively simple transmission mechanism; ii) the engine speed can be confined to a narrow operating range through control of the motor generator A; and iii) the engine can be further downsized. The Toyota Prius is a typical example of this kind of architecture.

Competitive technological intelligence

Competitive Intelligence is a systematic and ethical process for gathering and analyzing information about the activities and general business trends to improve the performance of the involved organization [*Moretti*, 2004]. Once analysed, the information provides data on the behaviour, strengths, and weaknesses of competitors, as well as technological and other issues concerning the competitive environment to establish parameters for innovation areas. Competitive intelligence is a useful tool to understand the direction in which technologies are evolving [*Calof et al.*, 2015].

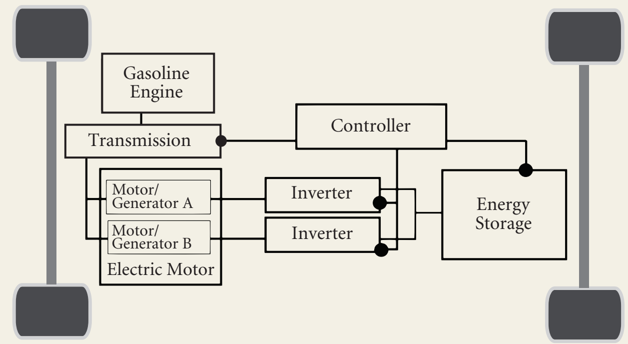
The society of Strategic Competitive Intelligence Professionals (SCIP) defines competitive intelligence as an ethical and systematic process to find information with specific tasks, such as analysing and managing information that may affect

Fig. 3. **Series hybrid system**



Source: [*Emadi*, 2005, p. 29].

Fig. 4. **Series-parallel hybrid system**



Source: [*Emadi*, 2005, p. 31].

the plans, decisions or operations of the company with the purpose of acting in a relevant, accurate, specific, and timely manner [*Brody*, 2008].

Similarly, Van Brakel [*Van Brakel*, 2005] defines competitive intelligence as a business discipline applied by companies and countries as a means to improve their competitiveness through the better use of information. One of the main benefits of this activity is to reduce risk when making decisions and to identify opportunities and threats that exist in the competitive marketplace.

Additionally, Rodríguez and Tello [*Rodríguez, Tello*, 2012] include technology in the concept of competitive intelligence and define it as Competitive Technological Intelligence (CTI): the process for monitoring the competitive and technological environment of an organization to support strategic decisions, especially those related to market, innovation, product design, and research and development. Companies should constantly innovate in the products and services they offer because consumer needs change [*Rodríguez, Esquivel*, 2013]. In particular, CTI provides a methodology to systematically monitor competitors, research entities, and universities to better understand R&D advances.

Patent analysis

CTI is developed through an analysis of primary (field research, including interviews) and secondary (articles, patents, reports, news) official information. Patent analysis is a critical element of CTI in research extensive fields, such as hybrid vehicles. The number of patent applications and patents granted are valuable statistics for understanding inventive activity of a given technology market [*Streltsova*, 2014]. Insights from patents reveal the leading companies, their research areas, the claims of intellectual protection, and emerging areas. Thus, actionable knowledge is obtained to identify opportunities or threats to innovation [*Rodríguez*, 2003]. Patent analysis also provides a means to predict product maturity and market trends [*Trappey et al.*, 2010]. Open patent data can illustrate research trends and future advances, and can also support corporate strategic decision making, the R&D sphere, and policy making [*Denisova et al.*, 2011].

To safeguard their exclusive right to their invention, which then allows them to own the exclusive rights to produce and market it, organizations or individuals can protect it through a patent. Thus, patent analysis is often used to monitor the R&D portfolios of competitors, and to analyse the global evolution of industries and companies [*Lai et al.*, 2006]. Moreover, it also provides knowledge to reduce the duplication of inventions, avoid patent infringement, and identify technologies to be licensed.

Patent analysis is frequently used by the most innovative companies to support decisions about mergers and acquisitions, determine competitors' areas of expertise, identify competitive trends (including the prioritization of R&D efforts), and finally, to strengthen the overall strategic planning process [*Ramos*, 2011].

There are several methods for patent analysis [*Trappey et al.*, 2011]. These include patent mapping, clustering, and life cycle analysis. Data mining tools are often used in patent analysis because they facilitate the processing of hundreds of bibliographic record fields (e.g. title, applicant, author, country). Besides, specialized software is required: several options exist on the market, including Gold Fire Innovator, Matheo Patent, Patent Insight Pro, and Vantage Point. Data mining software enable researchers to collect, synthesize, analyse, classify, and display information more efficiently. It is important to do a detailed analysis in order to determine which software best fits a specific project's requirements [*Lugo*, 2008]. Interpretation of patent maps requires an expert of the field; this operation cannot be fully automated regardless of the quality of the software [*Lee et al.*, 2006].

Patent analysis of hybrid vehicles

Numerous patent analysis studies have been made in this field since the early 2000s [*Ranaei et al.*, 2014]. However, only a few studies have applied this tool for hybrid vehicles. Porter and his colleagues [*Porter et al.*, 2015] applied a patent analysis tool as an input to a forecasting exercise on hybrid and electric vehicles. The authors analysed patent information from 2000 to 2012 through the Derwent World Patent Index, via Thomson Innovation. Results showed that intellectual property production on HEVs is led by the US, Japan, and Germany. On the other hand, Kwon and Jeong [*Kwon, Jeong*, 2013] analysed patent applications for green cars in the United States, Japan, Europe, Korea, and PCT international applications from 2000 to 2011. Patent information was searched for using WIPS (www.wipsglobal.com). The scope of the analysis on green car patents included electric vehicles (EV), plug-in hybrid electric vehicles (HEV), fuel cell electric vehicles (FCEV), and clean diesel vehicles (CDV). The US and Japan demonstrated the most prominence in hybrid vehicles research, followed by Korea.

Additionally, Ranaei et al. [*Ranaei et al.*, 2014] carried out a patent analysis on low emission vehicles. This study covered the time period from 1994 to 2013, and analysed patents related to battery electric vehicles (BEV), HEVs, hydrogen vehicles (HV), and fuel cell vehicles (FCV). Its authors calculated the growth technology curves. As a result, they estimated a steady increase in low emission technologies, including hybrid and battery electronic vehicles. However, the authors predict that this industry could reach a saturation point in a few decades.

We will further discuss the main findings of the two mentioned studies on hybrid vehicles [*Kwon, Jeong*, 2013; *Ranaei et al.*, 2014], then we present our results (section 4 below).

Derwent innovations index

The Derwent Innovations Index is a reference for many companies and research entities. It belongs to Thomson Reuters, a private database that contains patent applications and grants covering over 14.3 million inventions from 40 patent-issuing authorities worldwide. Tracking information for over 40 years, it includes information from the European Patent Office, Japanese Patent Office, the US Patent and Trademark Office, PCT (WO), etc. The Derwent Innovations Index is a highly valuable resource to better understand technological progress over time [Thomson Reuters, 2014b]. Information from patents, including that in Derwent, is an excellent way to analyse the behaviour of a given technology [*Mogee*, 1991].

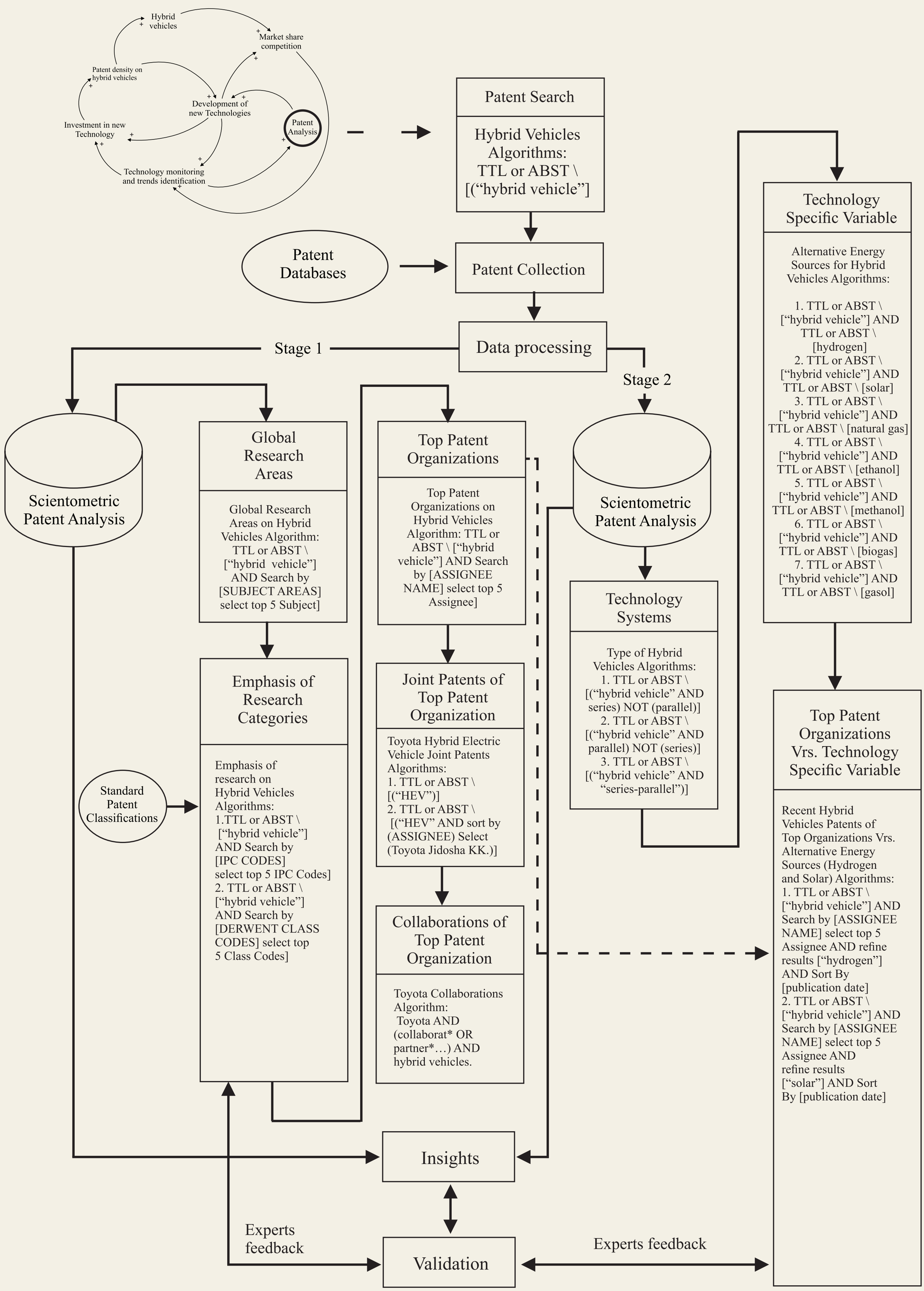
Methodology

The main purpose of this study is to develop a patent study on hybrid vehicles as an initial approach to identify the patent density in this field and the collaborative efforts of organizations with the highest patent activity, including identifying these organizations' strategic partners and the most recent patents. This paper contributes to ongoing research on hybrid vehicles with the aim of adding value to organizations interested in this field.

This study was developed by the research group on Competitive Technical Intelligence of Tecnológico de Monterrey, Campus Monterrey. Tecnológico de Monterrey is a prestigious private institute with over 30 campuses in Mexico, over 100,000 students, and more than 8,000 teachers and liaison offices in North America, Europe, and Asia. The headquarters are located on Monterrey Campus, where the main research efforts of this Institute are performed.

Based on the Systems Engineering approach, the study developed a scientometric methodology to examine the technology advancements through patent analysis. Figure 5 illustrates this methodology, consisting of interrelated phases through

Fig. 5. **Methodology for a systemic technology patent analysis**



Source: created by the authors.

a systematic process. The first stage consists of an initial patent search about the technology examined. This information could be collected from different patent databases such as Espacenet, USPTO, etc. Next, the data are processed to eliminate duplicates and irrelevant information. The second stage entails a scientometric patent analysis using special software. This activity is developed in two phases. The first phase identifies the key global research areas, emphasizes research categories (taking into account the different standard patent classifications), top patent organizations, joint patents of the organization identified with the highest patenting activity, and their technological collaboration efforts. The second phase identifies the patenting activity according to different technology systems: in this case, the type of hybrid vehicle. A posterior analysis is made to integrate a specific variable depending on the purpose of the study; in this case, the types of alternative energy sources were taken into account. Subsequently, a specific analysis of recent patents based on the previous variable is made considering leading organizations. Finally, it is important to emphasize that feedback from experts in the field is required throughout the whole process. Moreover, a final validation should be made to acquire new perspectives and enriching insights.

We developed a case study of hybrid vehicles, applying the Derwent Innovations Index of the ISI Web of Knowledge [Thomson Reuters, 2014a]. As shown in the Introduction, we created a Causal Loop Diagram to delineate the different parts making up the system of this study. Under this approach, a two-stage process was performed. The first included determining the number of patents for hybrid vehicles. For this, we took the time period from 2000 to October 31, 2014. Data collection was based on patents containing the term 'hybrid vehicle' in the field 'Topic' (title and abstract).

A total of 40,023 patents were obtained. These data were processed to eliminate duplicates, irrelevant information and standardize fields such as organizations' names. Next, the predominant global research areas were identified taking into account the Derwent classification. Subsequently, the emphasis of research was determined considering the International Patent Classifications (IPCs) and the Derwent Class Codes (DCCs). The leading patent applicant organizations were also identified.

The results indicate that automotive companies are the major players for technology inventions. Other entities (e.g., universities, research centres, and government agencies) that undertake their own R&D in this area have a lower impact in terms of patent applications. In this context, joint patents and technological collaborations of the leading patenting companies in the energy sector were analysed. To accomplish this aim, internet-based research identified the collaboration agreements in the energy sector. All the information gathered was processed to eliminate irrelevant information and prepare it for the analyses. The second stage performed specific analyses, and determined the patents corresponding to the different types of hybrid vehicles (parallel, series, and series-parallel) to then identify renewable energies. Recent patents of the leading patent applicant companies were identified according to the alternative energy sources with the highest number of patents. Finally, all the information was analysed and relevant insights were generated. The findings of this research were validated by experts in the field. Their feedback was useful and led to new perspectives and knowledge.

In the next section, we present the results of the case study.

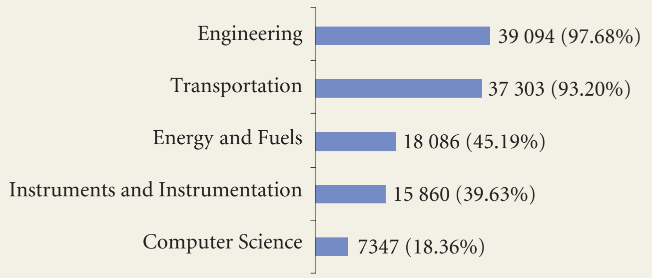
Discussion and Results

First stage

Global research areas

A total of 40,023 patents were obtained on 'hybrid vehicles'. As mentioned previously, the first stage of this analysis aimed to identify the general focus of research; to this end, we used the standard Derwent classification. As a result, the following patent global research areas were determined: Engineering (39,094 patents); Transportation (37,303 patents); Energy and Fuels (18,086 patents); Instruments and Instrumentation (15,860 patents); Computer Science (7,347 patents). The results are shown in Figure 6.

Fig. 6. **Number of patents by key global research areas in the field of hybrid vehicles, 2000–2014, based on the Derwent classification***



*As patents could belong to more than one area, the sum of the percentages exceeds 100%.

Source: authors' calculations.

Emphasis of research based on the top international patent classification (IPC)

The IPC, established by the Strasbourg Agreement of 1971, provides a hierarchical system of language-independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. The IPC divides technology into eight sections with approximately 70,000 sub-divisions. Each sub-division has a symbol consisting of Arabic numerals and letters of the Latin alphabet.

An IPC with more digits (numerals and letters) is more specific. The minimum number of digits is four, providing only a broad patent classification. Patents can belong to more than one IPC. The development of hybrid vehicles implies the use of technologies from a diversity of areas, so a high technical diversity is present as shown by Kwon and Jeong [*Kwon, Jeong*, 2013].

In our study, we identified the leading categories of research based on detailed IPCs. The top five main IPCs of hybrid vehicles are shown in Table 1.

The results indicate that research is mainly focused on control systems for hybrid vehicles, as illustrated by IPC B60W-020/00, followed by electric vehicle propulsion systems (represented by IPC B60L). Insights from Kwon and Jeong [*Kwon, Jeong*, 2013] indicate a similar trend: electric vehicle propulsion systems (B60L), power transmission systems (B60K), and control systems specially adapted for hybrid electric vehicles (B60W).

Emphasis of research based on the top Derwent Class Codes (DCC)

We also determined the patent categories based on the standard Derwent Innovations Index classification. DCCs classify patent documents into 'Chemical Sections' (AM), 'Engineering Sections' (PQ), and 'Electrical and Electronic Sections' (SX). The Top 5 DCCs are shown in Table 2.

Table 1. **Top patent categories of hybrid vehicles based on the IPC-WIPO system**

IPC	Patents	Share (%)	Description*
B60W- 020/00	9141	22.84	Control systems specially adapted for hybrid vehicles, i.e., vehicles having two or more prime movers of more than one type, e.g., electrical and internal combustion motors, all used for vehicle propulsion
B60L- 011/14	6861	17.14	Electric propulsion with power supplied within the vehicle (B60L 8/00, B60L 13/00 take precedence; arrangements or mounting of prime movers consisting of electric motors and internal combustion engines for mutual or common propulsion with provisions for direct mechanical propulsion
B60W-010/08	6126	15.31	Conjoined control of vehicle sub-units of different types or different functions (for the propulsion of purely electrically propelled vehicles with power supplied within the vehicle including control of electric propulsion units, e.g. motors or generators
B60K-006/00	5685	14.20	Arrangement or mounting of plural diverse prime-movers for mutual or common propulsion, e.g., hybrid propulsion systems comprising electric motors and internal combustion engines
B60W-010/06	5182	12.95	Conjoined control of vehicle sub-units of different types or different functions (for the propulsion of purely electrically propelled vehicles with power supplied within the vehicle, including the control of combustion engines

* The data in column 4 are from Section B — *Performing Operations; Transporting.*

Source: [WIPO, 2014b].

Table 2. **Top patent categories based on the Derwent Class Codes**

DCC	Patents	Share (%)	Description
X21	35 296	88.19	*Electric Vehicles (B60L)*. Electric cars, trolley buses. Propulsion, braking. Power supply lines, current collectors. Traction batteries. Control equipment.
X22	19 624	49.03	*Automotive Electrics (F02P)*. Vehicle accessories. Vehicle lighting. IC engine ignition. IC engine controllers. Batteries and charging. Starting motors, and generators. Engine and vehicle instrumentation. Non-engine related controllers e.g., transmissions, brakes.
X16	11 618	29.03	*Electrochemical Storage (H01M)*. Primary, secondary, and fuel cells and batteries. Battery chargers. Non-electrochemical storage of electric energy.
T01	7415	18.53	*Digital Computers (G06C-F)*. Electronic data processors, interfaces, and program control. Mechanical digital computers.
L03	4977	12.44	Electro-(in)organic, chemical features of conductors, resistors, magnets, capacitors and switches, electric discharge lamps, semiconductors and other materials, batteries, accumulators, and thermo-electric devices, including fuel cells, magnetic recording media, radiation emission devices, liquid crystals, and basic electric elements.

* The data in column 4 are from Derwent Innovation Index.
Source: [Thomson Reuters, 2009].

As with the IPC analysis, patents can also belong simultaneously to multiple categories of the DCC. The general classifications X, T, and L are the most important; in this system, these classifications correspond to the following topics:

- Electrical and electronic sections (S-X):
  - X: Electric Power Engineering
  - T: Computing and control
- Chemical sections (A-M):
  - L: Refractories, ceramics, cement and electro-(in)organics.

Although the IPCs and DCCs have different underlying principles, the results of both analyses were similar, particularly regarding the inclusion of electric power engineering, computing, and control systems.

Top patent organizations

An analysis was performed to determine the entities with the highest number of patents. Results indicated that automotive companies have more technological advances in hybrid vehicles compared to academic institutions. As shown in Figure 7, the top three patent recipients were: Toyota (13,266 patents), Nissan (2,397 patents), and Nippondenso (1,956 patents).

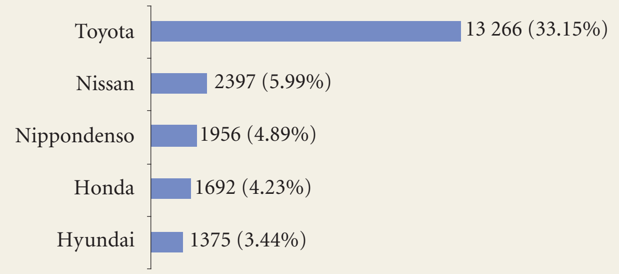
These results confirm the findings obtained by Kwon and Jeong [*Kwon, Jeong*, 2013]: Toyota Motor is the leader for patents in the field of hybrid vehicles, while Hyundai Motor and Honda Motor present a near-average patent density.

In addition, our results are also comparable to the findings of Ranaei et al. [*Ranaei et al.*, 2014] where in terms of battery electric vehicles (BEV), hybrid electric vehicles (HEV), and patents related to hydrogen vehicles (HV) or fuel cell vehicles (FCV), Toyota led due to its highest patent activity, followed by Nissan and Honda.

Toyota joint patents

A specific analysis on HEV of the top patenting company was made, in this case it was Toyota. We first identified the HEV patents between 2000 and 2014. Out of a total of 1,883 patents, 45 belonged to Toyota. Next, we analysed the joint Toyota patents to identify partnerships. Our results are presented in Table 3.

Fig. 7. **Number of patents in the field of hybrid vehicles received by the patent-leading companies in 2000-2014**



Source: authors' calculations.

Table 3. **Toyota Joint Patents on HEVs**

Toyota's Partner	N° Patent*	Publication Date*
Sanyo Electric Co. Ltd. (Saol-C)	JP2014093127-A	19.05.2014
Sanyo Electric Co. Ltd. (Saol-C)	JP2013157104-A	15.08.2013
Sanyo Electric Co. Ltd. (Saol-C)	JP2013157130-A	15.08.2013
Aisin Seiki KK (AISE-C)	JP2011244529-A	01.12.2011
Yokohama Nat. Univ. (Uyyo-Non-standard)	JP2011097740-A	12.05.2011
Fujitsu Denso Ltd. (FUTD-C)	JP2010102944-A	06.05.2010
Aisin A.W. Co. Ltd. (AISW-C)	JP2009067256-A	02.04.2009
Matsushita Denki Sangyo KK (MATU-C)	JP2004088819-A	18.03.2004
Fuji Electrochemical Co. Ltd. (FJIC-C)	JP2004088878-A	18.03.2004
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C) Panasonic Co. (MATU-C)	JP2003017142-A	17.01.2003
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C)	JP2003079051-A	14.03.2003
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C)	JP2003004822-A	08.01.2003
Nippondenso Co. Ltd. (NPDE-C) Denso Corp. (NPDE-C)	JP2003032907-A	31.01.2003
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C)	JP2003007271-A	10.01.2003
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C)	JP2003022837-A	24.01.2003
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C) Panasonic Co. (MATU-C)	JP2002367684-A	20.12.2002
Nippondenso Co. Ltd. (NPDE-C)	JP2001352688-A	21.12.2001
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C)	JP2001297801-A	26.10.2001
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C) Panasonic Co. (MATU-C)	JP2002015781-A	18.01.2002
Matsushita Electric Ind. Co. Ltd. (MATU-C) Matsushita Denki Sangyo KK (MATU-C) Panasonic Co. (MATU-C)	JP2001313019-A	09.11.2001
Matsushita Electric Ind. Co. Ltd. (MATU-C)	JP2001314041-A	09.11.2001

* The data in column 2 and 3 are from the authors' analysis of Derwent Innovation Index Patent Database.

Source: [Thomson Reuters, 2014b].

Toyota jointly developed and protected a wide range of technologies related to HEVs from 2000 to 2014 with various companies including: Panasonic Corporation, Sanyo, Asin Seiki Co. Ltd., Yokohama National University, Fujitsu Denso, Aisin A.W. Co. Ltd., Matsushita Denki Sangyo, Fuji Electrochemical, Matsushita Electric, and Nippondenso (which belongs to Toyota). These results will be backed up in the next section, which examines the active collaborations Toyota maintains in the sphere of technological R&D on hybrid vehicles.

Technological collaborations of the top patenting organization

Collaboration in the industry to reach a leading technology position is increasing worldwide, including for automotive companies. From the broad perspective of co-evolution of the vehicle sector, the following actors are involved: car manufacturers, engine component suppliers, car users, car repair shops, sales persons, journalists, universities, research centres, banks, venture capitalists, shareholders, and policy makers [*Dijk, Yarime,* 2010].

Unquestionably, car manufacturers play an influential role in this co-evolution. As shown in the previous section, Toyota Motor Company leads on patenting activity for hybrid vehicles. In terms of collaboration and patent domain, we first highlight three main issues from Kwon and Jeong [*Kwon, Jeong,* 2013]:

a) Toyota Motor became more competitive due to open innovation in the last five years; b) Toyota Motor acquired significantly more patents in hybrid vehicles compared to in other domains; c) Toyota Motor, together with Hyundai Motor and Ford Global Technologies, became the R&D leaders thanks to their international collaboration networks.

Considering the importance of Toyota Motor, we carried out an in-depth analysis of its collaboration initiatives in the field of hybrid vehicles (Table 4).

In addition, Toyota has established a diversity of collaborations a long time ago. For example, the collaboration between Ford and Toyota Motor Corporation in 2005 enabled the co-development of hybrid cars and the sale of Ford vehicles in Japan. In conclusion, Toyota Motor's leadership in the market of hybrid vehicles is the result of a significant balance between their own developments and those produced through their strong collaborative technology network. Toyota currently remains the leader in developing hybrid models of cars. For example, in January 2014, they launched the completely redesigned 'Voxy' minivan through the Netz dealers in Japan, and the completely redesigned 'Noah' minivan through Toyota Corolla dealers. Monthly sales targets for Japan are 4,600 units of 'Voxy' and 3,400 units of 'Noah' [Toyota Motor Corporation, 2014].

Second stage

Patent activity according to the type of hybrid vehicle

The starting point of the second stage was to identify the most active types of hybrid vehicles in terms of patents. For this purpose, we considered the classification previously presented on parallel, series and series-parallel. Analysing the total of 40,023 patents, the results obtained indicate a predominance of parallel hybrids (1,475 patents), as shown in Figure 8.

Patent activity according to alternative energy sources

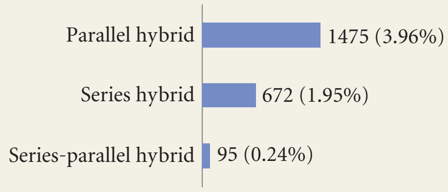
For the purpose of this research, it was also important to identify alternative energy sources with the highest patenting activity.

Table 4. **Recent collaboration efforts of Toyota Motor Co. Ltd. in the field of hybrid vehicles**

Partner Organization	Year	Objective
The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL)[a]	2013	To enhance NREL's research related to hydrogen fuel, renewable hydrogen production, and vehicle performance. For this task, the NREL received four fuel cell hybrid vehicles - advanced (FCHV-adv) on loan from Toyota Motor Co. through a two-year cooperative research and development agreement.
BMW Group[a]	2013	Joint development of a fuel cell system, architecture and components for a sport vehicle, and R&D on lightweight technologies. Both entities also signed a binding agreement to start collaborative research on lithium-air batteries including a post-lithium-battery solution.
Nissan Motor Co., Ltd.[a] Honda Motor Co., Ltd.[a] Mitsubishi Motors Corporation[a]	2013	To promote the installation and use of chargers for electric-powered vehicles (PHVs, PHEVs, EVs), creating a charging network service more convenient for drivers in Japan. A new company: Nippon Charge Service was created for this task.
Energy Duke Energy Systems Network[a]	2012	To provide a simple and affordable smart grid communication protocol between the vehicle, the charging station, and the utility company, to effectively manage hybrid's vehicle charging. The pilot project involves 5 Prius Toyota plug-in hybrid vehicles driven by Duke Energy customers.
Osaka Gas Co., Ltd.[a] Chofu Seisakusho Co., Ltd.[a] Aisin Seiki Co., Ltd.[a]	2012	To develop a residential use of solid oxide fuel cell (SOFC) co-generation system (SOFC system). The resulting product, ENE-FARM Type S, achieves a power generation efficiency of 46.5% for a residential-use fuel cell.
Ford[b]	2011	To develop a hybrid-electric powertrain earmarked specifically for rear-wheel-drive light pickup trucks and SUVs. However, after a two-year 'feasibility study,' they decided to end this hybrid collaboration before it starts.
Tesla Motors[c]	2010	To develop production systems, EVs as well as providing engineering support. Toyota acquired a 3% equity stake of Tesla Motors. Tesla Motors will help Toyota create a plug-in EV, developing an electric powertrain, etc. Toyota will help Tesla by providing engineering and production expertise.
Kajima Corporation[a] Mitsubishi Heavy Industries, Ltd.[a] Nippon Oil Corporation[a] Sapporo Engineering Co., Ltd.[a] Toray Industries, Inc.[a]	2009	To establish a joint venture company in order to develop a next-generation cellulose-derived biofuel.

Sources: the data in Column 1 are from the authors' analysis of [a][Global Data, 2014], [b][*Visnic*, 2011; *Korzeniewski*, 2013], [c][*Karamitsios*, 2013].

Fig. 8. **Number of patents granted according to the type of hybrid vehicle, 2000–2014**



Source: authors' calculations.

Although the hybrid and electric car market is currently growing at a strong rate, manufacturers are already moving to new green technologies such as hydrogen fuel cells. The industry is looking for new energy sources more than electricity, and a steady growth is estimated in the next few years [MarketLine, 2014]. Figure 9 shows the results.

Patents involving the use of hydrogen (1,655 patents) predominate, followed by solar energy (413 patents) and natural gas (125 patents).

Recent patents of the top companies in the field of alternative energy

Considering the broad scope of the 40,023 patents obtained for 'hybrid vehicles', we further analysed the top five patenting companies and the two most important alternative energy sources: hydrogen and solar energy. For this aim, the search strategy combined the top applicants (assignee name of each patent) with the 'hydrogen' or 'solar' keyword in the 'title' and 'abstract' fields. As a result, we obtained 1009 patents. Table 5 presents the most recent of these patents.

Toyota stands out for owning the absolute majority of these recent technological advancements in the field of batteries, including a power supply device for supplying electric power to the controlled unit. On the other hand, Hyundai stands out for its patented invention related to a hands-free system for opening the trunk.

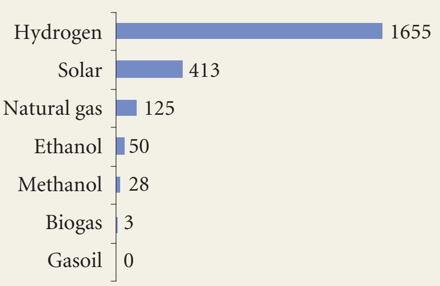
Advancements in the use of solar energy for hybrid vehicles were also investigated by considering the top five companies. A total of 56 patents were found for solar energy; the most recent of which are presented in Table 6.

In this case, the company Nippondenso has the highest patent activity, which is partly owned by Toyota. Nippondenso's current research focus is on photovoltaic power generation and power conversion and its controllers.

Conclusions

This study described the technological landscape of hybrid vehicles using a systemic patent analysis. This research is the first attempt to identify and analyse patent density for hybrid vehicles from 2000 to 2014. A total of 40,023 patents were analysed, which enabled us to conclude that the global R&D priorities in this field include areas such as engineering (39,094 patents), transportation (37,303 patents), and energy and fuels (18,086 patents). Based on standard classifications, the industry's efforts are focused on IPC B60W technologies: these

Fig. 9. **Number of patents granted in the field of alternative energy sources for hybrid vehicles, 2000–2014**



Source: authors' calculations.

Table 5. **The most recent patents granted to the top companies in the field of hydrogen**

Patent Number	Applicant	Publication Date
JP2014184816-A	Toyota Jidosha KK (~TOYT-C)	02.10.2014
JP2014187771-A	Toyota Jidosha KK (~TOYT-C)	02.10.2014
EP2784754-A1	Hyundai Motor Co. Ltd. (~HYMR-C). Ltd.	01.10.2014
JP2014180960-A	Toyota Jidosha KK (~TOYT-C)	29.09.2014
JP2014167845-A	Toyota Jidosha KK (~TOYT-C).	11.09.2014

Source: Derwent Innovation Index Patent Database [Thomson Reuters, 2014b].

are the control systems specially adapted for hybrid vehicles i.e. vehicles with two or more prime movers of at least two different types [WIPO, 2014a]. Alternately, the DCC analysis indicated that patent activity mainly focuses on electric cars, trolley buses, propulsion, power supply, traction batteries, and control equipment. The patent leaders for hybrid vehicle technologies were identified as follows: Toyota Motor Co. Ltd., Nissan Motor Co. Ltd., Nippondenso Co. Ltd., Honda Motor Co. Ltd., and Hyundai Motor Co. Ltd. Moreover, we found that Toyota has developed joint patents for HEV with organizations such as Sanyo, Aisin Seiki Co. Ltd., Yokohama National University, and others. Additional results were obtained to validate the strong collaborative strategy that Toyota follows for R&D on hybrid vehicles.

In terms of the type of hybrid vehicle researched, the parallel type predominates with 1,475 patents, followed by the serial hybrid with 672 patents. As for alternative energy sources, the most extensive research has been carried out on hydrogen with 1,655 patents, followed by solar energy with 413 patents. Natural gas ranks third (125 patents).

Finally, we analysed the leading companies and their recent patent efforts according to the top alternative energy sources. This analysis confirmed the leading position of Toyota Motor Co. Ltd., which is developing new technologies for using electric, hydrogen, and solar energy for hybrid vehicles. The results obtained aim to help the sector's stakeholders better understand current research in terms of the global research priorities, the technological categories, the top patenting organizations, joint patents, collaboration efforts, the types of hybrid vehicles and alternative energy sources, as well as the latest patents of leading companies. Moreover, we showed the importance of collaborative research in helping companies occupy leading positions in the market. These results could support the RD&I strategic decision-making of stakeholders in the sector. Finally, our methodology can be applied in future research to other technologies.

Recommendations and limitations

The present study provides an initial outlook at research on hybrid vehicles and collaboration efforts through a systemic patent analysis. To gain more in-depth insights, it is necessary to focus on specific topics because the area of study is so large. In future research, it would be interesting to determine the correlations between the variables characterizing the trends and evolution of the technical advances through technology mapping. Moreover, it is important to remember that patent analysis only covers one part of the industry's strategic diversity; a more extensive market analysis is needed. Toyota, the leader in patent and collaborative activity, saw its market share erode in 2013 following an increase in sales by its competitors. Thus, the company Ford has recently significantly

Table 6. **The most recent patents granted to the top companies in the field of solar energy**

Patent Number	Applicant	Publication Date
JP2014176251-A	Nippondenso Co. Ltd. (~NPDE-C)	22.09.2014
JP2014174876-A	Nippondenso Co. Ltd. (~NPDE-C)	22.09.2014
JP2014171274-A	Nippondenso Co. Ltd. (~NPDE-C)	18.09.2014
JP2014166056-A	Nippondenso Co. Ltd. (~NPDE-C)	08.09.2014
JP2014166055-A	Nippondenso Co. Ltd. (~NPDE-C)	08.09.2014

Source: Derwent Innovation Index Patent Database [Thomson Reuters, 2014b].

increased its presence on the alternative fuel vehicle market; pure electric vehicles, such as the Tesla Model S and Nissan Leaf, have also been quite successful [MarketLine, 2014].

Nevertheless, Toyota continues to be innovative, as discussed earlier. At the start of this year, Toyota launched the latest versions of their hybrid vehicles in Japan. Expert analysts of the industry predict they will be very successful in this market.

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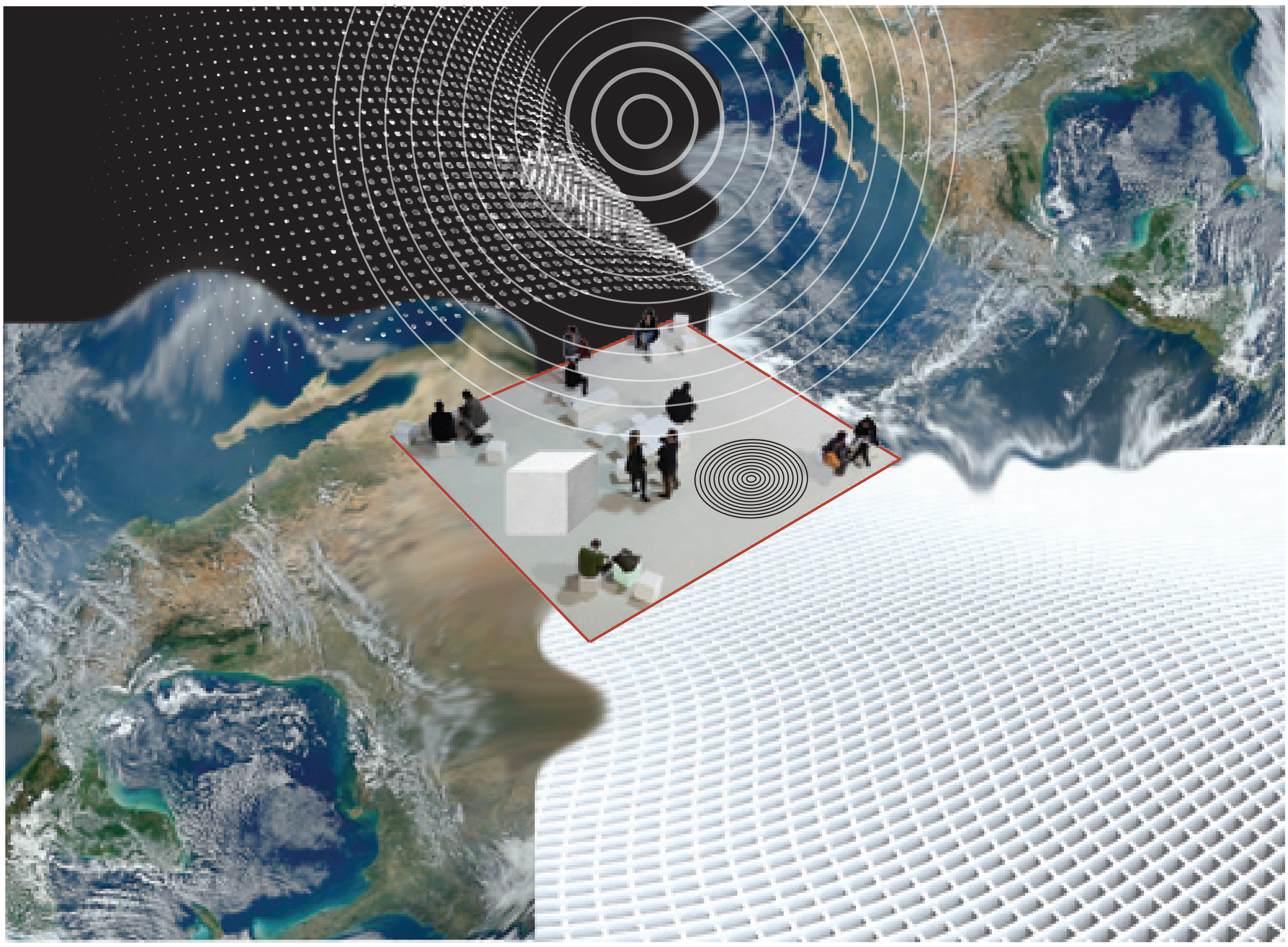
The Role of Companies in Human Capital Accumulation: A Cross-Country Analysis

Natalia Bondarenko



The development of human capital in forms in which it accumulates can be effectively investigated through a case study of the participation of the adult economically active adult population in lifelong learning. This study is devoted to assessing the involvement of managers and employees at Russian companies in lifelong learning and the role of Russian firms in organizing this type of education compared with practices in the European Union (EU) and the OECD. The paper is based on a comparative analysis of international sociological surveys and a survey of Russian employers in six sectors of economy, conducted by National research Research university University HSE and the Levada Center as a part of project 'Monitoring of Education Markets and Organizations'[1], with the support of the Russian Ministry of Education and Science.

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Keywords

human capital; top-managers of companies; lifelong learning; formal training of adult population; higher education; inequality in education and training; professional skills; innovation activity of companies

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[1] Materials on the project 'Monitoring of education markets and organizations' can be found at: http://memo.hse.ru and http://memo.hse.ru/en.

A comprehensive evaluation of the innovative potential and efficiency of the economies of certain countries on a macro level involves key indicators of human capital quality [*Healy et al.*, 2011]. Added to these, along with the average duration of training and the proportion of the economically active population (aged from 25 to 64 years) with a higher education, researchers often look at the number of participants in lifelong learning programmes. This is because individual capabilities and talents, educational capital accumulated through formal training, and skills and competencies acquired in life, including through a professional career, are the basic elements of human capital.

On a micro level, quality labour resources serve as a guarantee for employers of a company's effective current operations, opportunities to implement new projects, to introduce and adapt innovative products, technologies, etc. Certain micro-studies, including several Russian and regional studies, have corroborated the hypothesis that participants in lifelong learning programmes who are regularly raising their skill sets tend more frequently to show high levels of interest in innovation, a readiness to establish new firms and to develop and launch new goods onto the market, to implement new technologies, etc. [BIS, 2010; *Verdonschot*, 2012; *Gokhberg, Poliakova*, 2014; *Trubin*, 2011].

In OECD countries, the problem of differentiating human capital attracts the utmost attention from specialists. A number of studies have been dedicated to identifying key factors and assessing the extent of educational inequality, its impact on economic growth and the effectiveness of measures to reduce inequality [European Commission, 2014, pp. 23–28; OECD, 2014, pp. 49–50]. Researchers in the EU have confirmed that differences in human capital indicators turn out to be more significant not so much between national economies, but between socio-demographic groups within national economies (in particular, between groups whose parents had lower cultural, economic or social status and those whose parents had higher positions in the social stratification) [*Blanden, McNally*, 2015, pp. 16, 20–21; European Commission, 2014, p. 25]. Sustaining stable economic growth cannot be simply reduced to ensuring that human capital indicators remain positive (for example, the proportion of those with a higher education); it also requires a reduction in educational inequality by improving the professional and qualification status of some of the poorest groups of the population. Attention has been paid to these groups as a matter of priority as a result of statistical calculations showing that equal access for economically disadvantaged citizens to education and skills training results in smoothing over existing differences in labour productivity and the pay received [*Blanden, McNally*, 2015, pp. 27–28].

Experience of lifelong learning studies

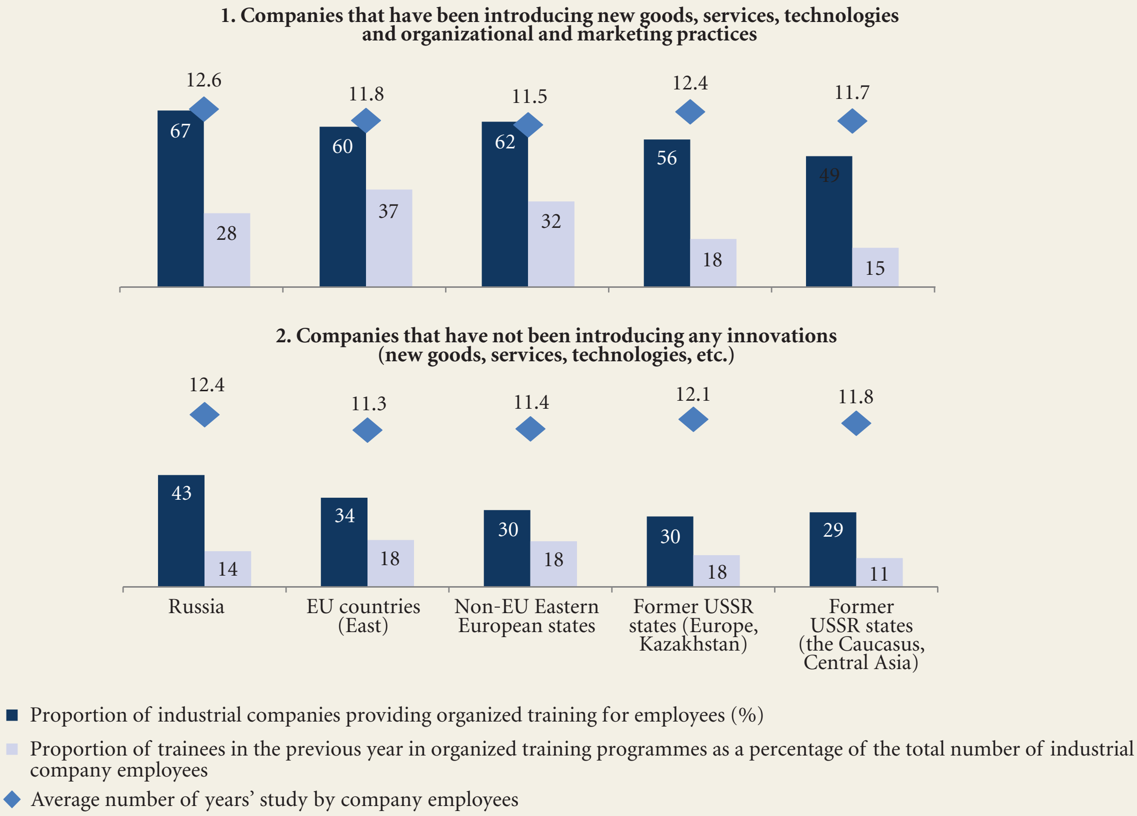
What are the evaluations of human capital quality and the prospects of improving quality in Russia formed from? What impact does the level of involvement of certain groups of the economically active population in lifelong learning have? What is the extent of educational inequality in Russia? Which forms of lifelong learning are prevalent and what is the extent of involvement by employees, companies and the state in such programmes? The responses to these questions would be incomplete if they were only based on education and employment statistics. Data from sociological surveys, which have been developed intensively in certain countries[2] and on an international level[3], make it possible to significantly add to researchers' and experts' understanding of human capital accumulation and renewal. The results of such regular samples are used in administrative decision-making and by companies themselves, as well as by governments when developing balanced labour and education policies.

In Russia, as part of the 'Monitoring of Education Markets and Organizations' project, regular pan-Russian employer surveys have been carried out since 2005

[2] Cf., for example, the employers' study on professional skills and know-how among workers in the United Kingdom: [*Kik et al.*, 2014].

[3] In particular, the European employers' survey on worker professional skills requirements [Cedefop, 2013], a study by companies on staff involvement in lifelong professional learning in companies [Eurostat, 2010], and a survey on the skilled worker shortage problem [Manpowergroup, 2014].

Fig. 1. **Educational capital of workers and training in industry: international comparisons**



Source: data from the BEEPS survey for 2012-2013 [EBRD, 2014].

across six economic sectors[4] [*Krasilnikova et al.*, 2005, p. 56-57]. This article focuses mainly on comparing the results of the 'Monitoring of Education Markets and Organizations' project with data from similar surveys carried out in a number of OECD countries and in the EU, including surveys carried out by Eurostat on lifelong professional training for business employees (Continuing Vocational Training in Enterprises Survey, CVTS), adult education (Adult Education Survey) and the work force (Labour Force Survey). Another source is data from the international business environment and conduct survey carried out by the European Bank for Reconstruction and Development (EBRD) (Business Environment and Enterprise Performance Survey, BEEPS) [EBRD, 2014], which was also taken by Russian companies.

The BEEPS survey for 2012 and 2013 showed the leadership of the Russian labour market in terms of the level of formal professional education among workers (Fig. 1). In this regard, Russia exhibits some clear competitive advantages over EU member states, including the former Eastern Bloc. In particular, this means the higher average length of training for workers in industry with a higher education. Figures for post-Soviet Belarus, Ukraine and Kazakhstan are closer to Russian figures in this respect, which is attributable to them inheriting a common vocational education system. The proportion of workers with a higher education as a percentage of the total number employed in industry in Russia is more than 35%, in former USSR states in Europe and Kazakhstan this figure is roughly 30%, and in Eastern Europe, it is a little over 16%. Other indicators of the state of the domestic labour market appear much worse against the global backdrop. For instance, the proportion of workers for whom Russian compa-

[4] Carried out by NRU HSE together with the Yuriy Levada Analytical Center (Levada Center), with support from the Russian Ministry of Education and Science. The aim of these employer surveys is to study their interest and willingness to play a role in the process of modernizing the professional education system, receive their views on the readiness of the qualified labour force to meet current and future business needs, and to analyze companies' needs for basic and continuous professional training for their staff. Available at: http://memo.hse.ru/concept, accessed 24.03.2015.

nies have been organizing training is less than the figures for EU countries. Even those Russian industrial enterprises which have been introducing new goods, services, technologies, work methods, forms of organization and product promotions still fall behind these countries.

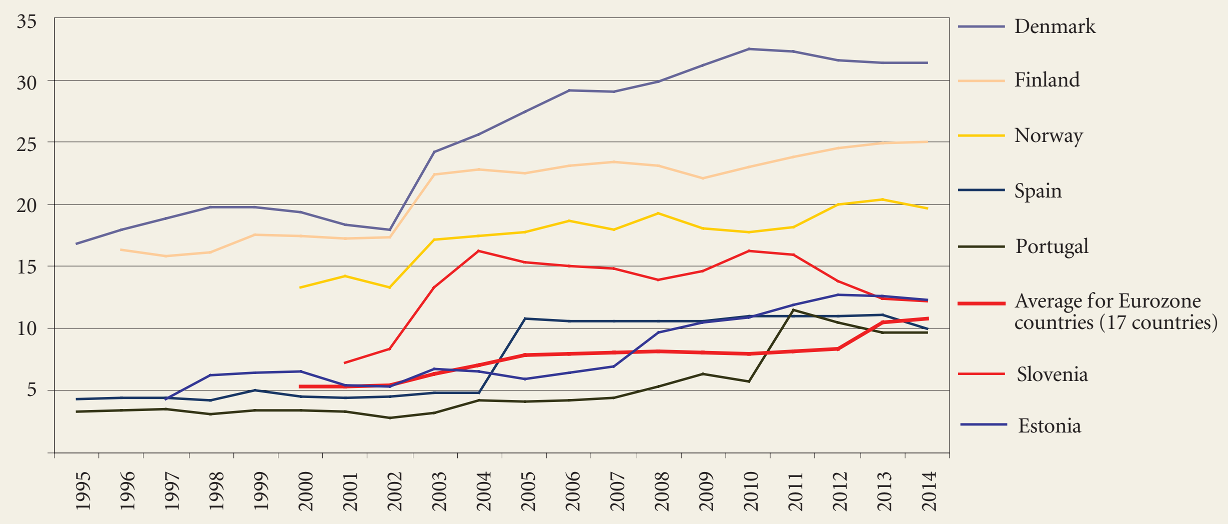
International surveys of company managers, including those that are dedicated to continuous professional staff training [Eurostat. 2010] and the demand for qualified workers in the EU [Cedefop, 2013], point to the indisputable trend of the growing importance of universal conduct skills among staff (*soft skills*) alongside traditional core skills (*hard skills*). Accordingly, the demands that companies are making of their employees are changing: greater employee flexibility and adaptability and refusing to follow strict routine rules and procedures. The higher the vocational and professional status of an employee, the broader the range of universal skills are that are expected of that employee. According to data from the European Centre for the Development of Vocational Training (Cedefop), employers involved in innovation activity are the main drivers of demand for professional skill sets.

According to the results of a pilot survey of EU companies in 2012, *regardless of an employee's specialization*, employers forecast medium-term primary demand for universal skills: the ability to work in a team (essential for 90% of companies), the ability to learn (88% of companies), the ability to easily master new equipment and materials (81%), independence in setting work objectives and choosing work methods and schedules (81%), and the ability to convincingly defend a point of view (75%) [Cedefop, 2013]. Thus, among the most sought-after skills were those which required sustainable continuous training practices for validation and development.

In the Eurostat surveys devoted to continuous professional training, the growth in the proportion of companies (in particular, small and medium sized) involved in such programmes annually was 20-30%, relative to 1993 levels [*De Broeck*, 2008, p. 5]. The comparison of figures for the mid-1990s and 2014 as part of the Labour Force Survey also recorded a steady increase in the proportion of the EU population aged 25-64 involved in continuous education (Fig. 2). The level and rate of growth in this figure differs from country to country: those most actively involved in lifelong learning are the Scandinavians, and the least are those from southern Europe.

An attempt to explore the nature of Russian companies' demands for universal and special professional skills among workers and to predict changes in these

Fig. 2. **Involvement of the adult EU population in any form of continuous education, both related and unrelated to professional activity** (proportion of respondents aged 25-64 involved in various forms of continuous education in the four weeks preceding the survey, %)



Source: EU Labour Force Survey [Eurostat, 2015].

requirements over the next 2–3 years taking into account plans to modernize a business was made in our employer survey as part of the 'Monitoring of Education Markets and Organizations' project. The list includes the key skills mentioned in an equivalent British study [*Kik et al.*, 2014] and CVTS survey [Eurostat, 2010]. This borrowing makes it possible to compare the specific features of the Russian and international labour markets revealed in the studies.

Roughly half of Russian employers surveyed under the 'Monitoring of Education Markets and Organizations' project in 2014 forecast changes in their requirements in terms of the professional skill sets of core worker categories. The differences in evaluations are down to the varying degrees of involvement of the companies in the innovation process (Table 1). Players which have adapted or developed new products, technologies, work methods, product promotion methods, etc. in the last 2–3 years or have planned to modernize in the near future are 2.5 times more likely (up to 55% of the companies in the group) to forecast such changes. It is not surprising that these companies are more likely to demand higher computer literacy, social and communication skills and ability to learn across all worker groups. Less routine work in an innovative organizational and technological environment requires independent decision-making skills, initiative and a customer orientation. Workers are also expected to exhibit traditional performance qualities: discipline, efficiency, and a responsible attitude toward set tasks.

According to current evaluations, employers *faced with the problem of low worker qualifications*, including scarce professional skills for all worker categories, mentioned universal behavioural skills as often as or more often than specialized (Table 2). Discipline and ability to learn are the most important for skilled workers (in roughly 40% of cases). With regard to specialists, in addition to the previously mentioned qualities, employers require increasing autonomy in decision-making (in almost 60% of cases) and the development of teamwork skills and customer interaction skills (in more than 40% of cases). For comparison, in roughly 40% of cases a lack of specialist knowledge among specialists was indicated.

The detailed breakdown of the data obtained through the manager surveys makes it possible to identify the demand of the management of different companies for particular skills depending on the administrative position of the respondent, his or her age, and even the extent of the innovative orientation of the company (Table 3). The results of the study confirm that the optimal form of developing (updating) sought-after professional qualities among workers is *regular* involvement in various lifelong learning programmes.

Table 1. **Professional skills sought by innovative companies over the next 2-3 years** (proportion of respondents selecting the corresponding response as a percentage of all surveyed managers of businesses developing and/or introducing innovations and having plans to modernize the technologies that they use, %)

	Specialists	Skilled workers	Professionals
Core knowledge and skills (hard skills):			
special professional knowledge, skills for work in the workplace	17	20	13
basic computer literacy, knowledge of software	28	13	20
general educational skills (reading, maths), general culture	5	5	4
Universal conduct skills (soft skills):			
ability to retrain, master new skills	24	26	23
independent work-related decision-making skills	22	13	13
customer skills	14	7	12
teamwork, group skills	11	7	10
time-management, work-management skills	16	14	16
office administration skills	6	3	7
discipline, efficiency	12	22	10
desire/interest in working in the workplace	8	16	9

Source: data from the 'Monitoring of Education Markets and Organizations' 2014 employer survey.

Table 2. **Most scarce specialist and universal worker skills from an employer's perspective** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)

Question to managers: 'What do workers with inadequate professional skills need above all else?'

	Specialists	Skilled workers	Professionals
Core knowledge and skills (hard skills):			
special professional knowledge, skills for work in the workplace	43	52	56
basic computer literacy, knowledge of software	12	20	12
general educational skills (reading, maths), general culture	29	24	18
Universal conduct skills (soft skills):			
ability to retrain, master new skills	42	34	27
independent work-related decision-making skills	59	28	32
customer skills	41	21	18
teamwork, group skills	11	19	3
time-management, work-management skills	42	46	29
office administration skills	40	26	39
discipline, efficiency	29	46	40
desire/interest in working in the workplace	25	35	20

Source: data from the 'Monitoring of Education Markets and Organizations' 2013 employer survey [*Krasilnikova, Bondarenko*, 2014, p. 36].

Managers' careers and education

It is with good reason that that we selected managers as the respondents to the surveys giving the results used in this article: the dominant management model in Russian companies (including small and medium sized) is typically a rigid vertical structure in which the key role in managerial decision-making and policy-making rests with executives. Their will shapes which developmental areas of human capital will receive financial support, which organizations will become partners in staff training, and which training practices will be adopted. All of these decisions are not in the least bit dependent on the level of competence of the company's management, its focus on change and renewal, or their satisfaction with professional training for staff. Rather, the effectiveness of the firm's management as a whole depends on the qualifications of the managers. In the

Table 3. **Importance of particular professional skills among workers for various categories of managers** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)

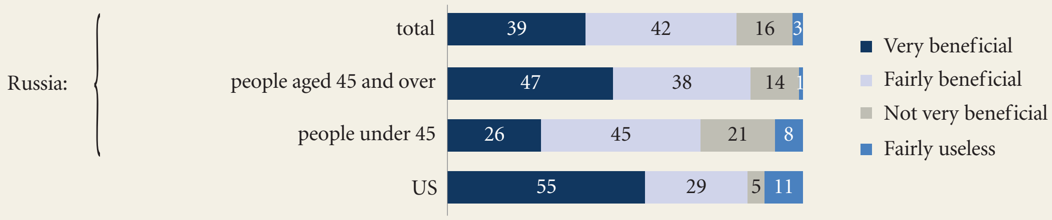
Question to managers: "Select one of the variants to complete this sentence: 'As a minimum each month, it is necessary to...'"

	Learn something new at work		Find out about new developments (products, technologies, etc.)		Solve entirely new problems requiring a rapid response		Solve new more complex problems (which require more than half an hour to complete)	
	Managers	Deputies	Managers	Deputies	Managers	Deputies	Managers	Deputies
	53	61	53	64	66	61	65	60
Depending on the age of the respondent								
Up to 45 years	55	63	59	62	76	56	73	56
Over 45 years	52	59	50	66	61	66	61	65
Depending on the level of innovation of a company (involvement in the development/introduction of new products and technologies, work methods, forms of organization, forms of product promotion, etc.)								
Pioneered / developed	59	69	60	73	72	68	72	68
Did not pioneer / did not develop	31	51	35	51	42	49	42	47
Depending on the size of the company								
< 50 people	58	82	58	88	59	80	53	79
50–249 people	47	60	49	63	65	60	67	59
> 250 people	57	66	61	67	64	63	71	64

Source: data from the 'Monitoring of Education Markets and Organizations' 2014 employer survey.

Fig. 3. **Importance of a higher education for the successful professional activity of company managers** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)

Question to managers: "How useful were your studies at a university or training institute in terms of preparing you for your work / career?"



Sources: for Russia, data from the 'Monitoring of Education Markets and Organizations' employer survey for 2014; for the US, the Higher Education, Gender and Work Survey databases [PEW Research, 2013].

work [*West et al.*, 1999], which uses hierarchical regression models on a case study of industrial companies, they recorded a statistically significant connection between the average level of education in a team of top managers (as the independent variable) and the efficiency of the business' operations, expressed in productivity and profitability.

As part of the 'Monitoring of Education Markets and Organizations' employer study, a group of senior (executives and deputies) and middle managers were surveyed (mostly heads of HR departments and finance and business divisions) (Fig. 3).

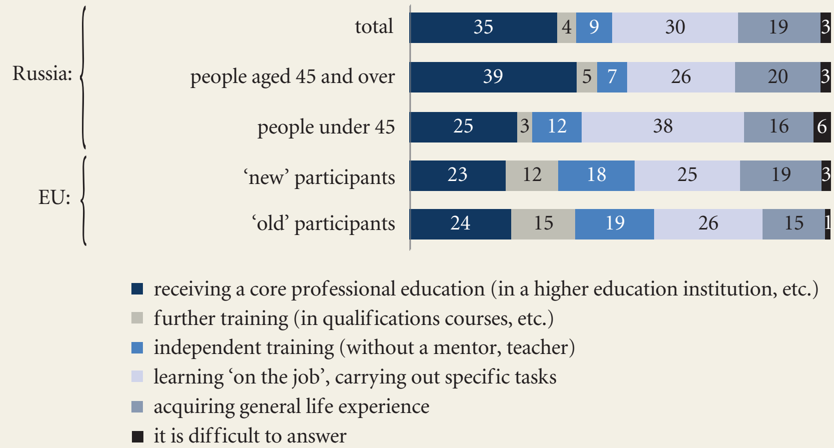
The vast majority of surveyed Russian managers considered their higher education to be rather useful, and among those who received their first professional education during the Soviet era, i.e. those respondents over 45 years of age, one in two indicated that their training was very useful to their future work. The managers among the post-Soviet graduates, i.e. those younger than 45 years of age, expressed similar opinions in half as many cases. The emerging generational gap can be explained by the declining quality of teaching in higher education in recent history as a result of teaching programmes falling behind demand from the external environment. Even in the 2005 'Monitoring of Education Markets and Organizations' survey, the most common view among company managers was that the period 1980–1990 was the decade with a higher level of professional training in Russian higher education institutions [*Krasilnikova et al.*, 2005, p. 33]. The low level of satisfaction with the quality of education in terms of progressing the careers of managers is down to the focus of young managers on continuing their training without the traditional five-six year limitation. For comparison, university education satisfaction among American managers and businessmen, according to the results of the Higher Education, Gender and Work Survey [PEW Research, 2013], is relatively high: more than half of respondents considered their time spent in higher education productive in terms of their future profession.

According to the majority of surveyed managers of 45 years of age or more (35%), they acquired their core knowledge and skills in formal training at a higher education institution (Fig. 4). Key to the professional development of younger managers, according to their own assessments, was informal training, in the form of self-education for 12% and during work (38%). Moreover, Russian managers under the age of 45 mentioned informal ways of obtaining the skills they needed at work *more frequently* than their colleagues in the EU. For a large group of company managers in the EU (up to 15%), further education was the main form of professional training. In Russia, where less than 5% of those surveyed selected this, further education plays an important role only in certain sectors, in particular in relation to innovation activity, where 15% of managers picked this option.

The survey of the management of Russian companies on the subjective needs for new knowledge, skills and higher overall qualifications in turn also shows a number of intergenerational differences (Fig. 5). It was more often younger managers (with more than half of those under 45 years of age) pointing to

Figure 4. **Importance of a higher education for the successful professional activity of company managers** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)

Question to managers: "Select one of the variants to complete this sentence: 'The majority of the knowledge and skills that you use in your current job were mainly acquired as a result of...'"



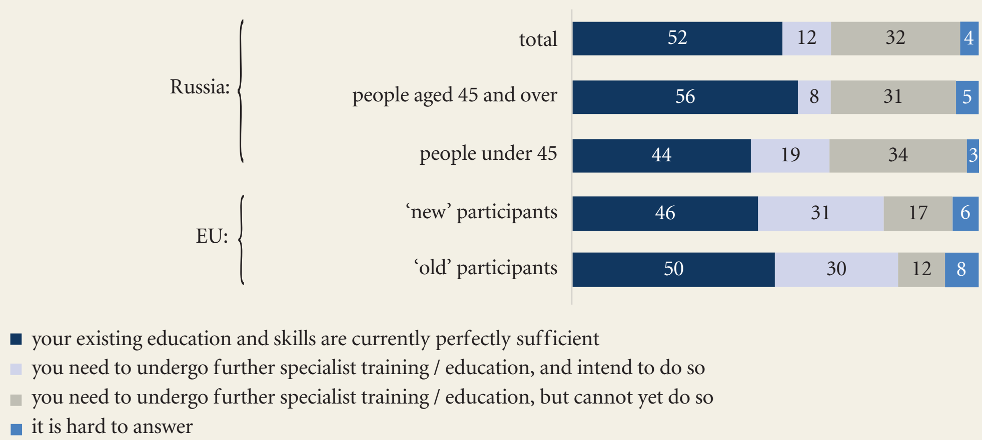
Sources: for Russia, data from the 'Monitoring of Education Markets and Organizations' employer survey for 2014; for the EU, the Eurobarometer 62.1 databases [European Commission, 2004].

a lack of available professional knowledge. According to data from the Eurobarometer, the majority of managers in Eastern Europe feel that their acquired knowledge and skills are lacking in terms of their professional development [European Commission, 2004]. However, compared with their counterparts in the EU, clear ideas and plans to make up for the skills deficit are not unique to Russian senior and middle managers, which can be attributed to the lack of development of the Russian education services market for the economically active population over 25 years of age.

For managers of Russian companies that are known for their innovation activity or have plans to modernize their business in the near future, it is common to see increased interest in updating professional knowledge and skills (up to 55%) and specific plans to make up for gaps in knowledge (up to 25%). The bulk of those surveyed, irrespective of their managerial level, industry or age, mentioned

Figure 5. **Satisfaction with the current level of professional training among company managers** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)

Question to managers: "Select one of the variants to complete this sentence: 'For career development and professional, career growth...'"



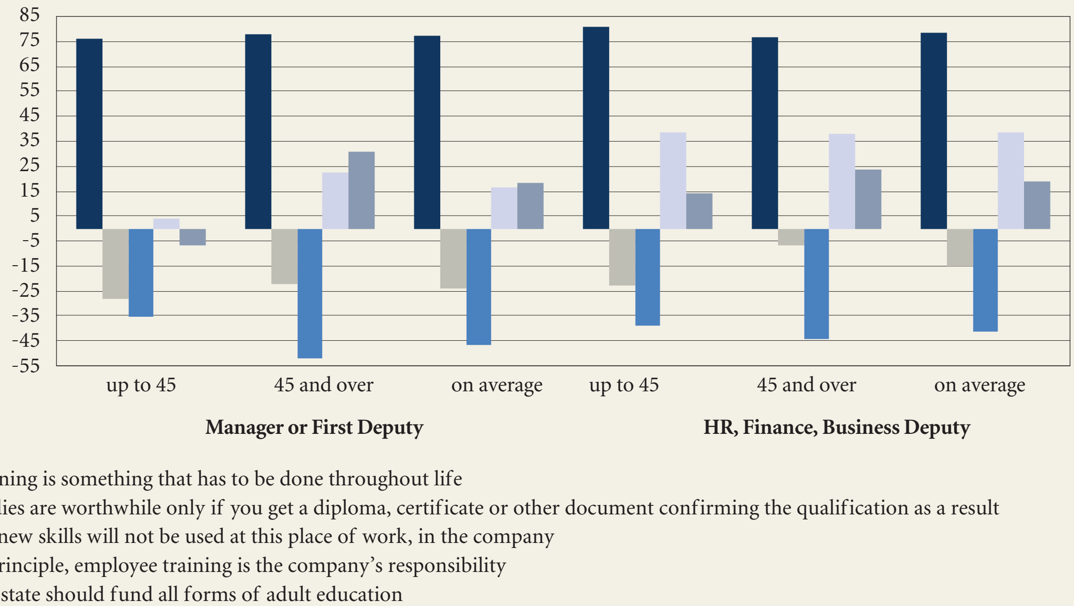
Sources: for Russia, data from the 'Monitoring of Education Markets and Organizations' employer survey for 2014; for the EU, the Eurobarometer 62.1 databases [European Commission, 2004].

preferential learning during their life (Fig. 6). However, what is important is not so much involvement in lifelong learning, but actual use of learning in the activities of the respondent and the company as a whole in the lifelong learning process. The surveys show that interest in this form of support for professional skills is more often than not informal in nature, especially among young senior and middle managers. In the eyes of the older generations, the formal, status side of training continues to play an important role. According to the majority of managers, their involvement in lifelong learning brings benefits not only to them personally, but has an impact on the activities of the company as a whole (something that young managers are somewhat less convinced of, however). In companies that have engaged in innovation activities of various forms during the last 2–3 years, views on the benefits of lifelong learning are even stronger.

The highlighted intergenerational differences in motivations and preferences linked to learning must be taken into account when developing government measures to encourage company investment in employee training and the development of further education programmes. Managers on various levels have disagreed about who precisely should be responsible for organizing workers' continuous training (Fig. 6). Middle managers and young managers are more likely to hold the company itself responsible for this, while executives, on whom the financial figures of the business depend, expect more activity from the state.

According to the international definition [Eurostat, 2005; Gokhberg, 2012, pp. 175–177], *lifelong learning* (or, according to Eurostat's statistical reports, *education, training and learning*) covers all forms of educational activities, both formal and informal, aimed at refining knowledge, skills and abilities that are both related and unrelated to one's professional activity. The main types of lifelong learning are formal, additional (*non-formal*), informal and self education (*informal learning*). The proportion of the adult population participating in formal education (through a school, higher education, college or other vocational training institution) is low as, by the age of 25, a basic education has, as a rule, already been achieved. Next, we will take a closer look at the activity of workers and company managers in further education — in the form of courses, lectures, seminars, one-off and regular training sessions, master classes, etc., i.e. non-core programmes — and informal education, including self-education — through studying literature, visiting exhibitions, libraries, taking open online courses, etc.

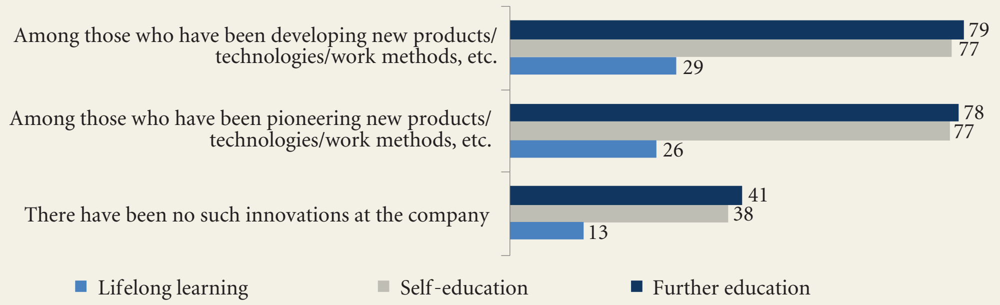
Figure 6. **Attitudes of Russian company managers towards training** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)*



* Indices are provided for each judgement, calculated as the difference between the proportion of positive and negative responses in the range between 'agree – disagree'.

Source: data from the 'Monitoring of Education Markets and Organizations' 2014 employer survey.

Figure 7. **Involvement of company managers in lifelong learning in the four weeks before the survey** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)



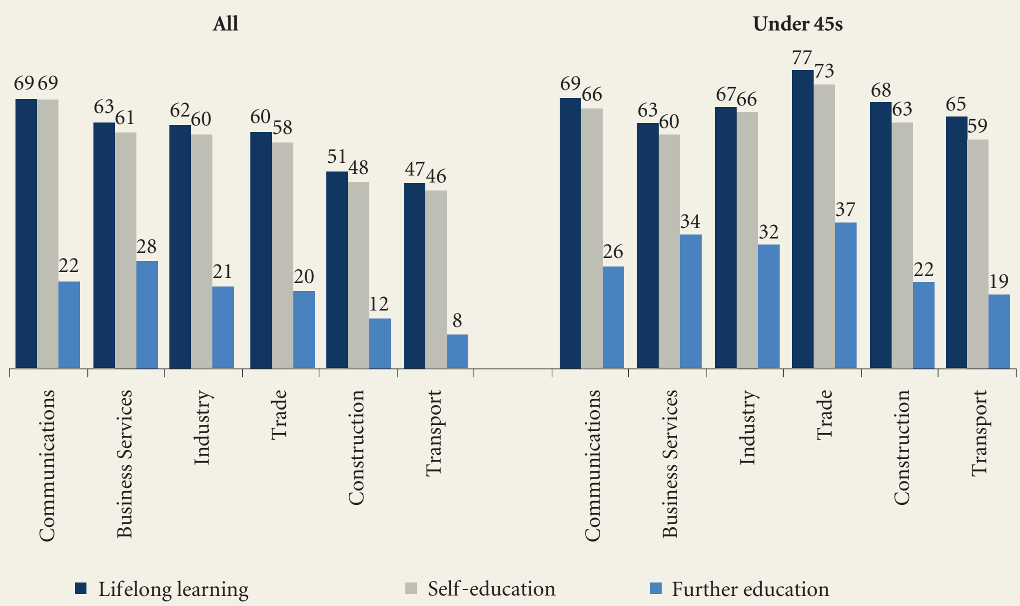
Source: data from the 'Monitoring of Education Markets and Organizations' 2014 employer survey.

The actual involvement of a manager in the various forms of lifelong learning is attributable to the nature of the company that he or she manages, its level of innovation and the size of the company. The survey results revealed that further education, both related and unrelated to the professional activity for an equal period of time, was received by almost twice as many managers of companies with over 250 workers (up to 37%) compared with those whose employee numbers are lower. The management personnel of large companies are less willing to engage in self-education.

We have already noted that the higher the demand for lifelong learning among managers, the greater the extent of the modernization and innovation activities at the company. Managers of companies that have been developing or introducing new products, technologies, work methods, forms of organization, etc. over the last 2–3 years are twice as likely to participate in lifelong learning compared with their counterparts involved in more traditional forms of activity (Fig. 7).

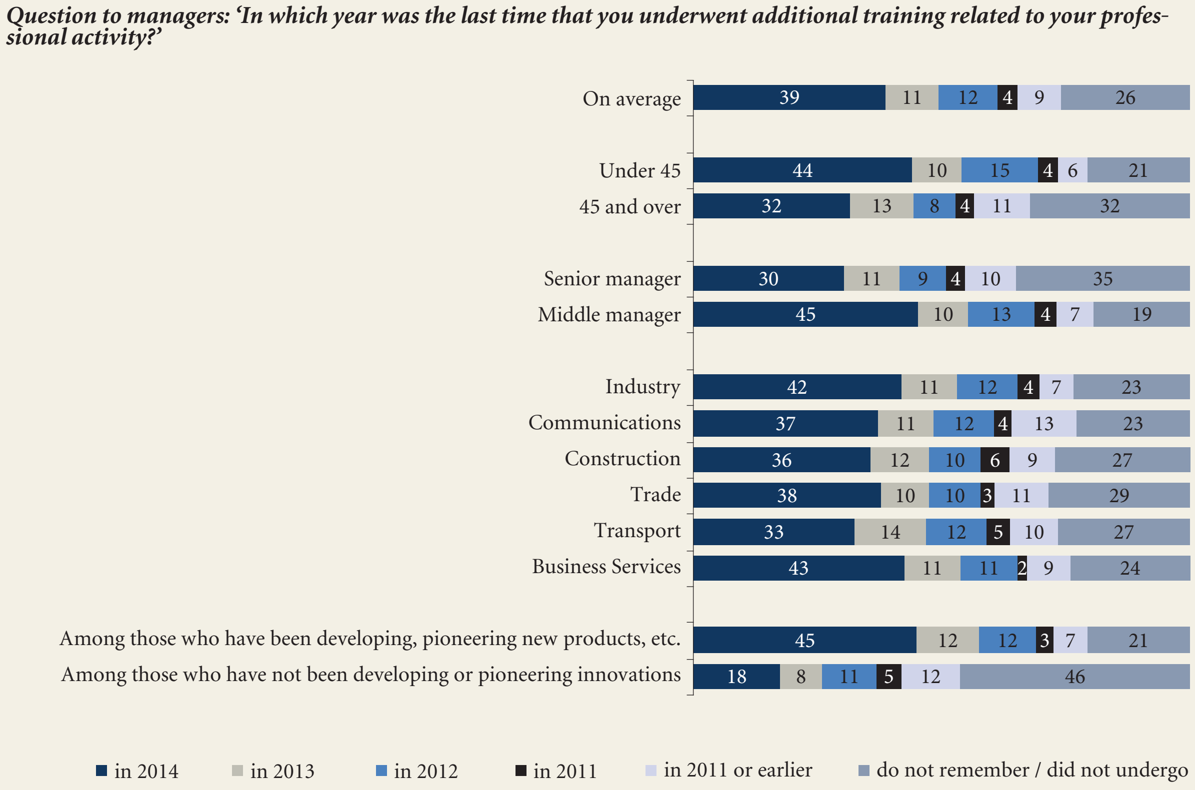
The age of management also affects education activity. An analysis shows that the inter-industry differences are virtually smoothed over in the group of managers aged younger than 45 years (Fig. 8). Members of this specific age cohort are more active than others in terms of updating and increasing their professional knowledge and skills.

Figure 8. **Involvement of company managers in lifelong learning in the four weeks before the survey** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)



Source: data from the 'Monitoring of Education Markets and Organizations' 2014 employer survey.

Fig. 9. **Regularity of company managers' involvement in additional training programmes**
(proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)



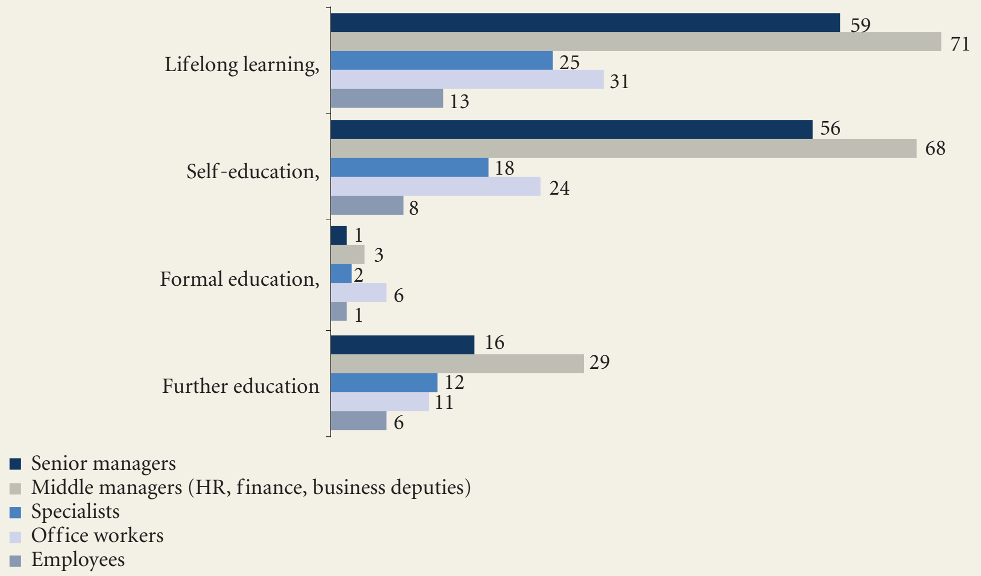
Source: data from the 'Monitoring of Education Markets and Organizations' 2014 employer survey.

When assessing the regularity of training linked to managers' professional activity, surveys recorded that roughly half of all respondents had participated in programmes such as these within the last two years, in 2013 and 2014, and roughly one quarter had been involved within the last four years, i.e. including 2011 and 2012 (Fig. 9). However, more than a quarter of respondents were unable to give or refused to answer the question on when they last raised their qualifications: among top managers this figure was 35%, while heads of departments were more proactive in using their opportunities for additional training.

An inter-industry comparison shows roughly comparable regularity of involvement in additional training programmes by members of companies from different industries. The positive correlation between an innovative environment and continuous professional education practices is also corroborated by data on the last time that managers took such a course. 45% of managers of companies which had developed or introduced new products, technologies, etc. had recently undergone professional training in the year of the survey. Only 18% of managerial staff engaged in refining their knowledge and skills in more traditional industries.

Changes in the nature of the requirements in terms of employees' professional skills at modern companies are giving rise to demand for updated skills and knowledge both among managers and subordinates. According to employers (including British employers [*Kik et al.*, 2014]), the lower the professional status of an employee, the less likely that he or she will be to satisfy the growing demands of a company. Consequently, low-skilled workers need to involve themselves more actively in lifelong learning programmes, access to which is, as a general rule, difficult.

Fig. 10. **Involvement of workers with various professional statuses in lifelong learning** (proportion of respondents aged 25–64 involved in various forms of continuous education in the four weeks preceding the survey, %)



Source: data from the 2011 'Lifelong Learning' study [HSE, 2013] and the 2014 'Monitoring of Education Markets and Organizations' employers survey.

Russian surveys[5] show a high level of differentiation in the level of involvement in lifelong learning between various levels of management and general workers. The gap between workers and middle and senior managers is particularly high (Fig. 10). In the four weeks preceding the survey, 6% of skilled workers, almost 30% of middle managers, and more than 15% of company managers participated in this type of programme.

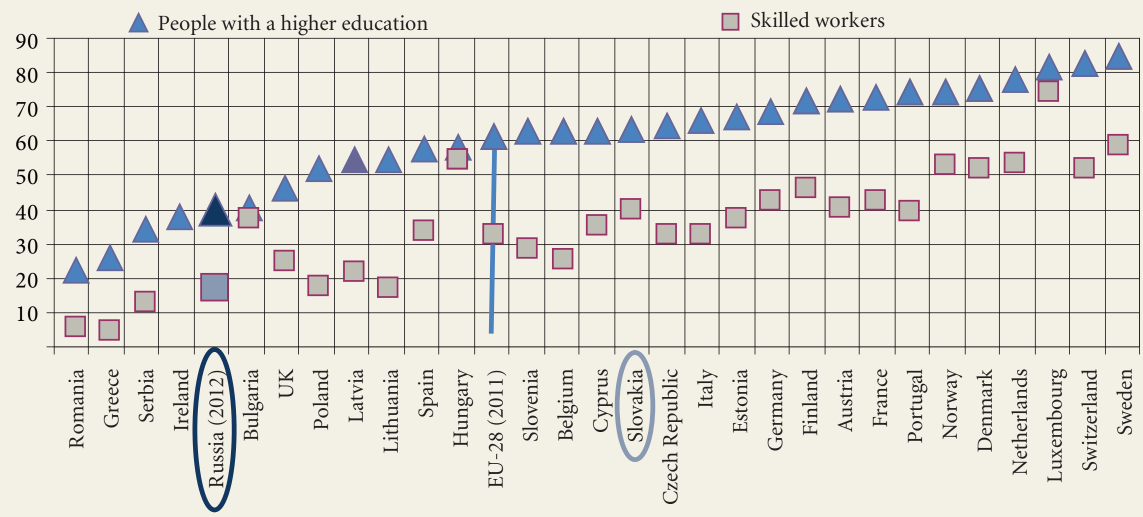
The aforementioned inequality in access to lifelong learning between 'gold', 'white' and 'blue collar workers' exists on the European labour market too. A comparison of materials from the Adult Education Survey [Eurostat, 2011] and the pan-Russian 'Lifelong Learning' study [HSE, 2013] shows that the extent of this differentiation is significantly higher in Russia than in leading European countries. In Germany, Switzerland and the Scandinavian countries the gap between workers with a higher education (managers, specialists) and skilled workers in this regard is less than one and a half times, while in Russia it is three times.

Although the proportion of university graduates among Russian company employees is higher than equivalent sectors in the EU, they show less inclination to increase their knowledge and skills through lifelong learning compared with their European counterparts. Eastern Europe lags behind older EU members in this regard, with a few exceptions. In particular, Slovakia has been able to develop effective mechanisms to involve the adult population in lifelong learning: the level of involvement among both managers and specialists as well as skilled workers is higher in Slovakia than the European average (Fig. 11). In Russia, this figure is well below the European average (Fig. 12).

As it turned out, specialists and managers prefer forms of lifelong learning such as conferences, meetings, and seminars, and tend to avoid longer forms of learning such as courses, etc. (Table 4). According to labour market experts [*Konovalova*, 2008], Russian companies are more attracted to programmes that do not involve prolonged periods of absence for employees from the workplace: one-day events, high intensity mini training sessions or series of short modules, talks by trainers and consultants and corporate conferences, etc. However, ex-

[5] Hereinafter, analysis of Russians' involvement in lifelong learning is based on data from specialist pan-Russian surveys on 'Lifelong Learning', carried out by NRU HSE in conjunction with the Levada Center in 2011–2012, representing the urban and rural adult population in Russia (over 18 years of age) [HSE, 2013].

Fig. 11. **Involvement of workers with a higher education and skilled workers in lifelong learning by country** (proportion of respondents aged 25–64 involved in various forms of continuous education in the four weeks preceding the survey, %)



Source: for Russia, data from the 2012 'Lifelong Learning' study [HSE, 2013]; for other countries, the Adult Education Survey 2011 [Eurostat, 2011].

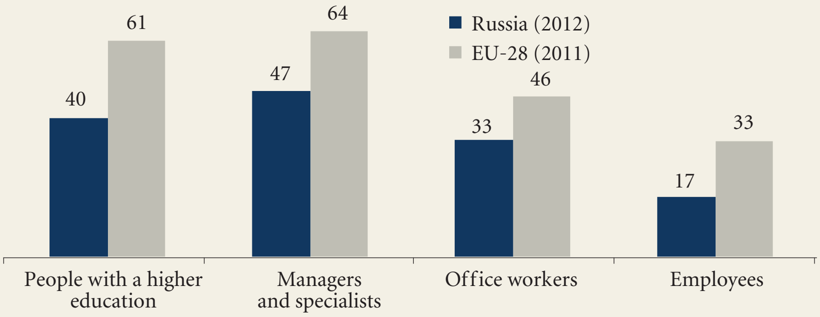
perts point out that such forms of education are ineffective in terms of establishing sustainable professional skills among workers, and the vast majority of training companies and consultants consider them incompatible with quality education services.

Involvement of companies in providing lifelong learning to workers

The aforementioned backwardness of Russian employers compared to European countries in terms of staff training is confirmed by information on key sectors of the economy (Table 5). A similar situation can even be observed in high-tech sectors such as communications and ICT.

An even larger gap can be seen in small business. However, according to existing data [*Krasilnikova, Bondarenko*, 2014, p. 43], professional training programme activity in companies with staff numbers exceeding 250 people is roughly the same in Russia and the United Kingdom. Slightly more than half of Russian companies employing up to 100 people and 93% of British firms of the same size have been implementing programmes such as these. A similar statistic for companies with less than 25 workers shows the significant superiority of British companies (77%) over Russian (almost three times fewer).

Fig. 12. **Involvement of various population groups in the corresponding age in Russia and the EU in lifelong learning** (for each group, proportion of respondents aged 25–64 involved in various forms of continuous education in the four weeks preceding the survey, %)



Source: for Russia, data from the 2012 'Lifelong Learning' study [HSE, 2013]; for the EU countries, the Adult Education Survey 2011 [Eurostat, 2011].

Table 4. **The experience of certain categories of workers in various forms of education over the last 12 months**

	Share of those who participated out of the total number of employees in the relevant category (%)	
	Regular personnel	Specialists and directors
Number of respondents	*145*	*316*
In regular (weekly, monthly, etc.) or one-time professional conferences, seminars, training sessions, meetings for the exchange of experience	8	17
Studying in courses for raising one's qualifications, courses for the receipt of a new profession	7	14
Studying with the use of a computer, including online courses	5	10

Source: data from the 2012 'Lifelong Learning' study [HSE, 2013].

Companies that are working to modernize their product range, technologies, equipment, work methods, etc. (i.e. are innovation-active) tend to implement the most active staff training policies. They are more likely than other businesses to organize (re)training for employees (up to 76% of companies), to develop appropriate plans and to contribute to budget spending for this purpose (up to 41% of companies). However, Russian experts suggest that Russian managers often do not have enough information about the situation on the labour market and do not have a detailed description of the skill sets and qualifications of their workers, which reduces the effectiveness of any education initiatives and gives rise to disagreements between company managers and external organizers of training courses [*Konovalova*, 2008]. According to the 'Monitoring of Education Markets and Organizations' survey for 2014, only 30–40% of employers providing funding for training for their own employees carried out a systematic assessment of the training needs of their employees (in European countries, this figure is higher than 70%). Less still, roughly 20–30%, is the proportion of companies that assessed the effectiveness of such programmes and tested workers after they had finished the course (the equivalent European figure is 57% [Eurostat, 2010]).

The maximum return on investment from manager training comes when 'advanced' knowledge and skills acquired by higher workers are passed on to subordinates and when training processes are synchronized within a company. A similar knowledge exchange mechanism is particularly important in businesses whose activity is linked to innovation (i.e. not based on mass production, but on the project principle). In this case, middle managers (heads of department, team-leaders) act as exchange agents, for whom mentoring or tutoring becomes their prerogative. The role of mentor also requires special training for ordinary employees in a company. Training programmes for line managers are offered in a number of European countries, for example, Germany, France and

Table 5. **Company activity in terms of organizing staff training in key industries in Russia and the European Union** (%)

	Industry		Telecommunications		Construction		Trade	
	EU-28 (2010)	Russia (2014)	EU-28 (2010)	Russia (2014)	EU-28 (2010)	Russia (2014)	EU-28 (2010)	Russia (2014)
Companies that organized employee training	63	67	80	62	64	57	63	42
Companies that have approved plans or a budget for employee training	36	40	53	42	36	28	36	23
Companies that have carried out a systematic analysis of employee training needs (out of the total number of companies offering training)	71	40	83	32	71	30	71	30

Sources: for EU countries, data from the Continuing Vocational Training Survey [Eurostat, 2010]; for Russia, data from the 'Monitoring of Education Markets and Organizations' employer survey for 2014.

Table 6. **Most significant obstacles and constraints to doing business according to company managers** (proportion of respondents selecting the corresponding response as a percentage of the total number surveyed, %)

Question to managers: "Select one of the variants to complete this sentence: 'The biggest obstacles to business are linked to…'"

	Russia	New EU member states	Non-EU countries in Eastern Europe	Former USSR countries (Europe, Kazakhstan)	Former USSR countries (the Caucasus and Central Asia)
... the quality of the business environment, the nature of state regulation (operation of courts, level of taxes, tax administration, quality of legislation)	53	46	40	27	29
... access to resources (labour, financial) and infrastructure (electricity, land, roads)	28	24	25	42	33
... a criminal, corrupt, unstable environment, including political instability	19	31	34	31	38

Source: data from the 2012 and 2013 BEEPS surveys [EBRD, 2014].

Italy as part of Cedefop's ADAPT initiative, and in France FED Construnet, etc. [*Janssens*, 2001, pp. 63–65]. Corporate training is not built on traditional class-based lessons: knowledge transfer takes place through a mentor (*'more guidance, less learning'*) through mutual learning and the exchange of experience between managers and workers (*cross-training*). Even the role of organizations providing education services is changing — their task is transforming into a consultancy role for company managers on questions of staff training: developing teaching materials, skills and knowledge transfer techniques, etc. This guarantees a progression from the development of standard mass staff training programmes to individualized solutions (*'training workshops'*).

The prospects of Russian employers further implementing various forms of professional staff training are not in the least affected by the constraints and challenges facing business in the country. According to the results of the 2012 BEEPS survey, the quality of the business environment and the nature of state regulation give rise to the greatest difficulties (Table 6). Even company managers in new EU member countries pointed to these barriers. However, while excessive taxation and limited access to resources (especially, financial resources) often cause the most concern among Russian businessmen, in the EU the issues are labour regulation, the functioning of the judicial system and the nature of tax administration.

By the end of 2014, amid the economic crisis, falling rates of production growth and stricter corporate lending requirements of banks, the staff deficit problem and the problem of low levels of qualification took a backseat for Russian companies. In all likelihood, this situation will continue in the short term, and for a large number of businesses, human capital development will not be a priority for investment. Moreover, the reduction in costs will involve the curtailment of already implemented modernization projects, a fact that is confirmed by sociological data: among the key constraints to upgrading technology and equipment and introducing new products and work methods, respondents mentioned general economic instability (29%) and difficulty in obtaining funding (20%) [*Krasilnikova, Bondarenko*, 2014]. Clearly, the cost of additional staff training is an important component of such projects.

Today, such an important (on account of its flexibility) innovative element of the education system as further adult education receives virtually no state funding. With the implementation of anti-crisis measures across the entire country's economy, it would seem extremely pertinent to pay particular attention to partnerships with companies specializing in training and investment in lifelong learning, both of which can provide a positive long-term effect. F

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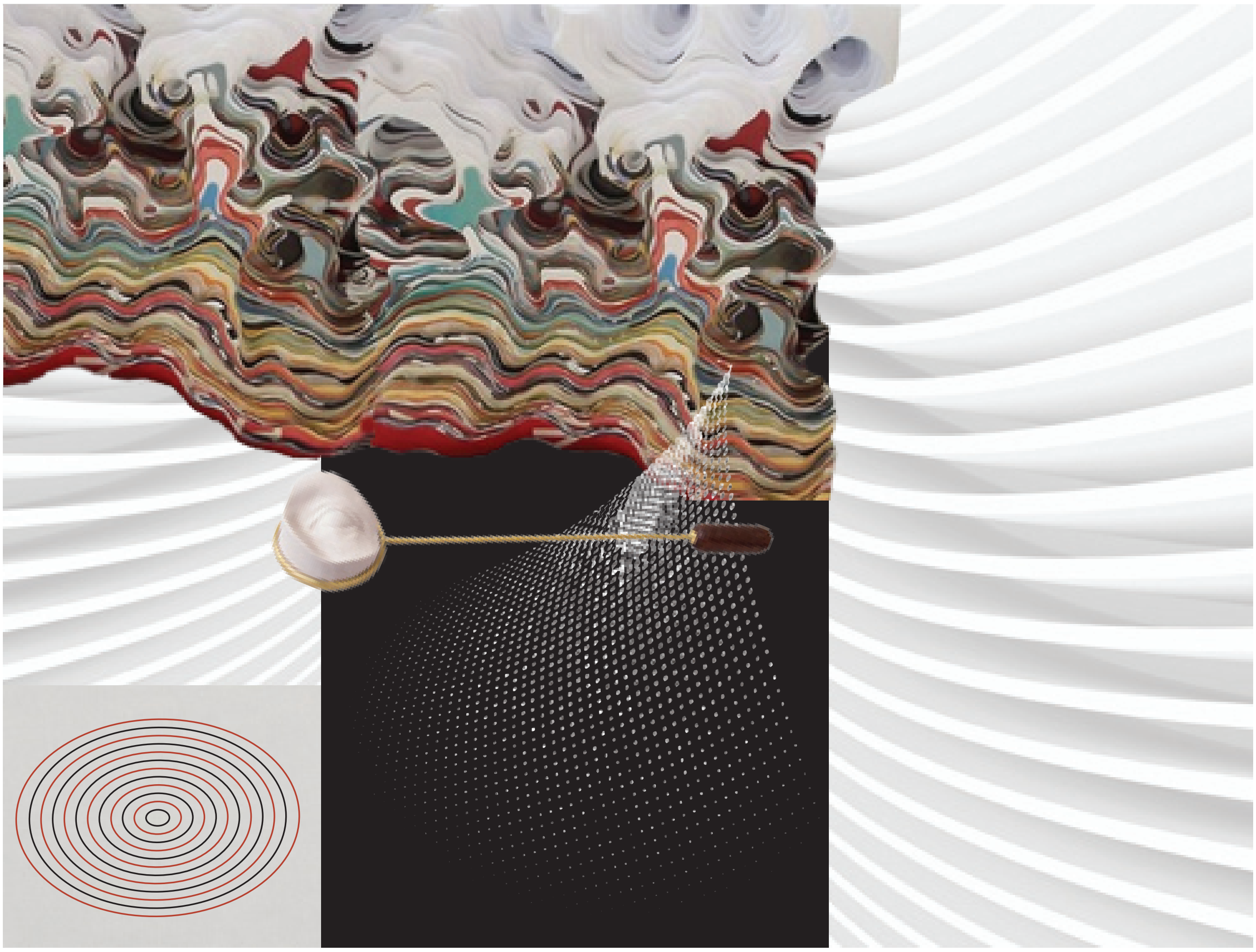
From Research Project to Research Portfolio: Meeting Scale and Complexity

Jonathan Linton, Nicholas Vonortas



Investment in research and innovation faces increasing scrutiny in countries that already do a lot of it.

How much investment is optimal?

How can we tell if and when our research activities offer less value for the dollar spent on them?

How can we ensure that the benefits of investments accrue to those who incur the cost?

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The mere scale of the scientific enterprise and its core role in the growth and well being of nations urgently requires a better understanding of the achievements and challenges to these investments [*Lane*, 2009]. The expanding volume and complexity of the enterprise — due to both the convergence of traditionally separate fields and the grand challenges science is asked to address (health, environment, energy, education) — fuel arguments for a reconfiguration of the existing systems of science and innovation to better serve society [*Kintisch*, 2006].

Scientists need to proactively engage in the discussion over the need to improve the efficiency and effectiveness of societal investments to ensure that the next generation of the management and decision-making process for our science, technology and innovation system is rooted in sound principles rather than shaped largely by political interests and budgetary concerns. We propose supplementing peer review with research portfolio evaluation approaches and decision-making tools that can better assess research uncertainties and other special features of the transformation of the resulting knowledge into improved social well-being. A coupling of research quality review by peers with more systematic portfolio meta-analysis of recommended projects is both possible and essential.

The need for change has been evident for some time. Both industry and public sector have gradually changed the way they account for research. In the public sector, GPRA was put into place by the American Congress twenty years ago and the Program Assessment Rating Tool (PART) by the Office of Management and Budget only a few years later (now retracted). Proposed changes can be dangerous. Recently the proposed High Quality Research Act [*Mervis*, 2013] created much unhappiness and tension in the United States. Nobody is against quality, but the demand to certify how each piece of the science-funding puzzle is needed independently for the future benefit of a country is a tall order. Yet, who can stop elected policy officials from making such “worthy” demands? Scientists can! By counter-proposing a principled research portfolio evaluation system allowing vast improvements in investment decisions. Rather than a radical proposition, this falls clearly within the Science of Science and Innovation Policy remit.

Challenges of the Peer Review System

While the peer review system has served science well, it has not been free of debate [*Feller*, 2013]. Chief concerns include: lock-in to existing trajectories of scientific inquiry and the difficulty of linking the best single research projects to the pragmatic challenges that society faces. None of this is insurmountable, but the opaqueness of scientific inquiry for the majority of the public (the ultimate user) combined with the perception that scientists are a ‘club’ — supported generously by society so that members of the ‘club’ can decide how to allocate funds to each other — has weakened public support. This perception can be reduced by the systematic use of research portfolios governed by appropriate objectives and appraised in responsible ways.

The use of objectives for research is a problem only if misapplied. Hence, the scientific community must state how they are applied. The existing concerns of outside stakeholders can be taken into account without violating the fundamental principles of the peer review system. We need to enhance the process of dividing research funds into smaller disciplinary or functional budgets, by further clarifying the objectives of each fund and by making a clear statement regarding subject coverage for each fund/portfolio — including insights into breadth, completeness of coverage, and even the research overlap and/or duplication that may be helpful. The overall risk and risk distribution must be specified. Finally, whether a portfolio is directed/undirected and focuses on a specific field, discipline or is multidisciplinary should be stated.

Having set objectives for each research fund, some enhancements of the peer-review process are required. Currently, the review system’s consideration of portfolio fit ceases once resources are assigned to a project fund. Successful implementation of a portfolio-based approach requires assessing both the inherent quality of the proposed research project and its similarities/differences in terms of subject content and risk with other projects under consideration. This modification still ensures that the best projects based on peer-review are selected. However, if lesser projects are ill-fitted with the objectives of the overall portfolio, they will be replaced with the next best peer-reviewed project(s) that fit the portfolio better. Portfolio-based peer-review committees will have to assess the risk and fit between projects, thus insuring that detractors cannot offer a rational argument against either individual or overall outcomes. Reviewers will undertake this task 'armed' with a toolbox that has been significantly enriched during the past couple of decades[1].

Moving to Portfolios

While the existing portfolio management knowledge infrastructure is advanced already, further developments are required given that scientific knowledge differs significantly from other investment subjects in which such methodologies are applied. Science projects and portfolios differ from their non-science counterparts (physical capital and financial investments) because the likelihood of sudden and extreme successes and failures is higher. They differ because of the presence of technological as well as market uncertainty. They differ because of intellectual property and the complications of imperfect appropriability. And they differ because science is cumulative — it typically builds progressively on previous results. The current state of the art for project and portfolio management of science, technology, and innovation confronts us with short, medium, and long-term needs.

In the short-term it is critical to abandon tools that while popular and appropriate for engineering economics, capital budgeting and financial analysis, are inherently biased against the desirable uncertainty associated with research. Tools such as NPV (Net Present Value) are counter-productive, appropriate only for projects with predictable outcomes and cash flows (such as a toll bridge)[2]. The lack of a priori predictability is a characteristic of science that must be accepted and embraced. The interrelation of projects — both synergies and duplication — must be considered as they lead to portfolio modification, thereby providing better overall value. Sufficient replication is needed to provide the necessary breadth and depth of research [*Nelson*, 1990]; this should be distinguished from careless duplication — such as duplicating infrastructure that has sufficient capacity to be utilized for multiple research projects. The challenges of cumulativeness of science and of the incomplete appropriability of results must be taken into consideration.

Several approaches for assessing research investment portfolios have been identified [*Linquiti*, 2012]:

- *Qualitative methods focusing on multiple objectives.* Projects are sorted into ad hoc categories based on a taxonomy of characteristics. Categories are then reconciled with overall organizational strategies and resources allocated;
- *Quantitative methods focusing on multiple objectives.* A weighted scoring system for each important attribute of research projects is used to provide an overall score for each project. Linear programming selects projects to maximize the aggregate score within the portfolio, subject to constraints.

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[1] Several agencies have such committees already, including NSF, DOE, NIH, etc. What we are really proposing is a significant extension of their role and their systematic use of formal analytical tools and models.

[2] $NPV\,(i) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$, where N is the total number of periods, t is the period under consideration, R is the return for period t, and i is the interest rate.

Alternatively, Data Envelopment Analysis determines the set of attribute weights that maximize the efficiency of each project.

- *Quantitative methods focusing on a single objective.* Non-linear programming methods consider the correlation between projects and, for a target portfolio return, identify the projects that offer the lowest variance in portfolio return. For complex portfolios that exhibit multiple non-linear relationships, non-standard probability distributions and complex decision rules, stochastic like Monte Carlo simulation are used.
- *Dynamic methods.* Interactions among research projects, economies of scale and scope, and complementarity/substitutability offer different risks and returns to alternative combinations and sequences. Real option and decision tree methods can be applied to determine alternative research portfolios [*Vonortas, Desai*, 2007]. Still largely untested in public sector research environments, these methods are quite promising and deserve a close look.

In the medium term, we need to obtain the most appropriate scope and balance of risk and return through the selection of a combination of high-risk high-return and lower-risk lower-return projects. Review procedures that better determine the term 'impact' could, for instance, be based on real options for methodologies to capture both potential upside benefits and downside costs (and failures) while utilizing critical peer review input for appraising technical risk [*Vonortas*, 2008]. Viewing a research portfolio as a set of options, this approach can vastly improve the handling of market and technical risk that affects research. It is dependent on committees of scientific experts providing core research features.

Of course, as scientific discovery has an underlying distribution that is non-Gaussian, we cannot adopt the tools of financial portfolio management unchecked [*Casault, Groen*, 2012]. Balancing research portfolios requires models able to deal with the inherent differences in the underlying distributions. Further development and testing on real research project portfolios is necessary. Research in real options [*Triantis*, 2003; *Brosch*, 2008] must address questions like: How does the performance of a research portfolio depend on the relationship among the likely performances of the research projects? What types of relationships drive the risk and the return of the whole portfolio? How can the information about these relationships be utilized to improve the process of research project portfolio formation?

In the long-term the need is to institutionalize research portfolio analysis, thereby, also abandoning the current common practice of accepting low risk projects utilizing traditional techniques, while approving high-risk projects on the basis of vague arguments of societal interest. Versatile analytical approaches capable of handling different levels of risk will replace the inherently negative term 'risk' with more neutral terminology reflecting both the positive upside and negative downside variations. Broad coverage of basic science must continue to avoid deep losses from ignoring unpredicted areas of future importance and their associated socio-economic benefits.

This goal is closer than it appears. A series of objectives associated with economic returns, societal benefits (e.g., health, environment, national security), risk tolerance, the coverage of different fields and disciplines, and degree of concentration on different parts of the discovery path from pure science to product development and application must be determined. Once these objectives are identified, the most suitable portfolio can be identified and eventually adjusted on a more dynamic basis — reflecting the acceleration of scientific progress and the convergence of traditionally separate fields. Interesting methods already under development [*Van Bekkum, Pennings*, 2009; *Zapata, Reklaitis*, 2010; *Bhattacharyya*, 2011] can become first-rate decision-making tools that prevent non-expert policy makers and managers from making simplistic statements justifying or rejecting research on the basis of emotional (rather than rational) appeal.

Implications

Differences between implications from applying conventional and portfolio approaches to research funding are represented in Figure 1. Each research project is like a piece of a puzzle. The classic peer review process (image on the left) tends to provide unintended overlap and allows for an ill fit between some of the pieces and unwanted gaps to occur. Areas of high risk and high return can be missed due to their controversial nature and split decisions typically resulting in negative funding decisions. Very high-risk projects (bright colors) are included in the system if they are deemed to be of national interest, thus circumventing split decisions. The portfolio approach (image on the right) includes more colors as it selects projects based on optimizing portfolio objectives, therefore not eliminating projects with split decisions which are the best available to satisfy a stated objective. In the classic peer review process, bright colors associated with high risk and a high frequency of split decisions have tended to be replaced with gray color associated with lower risk. The portfolio of projects provides a complete picture with good coverage of both field and risk level and no unintended overlap between projects. Still, the distortion of the target bands indicates that the portfolio approach is an improvement, not a panacea.

The implications of widespread use of research portfolio management are:

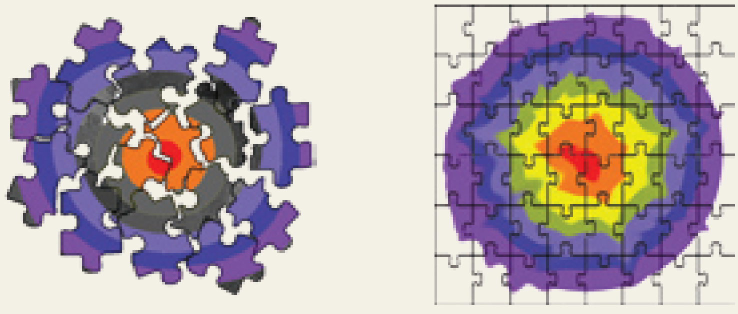
- Better allocation of resources:
  - decision-making based on the merit of both projects and entire portfolios of projects;
  - availability of early warning systems of 'gaps' in scientific inquiry;
  - ability to see the 'highways' between different types of research;
  - ability to holistically address the 'grand challenges' of research.
- Better justification of public resources for research: while risky research projects can — and should — fail, portfolios of projects are constructed so that the overall risk of technical and market failure is minimal.
- A leap forward in terms of greater value from our research base and clearer identification of extant gaps and opportunities, while preserving the critical role of the peer review system.

For enduring results, far-reaching policy actions are required:

1. Institutionalize portfolio methods of analysis and decision-making in the public sector and boost fledgling efforts in federal research agencies such as the National Institutes of Health (NIH), the National Science Foundation (NSF) and the Department of Energy (DOE) in the United States

Fig. 1. **Implications of project and portfolio approaches to research funding**

Project approach **Portfolio approach**



Source: compiled by the authors.

to move in that direction. In order to achieve this, one must consider the interrelation of projects as well as the risk/return trade-off for each project and between research projects that may or may not be part of the set of research projects selected. This depends on the availability of richer data both before and after program implementation that enables richer insights than is presently the case. It also requires program managers who understand how to use the information to assess the risk/return trade-off, the impact of correlation, synergy, and mutual exclusivity.

2. A new generation of research managers must be trained in the intricacies of science and technology policy and the complexities of modern decision-making support tools to ensure that portfolios are considered in relation to socio-economic objectives. Translating complex policy objectives into effective research portfolios remains partly an art — despite the emergence of numerous rigorous techniques — depending as it does on non-numeric decision-making processes.

3. Better define the 'impact' criterion in the evaluation of research proposals. Whereas individual projects are evaluated on their merit as sound scientific endeavors, their impact must be defined firmly in terms of association with and contribution to the broader objectives of the respective portfolio(s).

In conclusion, the scale and complexity of the contemporary technical enterprise as well as the convergence of traditionally distinct science fields has overpowered our current techniques for the management of science, technology and innovation. We echo the calls for a Science of Science Policy [OSTP, 1998]. More specifically we underline the urgent need for further developments in the support system of research management. The consideration of R&D as part of portfolio management offers a great leap ahead for obtaining greater value from our current research base and for clearly identifying the gaps and opportunities that will move us forward. F

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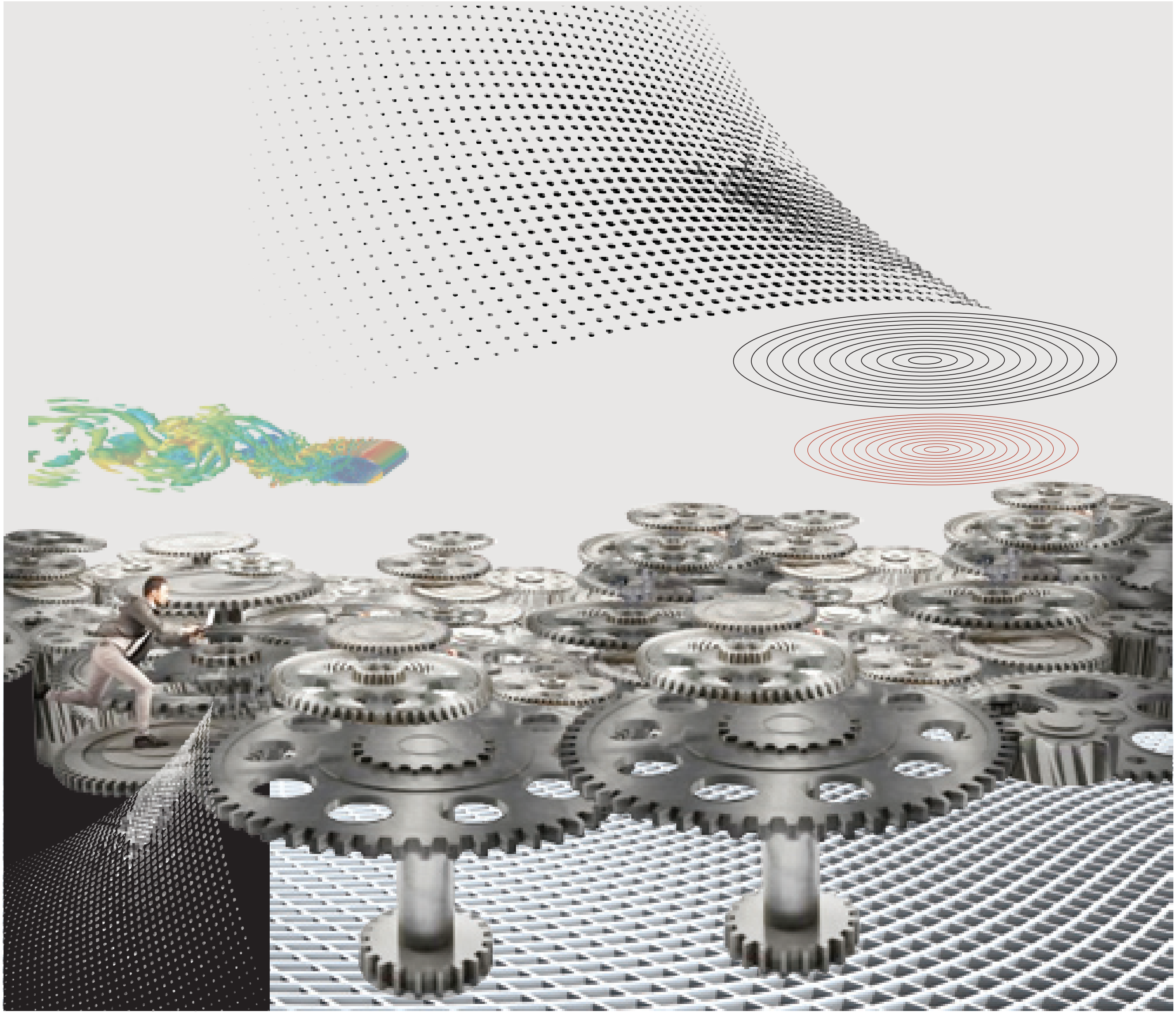
Entrepreneurship Theory:
New Challenges and Future Prospects

Alexander Chepurenko



To enable the sustainable development of the entrepreneurship theory its agenda needs comprehensive adjustments, and refocusing on new areas such as social, institutional entrepreneurship, etc. Research in the field should go beyond Western societies, covering the so-called transitional economies and emerging markets

There are some very important contextual differences between these societies, which make the entrepreneurship specific and make the investigation of new institutions and actors important, which might become challenging subjects of the future entrepreneurship theory.

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Entrepreneurship research is certainly one of the most dynamic areas within the cluster of socio-economic and managerial sciences in the last 20–25 years. This statement can be confirmed by the list of renowned international conferences held on related issues annually, the number of participants in these conferences, as well as by the growing number of leading international journals publishing on entrepreneurship.

The significance of the field was acknowledged by the launch in 1995 of the Global Entrepreneurship Research Award. This award has to date been bestowed upon more than two dozen outstanding thinkers who have had a big impact on the discipline of entrepreneurship, including David Birch, Bill Gartner, Scott Shane, Paul Reynolds, Isaac Kirzner, William Baumol, David Audretsch, Bengt Johannisson, Zoltan Acs, Josh Lerner and some other prominent scientists [HSE, 2013]. Moreover, one of them — William Baumol — was nominated for the Nobel Prize in Economics in 2014.

However, some questions concerning the self-legitimation and the future development of the field remain. The paper deals with the long-term prospects for entrepreneurship research.

First, there is the question of identity. Is entrepreneurship theory a well-established area of research or is it instead a field of intervention undertaken by representatives of economics, management, or social theory? The answer to this question depends on the definition of entrepreneurship theory. This paper argues that a new definition of entrepreneurship theory developed in the last decade may lead to not only a major conceptual shift but also to entirely new directions of research in other areas of the social sciences, which could be called the entrepreneurship research driven imperialism, its penetration into rather new areas of social research.

Second, our new knowledge on entrepreneurship is mostly derived from analyses of well-functioning and sustainable market economies. Are the approaches, concepts and the results in particular of such a 'Western-centric' theory relevant for other types of environments? What are the implications of broadening our geographical view?

Third, a research project's content, research methods, and organizational design may change because of developments in the IT industry. The ever-increasing penetration of social media may also offer new opportunities. To be entrepreneurial, entrepreneurship research should explore and use such opportunities.

Lastly, the audience of entrepreneurship research may also change. Now academicians, MBA students, and policy-makers benefit from the findings of entrepreneurship research. However, the situation is rapidly evolving, and new groups may become the recipients of entrepreneurship research.

It is the questions posed above that are discussed in the remainder of this article. We start with a short overview of the state of the art, then, we provide a short Foresight exercise of the prospective areas, actors, and research design of entrepreneurship theory in the future. A separate section is dedicated to entrepreneurship research in Russia. The article concludes with a discussion of fruitful avenues for further research in entrepreneurship.

State of the art and the identity problem

Since the 1980s, entrepreneurship has become a point of interest for many researchers in neighbouring fields, including management, economics, sociology, and psychology. First, following research that showed that small and medium sized enterprises (SMEs) create no fewer jobs than large firms, it became clear that the 'reevaluation of the role of small firms is related to renewed attention to the role of entrepreneurship' [*Wennekers, Thurik*, 1999, p. 28–29], as SMEs that establish new jobs are entrepreneurial 'by definition'. Later, another approach was suggested to explain the greater interest in entrepreneurship. This approach differentiated between managerial and entrepreneurial economies to identify the links between a post-materialist society and the new role of entrepreneurial activity in this context [*Audretsch, Thurik*, 2000; *Uhlaner, Thurik*, 2007].

The issue is less related to the post-materialism paradigm itself, and more related to the accompanying slowdown in the global economy in the last decade. Additionally, there is evidence that the fifth long wave of economic development is entering its final stage [*Hargroves, Smith*, 2005]. Only entrepreneurial creativity can help to speed up the growth of gross domestic product (GDP) and secure a stable increase in the wellbeing of nations.

Second, the rapid development of empirically based entrepreneurship research in the 1980s and early 1990s was in many ways inspired by the rising demand for entrepreneurship and/or leadership programmes in the business schools of leading Anglo-Saxon universities. Therefore, since then the entrepreneurship division has been one of the top sections in the Academy of Management in the USA based on the number and intensity of its members. Undoubtedly, such a close link to business schools had, and continues to have, a considerable impact on the character of research, which was primarily oriented on two core problems: who starts up a new business, and what are the (non-financial) pre-conditions of successful business growth? In that light, entrepreneurship research could be understood as an integral part of management.

Meanwhile, the development of the field in the 1980s was quite extensive. In the mid-1990s, another important factor influenced research on entrepreneurship. This was the transition of the economic system of several former socialist countries in Asia and Europe. Transitional studies from the very beginning brought new insights to the field of entrepreneurship. The path dependence paradigm soon transformed into a more precise study of entrepreneurial contexts in the new market economies and the influence of the institutional environment on the specifics of the performance of SMEs and of entrepreneurial strategies [*Earle, Sakova*, 2000; *Smallbone, Welter*, 2001; *Ovaska, Sobel*, 2005; *Smallbone, Welter*, 2009; *Aidis et al.*, 2010; *Welter, Smallbone*, 2011]. Second, the success of international, longitudinal projects such as the Panel Study of Entrepreneurial Dynamics (PSED) (and the Global Entrepreneurship Monitor (GEM) has meant that vast quantities of reliable, quantitative data are now available for comparative research on early entrepreneurial activity across nations [*Reynolds et al.*, 2005]. Third, the idea of a contextual approach [*Welter*, 2011] won many supporters; societal and social framework conditions and their impact on entrepreneurship became a focus of many projects and publications.

As a result, the field was characterized by spectacular growth, and the set of topics and theoretical concepts used in the literature widened significantly during the first decade of the 21st century [*Busenitz et al.*, 2003; *Uhlaner*, 2003; *Ireland et al.*, 2005; *Xheneti, Blackburn*, 2011; *Carlsson et al.*, 2013]. Moreover, other researchers have analysed the achievements in particular areas, such as social entrepreneurship [*Dacin et al.*, 2010], sustainable entrepreneurship [*Hall et al.*, 2010], cross-cultural entrepreneurship research [*Engelen et al.*, 2009], entrepreneurship in emerging economies and developing societies [*Naudé*, 2010; *Kiss et al.*, 2012], and methods in entrepreneurship research [*Short et al.*, 2010]. Now entrepreneurship research seems to be theoretically well supported. Broadly accepted theories exist at all levels (macro, mezzo, and micro) and are supported by various core scientific domains.

However, as research studies have become more longitudinal and more intensive, it has become evident that not all (small) firms are entrepreneurial firms (see for example, [*Shane*, 2009]). The majority of firms are unable to survive, with growth being the exception rather than the rule. Similar problems emerge when researchers try to link entrepreneurship theory with innovation. Innovation is not an intrinsic attribute of every firm; hence, many activities of new ventures and already established businesses would be ignored when using such a theoretical framework. The same is true when speaking about the establishment of new organizations, as in this case the development of already existing firms does not matter. Hence, a reconsideration of the field's definition is needed to remove 'political and methodological biases' [*Nightingale, Coad*, 2013].

Nevertheless, at the beginning of the last decade some debates around the core questions of the field occurred. First, the question of legitimacy: is entrepreneurship research a separate field, or rather a sub-field of research in more traditional areas? It is argued that any attempt to view entrepreneurship as something combined with (only) the creation and growth of small firms leads to a clear recognition that entrepreneurship is a sub-field of strategic management [*Shane, Venkataraman*, 2000, 2001].

Besides, every mature field of research seeks legitimacy, which is achieved when it moves from phase 1 ('pre-paradigm') to phase 2 ('normal science'). This transition to phase two is based on a widespread consensus about the appropriate methods, terminology and the kinds of experiments that may contribute new insights [*Kuhn*, 1962]. It is also important because such a consolidation is key for defining possible areas which may lead to new insights and research methods. The possible answer that we tend to accept and support is that the entrepreneurship research can be understood as a homogeneous field primarily in terms of the phenomenon of the 'emergence of new economic activity'. As a starting point, it is broad enough to cover different forms of establishing new economic activity; it implies the usage of different methods; it is appropriate in economic, social and behavioural sciences; and finally, it embraces micro, mezzo, and macro-levels of analysis.

However, in this case, not all aspects related to already established businesses — with the exception of intrapreneurship — refer to entrepreneurship research. On the other hand, several phenomena in other areas can be the subject of entrepreneurship research. These include social entrepreneurship [*Lyon, Sepulveda*, 2009; *Choi, Majumdar*, 2014], ecological activity to secure the earth's resources [*Patzelt, Shepard*, 2011; *Parrish*, 2010], and a theory bringing challenging insights into the understanding of human behaviour [*Shane*, 2009] and its logic [*Sarasvathy*, 2001].

Second, a discussion about the concordance between conceptual definitions of key phenomena and empirical observations might have some importance for empirical research in the field. We already have a wide range of proven methods to study entrepreneurship as the 'creation of new organizations' [*Gartner*, 1988]. However, we lack methods to collect empirically robust data on entrepreneurship defined as the 'creation of new economic activity' [*Davidsson, Wiklund*, 2001] or 'opportunity discovery and exploitation' [*Shane, Venkataraman*, 2000].

Prospects for entrepreneurship research as a field: prospective areas, actors, and research design

A theory can be manifested as a substantive field on its own within the scope of the social sciences if it is has a more or less consensual approach to the main research objectives, and shared views on the most fruitful research methods and expected outcomes. The same approach should be used when discussing the prospects of entrepreneurship as a theory.

The research area is defined by the sort of research questions that form a starting point of any new research project in the field. Following Shane and Venkataraman [*Shane, Venkataraman*, 2000], the fundamental starting points in entrepreneurship research could be formulated as follows: 'how, why, and when do entrepreneurial firms discover and exploit opportunities?'

Such an approach enables an intervention in subjects beyond the narrowly defined commercial areas, such as social entrepreneurship [*Austin et al.*, 2006; *Mair, Marti*, 2006] and its impact on the design of state-society relations; and institutional entrepreneurship [*Greenwood, Suddaby*, 2006; *Maguire et al.*, 2004] and its impact on the role of traditional sources of institution building (state, civil society).

Moreover, the paper deals with some unavoidable trends in future entrepreneurship research, resulting from a geographical expansion (encompassing the former socialist economies, and countries in the global south and east) and involving the entrepreneurial actions of people with totally different sets of resources, capital, and societal norms.

New areas

Entrepreneurship research was born in steadily developing, Anglo-Saxon market economies as a reflection of the dominating ideology of creativity, risk-taking ability, and the need to achieve on a personal level, and the growth aspiration and profit drive of private commercial firms. The concepts of the role of entrepreneurship [*Schumpeter,* 1936] and the driving motives of an entrepreneurial human being [*McClelland,* 1961] are abstractions that are characteristic of this group of societies, with their inherent forms of economic development.

However, in the contemporary world, there are new areas where entrepreneurship, in the sense in which we defined it above, is becoming increasingly important. First, there are **poor countries with resource-driven economies** (according to the World Economic Forum, WEF). In these countries, the exploration and exploitation of opportunity become a single possibility to secure a more or less acceptable wellbeing. As the data of the GEM for a several years show, the level of engagement in entrepreneurship is much higher in poor, resource-driven economies than in established market economies. Of course, in this case we see another kind of entrepreneurship — one driven by necessity rather than by opportunity, often based on social capital, and one where entrepreneurs' economic and human capital is rather limited. Hence, its specifics can only be understood within the existing framework conditions in these societies. For example, extended families and their resources play a significant role in establishing entrepreneurial ventures; remittances (immigrant money transfers to the home country) are important as a source of financing for domestic businesses; and the specifics of female entrepreneurship as a chance to become semi-independent from male dominance and household labour. All these factors may be of significant interest and importance to understand the chances and constraints of entrepreneurial activity in these countries. Besides, the big differences between the various countries in this group also influence the speed and type of entrepreneurial development. Above all, the type of state policy serves as a framework for the development of private ventures: for example, we can identify the Royal Cambodian model, the Doi-Moi model, and others [*Dana,* 2007]. However, to date only a few books and papers have been published and look at entrepreneurship in these economies [*Fick,* 2002, 2014; *Naudé,* 2010; *Herrington, Kelley,* 2013; *Simons,* 2012].

The second area of rapid growth of a non-Anglo-Saxon entrepreneurship model is in the **developed Asian societies** such as Japan and the new Asian tigers. Embedded in a strong state-dominated framework, the attempts to build an entrepreneurial community in Japan, the enlightened dirigiste political leadership in Singapore, or the crisis-driven developments in South Korea have had a massive impact on the formation of entrepreneurial strategies and visions of entrepreneurial success [*Dana,* 2007].

The third new area of entrepreneurship development is in **countries undergoing a process of systemic transition**. At the beginning of the process of systemic changes, most experts were very enthusiastic about the prospects for a market economy and democracy in countries of Central and Eastern Europe (CEE) and the Commonwealth of Independent States (CIS). The boom of the bottom-up, 'Schumpeterian' entrepreneurship seemed to become an evident inception stage and the inevitable condition of any modernization of economies and societies. Privatization should establish pre-conditions for it, and the transfer of Western experiences in, for example, SME policy was assumed to support a rapid development of newly established businesses. However, by as early as the mid-1990s, it became clear that the intensity of entrepreneurial start-ups and the entrepreneurial activity of the population overall were lower than expected in most of these countries.

As recognized by experts, privatization has not created more possibilities for entrepreneurship. Instead, in many post-socialist economies, privatization enabled a seizure of the most efficient assets either by the former 'nomenclature' or by large transnational companies, and led to so-called 'predatory entrepreneurship' [*Feige,* 1997; *Spicer et al.,* 2000; *Scase,* 2003]. Top-down created businesses appeared as a result of redistribution of former state-owned assets by political entrepreneurs using their informal connections with some decision-makers [*Rehn, Taalas,* 2004]. In contrast, the majority of bottom-up entrepreneurs (mostly micro and small firm owners or solo entrepreneurs, termed 'proletarian' businesses here because they do not own a significant portion of the resources that they use) continue to rent their production facilities and other material resources, even after 20 years. Their income is insufficient to buy out their premises.

Despite the more than two decades of systemic changes in the CEE and CIS countries, entrepreneurship under 'transition' is still under-investigated. Fruitful research attempts should study this phenomenon in different (and diverging) *contexts* of 'transition'. The most challenging questions are:

- How the interplay of formal and informal institutions and networks influences different models of entrepreneurial behaviour [*Rehn, Taalas,* 2004; *Batjargal,* 2006];
- The role of 'institutional traps' emerging in the process of transferring institutions and 'best practices' (some research has been carried out on the evolution of SME and entrepreneurship policy under 'transition': see, for example, [*Smallbone, Welter,* 2001]), and how these 'institutional traps' are reflected in weak outcomes of entrepreneurship in some of these countries;
- The variety and heterogeneity of productive, unproductive and even destructive entrepreneurial types under 'transition' [*Rona-Tas, Sagi,* 2005; *Sauka, Welter,* 2007].

Quantitative measurements need to be embedded into theoretical explanatory models that are based on qualitative analysis of the specifics of entrepreneurial and not on geopolitical presumptions (EU versus non-EU membership etc.). Some concepts of new institutional theory, such as different types of 'access orders' [*North et al.,* 2010] and different types of entrepreneurial behavior, may be useful to recognize the specifics of entrepreneurship performance within different institutional settings.

Furthermore, it is evident that the economic and socio-political systems of the 'transitional' economies and societies, as well as their entrepreneurial profiles [*Smallbone, Welter,* 2001; *Ovaska, Sobel,* 2005], are increasingly diverging. In fact, the term 'transition' now seems to conceal more than it reveals. Today, the term 'transition countries' is not a homogeneous group but rather a geopolitical label. In fact, the so-called 'common past', which shaped similar entrepreneurial framework conditions (EFC) at the start of the systemic 'transition', was rather an oversimplified idea. In reality, despite some commonalities, socialist economies and societies showed as many differences as there exist between the so-called 'Western' economies and societies, so it is appropriate to consider the 'varieties of socialism'. Moreover, the trajectories of transition made by these countries differed from the very beginning.

The fourth new area of entrepreneurship development is in **contemporary China and India**. The rationale for inclusion is not only because of the current incremental growth of entrepreneurial ventures (and especially the more intensified growth expected in these countries in the nearest future) [*Khanna,* 2008], but also because both these countries cannot be understood within the paradigms of 'transition' or 'third world'. China is not a transition economy as the introduction of market institutions is managed by the communist party which preserves political dominance. According to [*Jonas et al.,* 2013], entrepreneurship in China is very different to that found in Western economies in several ways. First, entrepreneurs who succeed in China have mastered 'integrated innovation': the skill of re-inventing any existing business idea to meet the demands of Chinese consumers. Often starting with Western-styled products, after many iterative steps of localization the end product differs significantly from the initial one. Second, Chinese entrepreneurs have a deep knowledge of the specifics of the Chinese economy which remains relatively closed to the rest of the world. Nevertheless, Chinese citizens continue to find ways to circumvent barriers and procure ideas from abroad, creating pent-up demand for new goods and services. Successful entrepreneurs are filling these gaps. Finally, Chinese entrepreneurs are aware of political constraints and are always aware of the possibility of government intervention. To avoid undesirable policy changes, some choose to enter lightly regulated sectors, while others try to comply with the five-year procurement plans. To date, we have little reliable empirical data on the development of entrepreneurship in China, and few academic papers deal-ing with the specifics of the Chinese ecosystem of entrepreneurship where formal and informal networks may play an important role [*Wong et al.*, 1995; *Liao, Sohmen*, 2001; *Zhang et al.*, 2006].

India is a country with high inequality and a large share of poor population, and yet its economy is growing in a much more dynamic and impressive way than in most developing countries. Moreover, the co-existence of necessity driven entrepreneurship [*Sridharan et al.*, 2014], especially among women [*Torri, Martinez*, 2014], under the predominance of the caste system in rural areas [*Folmer et al.*, 2010] and the clusters of modern, dynamic entrepreneurial firms in urban agglomerations are challenging topics for prospective research [*Koster, Kumar Rai*, 2008; *Monsen et al.*, 2012].

Besides the geographical broadening, there are other dimensions to the expansion of entrepreneurship research that go beyond the narrowly defined commercial aspects, such as social entrepreneurship. The development of this form of entrepreneurial approach to social problems has a twofold nature: first, the embedding of ideas of social responsibility, tolerance and solidarity into the middle classes in Western societies; second, a serious shortage of state budgetary funding to tackle urgent social problems both in Western and poorer countries of the world particularly. This empowers social entrepreneurs to influence the design of a new system of state-society relations. Features of this trend are ecopreneurship, driven by the idea of sustainable economic development and decreasing resources consumption, and institutional entrepreneurship.

Eisenstadt first used the notion of 'institutional entrepreneurship' [*Eisenstadt*, 1980]. DiMaggio used the term to characterize actors with sufficient resources to contribute to the genesis of new institutions in which they see 'an opportunity to realize interest that they value highly' [*DiMaggio*, 1988, p. 14]. However, the interplay between institutional entrepreneurship and the mainstream types of entrepreneurship has not been sufficiently studied. Some authors [*Phillips, Tracey*, 2007] have argued that an intensive dialogue is needed between these two traditions. Namely, a promising strand of future research would further examine not only how existing institutional arrangements influence entrepreneurship activity, but also how entrepreneurs can shape those arrangements. This issue is especially promising when looking at emerging market economies.

New actors

As the mainstream literature on entrepreneurship is based on both the facts as well as social and societal patterns of Western — particularly of Anglo-Saxon — societies, it usually assumes that an entrepreneur is an 'Anglo-Saxon' (sharing Protestant values, driven by opportunities) and who operates in a mature market economy and democracy. The single exclusion is an immigrant, or ethnic entrepreneur, but even he/she is trying to use resources and capital available to them to establish a sustainable business which would enable him/her to integrate into the host economy and society.

However, in the future, as entrepreneurial practices from beyond the area of traditional entrepreneurship research are integrated, the research approach will have to undergo unavoidable changes. These entrepreneurial practices are in 'other worlds' where different societal norms and values dominate, the market economy is less sustainable, and political regimes are either rigid or fragile. The new approach should take into consideration that when exploring and exploiting opportunities, people do not always have growth and wealth creation as their ultimate goals and criteria of success; that a high level of informality will be inherent and remain a long lasting strategy rather than an episode in processes of creating start-ups; that different incentives to become entrepreneurial may play important roles (for instance, independence from the clan or family, or further immigration, etc.); and that the concept of unproductive and destructive entrepreneurship [*Baumol*, 1990] may become quite important to understand the business behaviour and pragmatic strategies of entrepreneurial firm owners.

Another new important actor could be the 'olderpreneur', or an entrepreneur who entered into a new business after the age of 50. Current entrepreneurship research is primarily focused on young and well-educated actors in start-ups.

However, the world is changing: societies are ageing rapidly and improvements in wellbeing and healthcare have an impact on both the possibility (including through increasing the amount of accessible financial sources) and the ability and motivation of older people to explore entrepreneurship as a new opportunity. Until now, this entrepreneurial cohort has been under-investigated [*Curran, Blackburn,* 2001; *Vickerstaff, Cox,* 2005; *Mallett, Wapshott,* 2015].

Semi-skilled IT-entrepreneurs might become the third new actor in the field of entrepreneurship in the immediate future. To date, entrepreneurship in high tech industries has been understood primarily as a domain of well-educated techno-starters. Yet because of the level of IT technology already achieved, some IT-based entrepreneurship does not always require as high a level of specific knowledge and skills as in the past. For instance, in businesses using IT technologies as a 'black box' to improve selling practices or logistics, having a high level of alertness and a native born ability for effective management behaviour is much more important. Hence, some creative entrepreneurs who do not possess advanced knowledge about new technologies yet have a feeling for new niches and options in the development of virtual services and solutions can become successful and create another cohort of entrepreneurs.

Furthermore, new forms of labour relations and the rise of freelancing provide incentives for many freelancers to create their own business. Traditionally, the literature considers freelancing as an innovative form of professional career [*Dyer,* 1994; *Bögenhold et al.,* 2014]. Yet, the transition from a typical 'portfolio' career to business is a rather new field of research. We assume that in the near future interest in longitudinal studies looking at the transformation from self-employed to entrepreneurs will become more important.

New social technologies as well as the penetration of entrepreneurship into traditional societies should also attract researchers' attention to forms of start-up financing which have hardly been investigated before, such as crowdfunding in established market economies [*Tomczak, Brem,* 2013; *Fraser et al.,* 2015] or Islamic banking and its role in the development of entrepreneurship in Muslim societies. We are confident that the expansion of crowdfunding practices, above all in social entrepreneurship [*Lehner, Nicholls,* 2014], and in start-up financing [*Frydrych et al.,* 2014] will shift the focus of analysis of lending practices to a relatively new group of portfolio investors [*Belleflamme et al.,* 2013]. These investors belong neither to the cohort of professional business angels, nor to the famous '3Fs' (friends, family, and fools) as they would expect a certain reward on their investment and compare this future reward with the reward from alternative investment possibilities.

The expansion of Islamic banking in Muslim countries in the last few decades has been spectacular. Nonetheless, only a few papers have been published that examine the role of this specific system of risk and profit sharing between the bank and its clients in entrepreneurial ventures. These studies are mostly concerned with explaining the moral and philosophical foundations [*Baki Adas,* 2006; *Elfakhani, Ahmed,* 2013]. There is a huge shortage of empirically based studies on the financial infrastructure for entrepreneurship in Islamic countries ('Sharia compliant finance') and its impact on entrepreneurs' attitudes toward the uncertainties and risks associated with their business strategies.

Research design and methods

Entrepreneurship research must also address some design and methodological challenges. First, despite some very successful projects which have produced a lot of comparable empirical data (such as the aforementioned GEM and the PSED), we still have a shortage of longitudinally designed projects. Therefore, entrepreneurship research has to make do with predominantly cross-sectional research designs, which produce non-cumulative and inconsistent findings. Meanwhile, entrepreneurship research has become increasingly international and the most interesting studies are based on intensive cooperation between scientists from different countries and continents. A certain level of collective trust and a shared approach to the expected outcomes of empirical studies would help more collaboration develop, at an institutional level as well. We expect that in the future, international organizations, consortia of leading business schools, and business associations would collaborate on longitudinal projects. Such projects would have a significant impact on research, education and on the development and implementation of policy recommendations for fostering entrepreneurship internationally.

The internationalization of research projects will push researchers to become more interdisciplinary in their approach to data analysis. The reason is that the biggest problem of any comparative study is insufficient understanding of the socio-political and economic contexts of the data. There is no value in comparing non-comparable phenomena: entrepreneurship in established market economies vs. entrepreneurship in 'transitional' societies or emergent markets. More inter-disciplinary wisdom would be needed for a deeper understanding of societal norms, traits and attitudes, and the typical economic practices governing in different environments.

The fact that some new areas of entrepreneurship research will show significant qualitative changes in their framework conditions in the future — and consequently, changes in the forms of entrepreneurial activities and business norms and strategies — means that more good qualitative research (case studies, panel studies, etc.) will be needed.

The subjects of research are not alone in expecting changes in the future; we expect the methods for doing research on entrepreneurship to also alter in the future. 'Big data' mining [*Dahl*, 2010; *Tirunillai, Tellis*, 2014] and 'single source' [*Cannon et al.*, 2007; *Petrescu*, 2013] methods from marketing research will become widespread in entrepreneurial research. Moreover, focused enactive research [*Haskell et al.*, 2002] — not necessarily in the form already used in entrepreneurship literature [*Johannisson*, 2011; *Fletcher*, 2011; *Steyaert, Landström*, 2011] — will be used instead to create and moderate special focused groups in social media [*Cooke, Buckley*, 2008]. This kind of enactive research would enrich the palette of methods to discover the attitudes, perceptions, and self-representations of entrepreneurs.

Hence, more collaboration with different commercial providers of household and individual data (for example, data on consumer behaviour and expenses, financial strategies, economic engagement, attitude towards advertising) would bring new insights into entrepreneurial activities and entrepreneurs' behaviour, entrepreneurs' motives, and existing constraints. This approach would reduce the need for expensive empirical surveys, yet ethical questions concerning the research remain. It is much easier to guarantee the anonymity of respondents through data collected via traditional surveying than to provide data confidentiality when accessing the databases of market researchers [*Nunan, Di Domenico*, 2013].

New audience

To date, the audience of entrepreneurship research results has been quite traditional: academics, policy makers, entrepreneurs, and students. However, as entrepreneurship research is likely to encompass areas connected to other types of activities in the future, especially the third sector, some of the findings (in particular, the social implications of entrepreneurship, and the innovative practices of social and institutional entrepreneurship) might be of interest for a broader audience. Consequently, the definition of 'entrepreneurship' itself would be subjected to a certain amount of change.

Demand for new communication tools and platforms is growing (not only academic and business journals, or briefings for media and policy makers, but also social media). Furthermore, entrepreneurship researchers themselves should be prepared to become involved as policy advisors and in policy-making processes.

Entrepreneurship research in Russia: challenges

Entrepreneurship theory in Russia is under-developed. There are neither scientific journals nor conferences, and only very rarely do articles appear in leading journals in economics, management or sociology. At an institutional level, there are no centres of excellence which would carry out on a permanent basis research on entrepreneurship and provide methodological and organizational support for educational programmes in universities. Even in the area of applied research and policy advising, there are only 2–3 active institutions with a sufficiently high level of professional expertise. The achievements of international entrepreneurship research remain either unknown or ignored (with a few exceptions including [*Chepurenko, Yakovlev,* 2013; *Chepurenko,* 2013a, 2013b]. Often, entrepreneurship is not recognized as an academic discipline and instead only seen as a contingent field providing 'useful knowledge' (answering questions such as 'how does one become an entrepreneur?' or 'which support measures do SMEs need?')

There are several reasons for such a state of affairs. These include: i) the weakness of the market economy overall; ii) the limited receptivity to ideas that were developed by observing entrepreneurship in a dynamic, developed economy and 'the dominance of "unproductive entrepreneurship"'; iii) the very limited readiness of business schools and management programmes to pursue their own research projects in the field of entrepreneurship; iv) lack of research funding, etc. (for more detail, see [*Chepurenko,* 2013b]).

What are the most pressing areas of entrepreneurship to be explored by Russian researchers in the first instance? Below we summarize our recommendations as a detailed discussion will be the topic of another paper:

- Predatory entrepreneurship as a specific type of entrepreneurial behaviour and its roots (not only path dependence but also some institutional traps which emerged during the transition period);
- Ethnic entrepreneurship of immigrant groups, as well as the role of remittances from immigrants working in Russia as sources of business financing in their home countries;
- Clusters of informal entrepreneurs[1];
- Formats and mechanisms for hiring and employees' control in Russian entrepreneurial firms (there is empirical evidence suggesting that most Russian firms react to demand constraints in a very different manner than firms in established markets; yet, the strategies of labour relations used by Russian firms have been studied much less);
- Diversity of forms and levels of entrepreneurial activity in different contexts and types of settlements (contemporary urban agglomerations, big industrial centres, medium and small sized towns with tightly knit networks of just a few entrepreneurs, and rural areas with a developed agricultural economy);
- Innovative entrepreneurship and its constraints at macro-, mezzo- and micro-levels (from the role of the national innovation system to that of higher schools and academia in promoting entrepreneurship);
- Social entrepreneurship and its future prospects in a lower-income, individualistic society such as that in Russia.

Moreover, a developed academic community with the appropriate institutions, with a suitably formalized status, and endowed with effective mechanisms for self-renewal such as graduate-level university programmes, is needed. However, to develop entrepreneurship research, a radical transformation of the socio-economic environment toward an entrepreneurially friendly ecosystem is needed, as well as major changes within the educational and research systems. This includes, for example, establishing entrepreneurial universities, which could exist within the framework of a national innovation system, in turn based on a triple helix model. In the current state of Russia's society, entrepreneurship research will remain marginalized.

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[1] The semi-closed economy of the former 'Cherkizon' market in the centre of the capital city became a motivating factor for new federal level policy; meanwhile, clusters of shoemaking, textiles, and handicrafts industries in some republics of the North Caucasus, which have very specific types of local entrepreneurial ecosystems are not subjects of entrepreneurship research.

Conclusion

Entrepreneurship research is (still) challenging, as it has many open questions and opportunities to develop one's own career trajectories and intervene in related areas.

Given that entrepreneurship practices are changing over time, entrepreneurship researchers should be also prepared to change. They should be ready to consider studying new areas, new actors who become entrepreneurs in the 21st century, and master new research designs and methods.

First, a broader view of entrepreneurship enables researchers to open up possibilities for studying domains that were previously never accepted as areas of entrepreneurship research. It also means that it is possible to define entrepreneurship theory as a specific discipline rather than as part of any of the 'bigger' social disciplines such as economics, management, or sociology. If entrepreneurship research were to insist on a narrower definition (the creation of new organizations, or just of small business), it would not only reduce the possibilities for discovering new and promising research directions, but it would also confine it as a sub-field of one of the more traditional disciplines.

Second, a major geographical and societal shift should occur in prospective entrepreneurship research. This shift would reflect the fact that business is developing not only within the well-studied Western contexts but also (perhaps even to a greater extent) within the very different environmental and societal constraints and pre-conditions found in developing countries, in giant markets such as China and India, and in 'transitional' societies.

Third, it becomes not only possible but also obligatory to undertake cross-country, comparative analyses of entrepreneurship that are less formal, yet more substantial. That means researchers should treat entrepreneurship contextually, and avoid making superficial comments and policy recommendations.

Fourth, as new social strata and cohorts are increasingly engaged in entrepreneurial activity, they should be studied by entrepreneurship research; their backgrounds and previous experience, specific sets of entrepreneurial resources, aspirations and traits, and strategies of entrepreneurial action. Such an approach would open up more possibilities for representatives of social anthropology, ethnography, and cultural studies to participate in entrepreneurship research.

Fifth, the development of new technologies for data computing, storage and analysis will enable researchers to turn away from expensive surveys in some cases. Social media will bring new possibilities for enactive longitudinal research techniques to track in detail changes in both peoples' minds as well as entrepreneurial practices over time. F

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Long-term Stochastic Forecasting of the Nuclear Energy Global Market

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As a result of a number of catastrophic events in the nuclear energy sector, the increasing attention paid to the industry has acquired an undesirable and negative nuance. At the same time, this key economic industry — with high innovation potential — has achieved significant progress in making energy production more efficient and reducing production costs.

The authors of this article set out their own model to assess the future state of the nuclear energy market and present the results of their calculations of the expected volumes up to 2035, with several significant implications for policy changes in this sphere.

Strategic forecasting is critical both for global and local nuclear energy markets and even certain players in the industry. The nuclear energy market is characterised by high levels of persistence due to the long time-frames required for designing, constructing and operating nuclear power plants (NPP) which can take up to 100 years or more. In this article the nuclear energy market refers to the network of interrelated networks characterised in terms of physical volumes of several interrelated markets, such as:

- the construction and decommissioning of NPPs (expressed as the number of reactors or their electricity capacity in GW);
- natural and enriched uranium (in tons, tU);
- uranium enrichment services (in separative work units, SWU).

The main players in these markets are governments, state-owned and private companies, and international corporations. They are all interested in minimizing the risks in making decisions in technological, economic and political issues. One of the tools used to reduce these risks is regular publications by several international organizations and major energy companies containing industry development forecasts and the contributions of nuclear energy to the structure of the fuel and energy sector (FES) in certain countries, regions and the world as a whole. The most authoritative of these sources include the International Atomic Energy Agency (IAEA) [IAEA, 2014a, 2014b], the World Nuclear Association (WNA) [WNA, 2013, *Emsley*, 2013], the International Energy Agency (IEA) [IEA, 2012, 2014], the US Department of Energy (DOE) [DOE, 2014], the European Atomic

Energy Community (EURATOM) [European Commission, 2012], Ux Consulting Company, LLC (USA) [Ux Consulting, 2013; *Carter*, 2014], the Energy Research Institute (ERI) of the Russian Academy of Sciences (RAS) [ERI RAS, 2013], and the two energy companies ExxonMobil [Exxon Mobil, 2013] and British Petroleum [BP, 2013]. The regular reviews and development forecasts of the global energy market published by these organizations make a significant contribution to global debates on the future prospects of the industry.

The overwhelming majority of publications are based on so-called 'scenario approaches' to long-term forecasting, with a 20–30 year horizon. There are three main types of scenarios: pessimistic, moderate and optimistic (or, using the WNA's terminology, *lower, reference* and *upper*). The scenarios outlined in the forecasts of international organizations [IAEA, 2014a, 2014b; WNA, 2013; *Emsley*, 2013; IEA, 2012, 2014; DOE, 2014; European Commission, 2012; Ux Consulting, 2013; *Carter*, 2014; ERI RAS, 2013; Exxon Mobil, 2013; BP, 2013] are based on an analysis of the energy strategies of particular governments (both those with operational NPPs and those planning to construct NPPs) and take into account the economic development trends of these countries and the world overall. Virtually all forecasts show significant discrepancies between the three types of scenarios after 2020. Forecasts in 2013–2014 point to a lower growth in nuclear energy compared with earlier forecasts in 2011 (see for example, [WNA, 2011, 2013]). The pessimistic scenario reflects the political consequences of the incident at the Fukushima NPP, with construction plans reduced in developing countries and several reactors shut down in developed countries. The WNA's moderate scenario from 2013 assumes growth in the capacity of NPPs from 364 GW in 2011 to 574 GW in 2030, an increase of roughly 60%. The optimistic scenario anticipates the completion of established NPP construction projects in all countries and the extended operation of existing plants. The capacity of NPPs will grow by a factor of 1.9 to 700 GW.

Some of the discrepancies in the nuclear energy development scenarios by the aforementioned organizations and companies are largely linked to their attitudes towards 'green energy' (solar, wind, etc.) and the greenhouse effect from the use of hydrocarbon-based fuel, with virtually none of these forecasts offering any serious alternative to nuclear energy. Only the authors of the study by NIKIET (the Research and Development Institute of Power Engineering) [*Avrorin et al.*, 2012], which had a forecasting horizon up to the year 2100, pointed to the possibility and viability of starting the construction of next-generation fast-neutron reactors in the period up to 2030, which are capable of increasing the nuclear energy resource base by 100–200 times. However, the lifecycle of NPPs and the development of new reactors mean that replacing generations of equipment is extremely time-consuming in this sphere. This is shown in particular by the deferred construction (until after 2035) of commercial 4th generation reactors and nuclear energy systems with a closed fuel cycle, which are being developed as part of the GIF-IV and INPRO international projects [OECD, 2013, 2014; IAEA, 2011, 2014c].

It should be noted that all of the forecasts mentioned above, like our own model, are based on the assumption that there will be no level 6 or 7 accidents (according to the International Nuclear Event Scale, or INES) globally in the period up to 2040. If there are, new moratoria on NPPs will follow, together with the postponement and cancellation of new projects and even the partial refusal to continue operating existing units.

Nuclear energy market participants formulate forecasts of their opportunities and risks based on assessing the dispersion (or 5% and 95% quantiles) of supply and demand on the global market. According to the aims and strategies of market players, their risks may call for market requirements to be overestimated or underestimated. Therefore, in contrast with the widely used scenario approach [IAEA, 2014a, 2014b; WNA, 2013; *Emsley,* 2013; IEA, 2012, 2014; DOE, 2014; European Commission, 2012; Ux Consulting, 2013; *Carter,* 2014; ERI RAS, 2013], there is a need for tools which can set dispersions of expected tendencies and analyse arbitrary cross-sections of the nuclear energy market structure, vary the initial parameters and, in doing so, systematically measure the risks of a particular scenario materializing. Some studies [*Runte,* 2013; *Schneider et al.,* 2012; *Andrianova et al.,* 2008, 2011] have attempted a probabilistic analysis of expected industry development trends. *Runte* [2013] gives statistical data on the dispersal of certain dynamic NPP construction parameters (time frames, capacity, capital outlay, estimated cost of electricity, etc.) without forecasting more general processes: probabilistic nuclear energy development scenarios and the industry's requirements in terms of nuclear fuel cycle services. *Schneider et al.* [2012] look at the question of statistically measuring the cost of operating a reactor. *Andrianova et al.* [2008, 2011] outlined the development of the DESAE computer software, which uses a stochastic method to search for the minimum functions required to build a specific scenario, but without taking into account the dispersion of results. The authors of these two studies also pay particular attention to the possible structure of the industry, including various types of reactors (thermal-neutron and fast-neutron) and different fuel cycles.

In contrast with these approaches, our long-term global nuclear energy market forecasting method (with a 20–25 year horizon) is based on stochastic modeling of power unit lifecycles and the physical relationship between their type and capacity and demand for nuclear fuel cycle services. Using official reports by the WNA, IAEA and other sources [IAEA, 2012, 2014a, 2014b, 2014d; WNA, 2011, 2013; *Emsley*, 2013; IEA, 2012, 2014; DOE, 2014; *Schneider et al.*, 2013; *Sholly*, 2013], we created a database covering all types of operational thermal-neutron nuclear reactors and those under construction (or planned), with the majority falling under the second category, as generation III or III+ reactors. The model does not take into account 4th generation closed-cycle breeder reactors, as this type of reactor is not expected to be commissioned commercially until 2035 at the earliest.

The model makes it possible to obtain probabilistic distributions of these market characteristics, which are critical when assessing the economic risks of various global players in the nuclear energy market. Our article outlines the main principles and some of the results from using this model: NPP capacity dynamics in certain regions and globally and NPP demand for natural and enriched uranium and for separative work. We will also show the likely volumes of new plant construction and spent reactor decommissioning markets in different regions.

Nuclear energy development probabilistic forecasting method

The nuclear energy market probabilistic forecasting model is shown in Fig. 1.

The *first stage* involves making a list of all existing, planned, and proposed NPP unit in different countries using data from the IAEA, WNA and other sources.

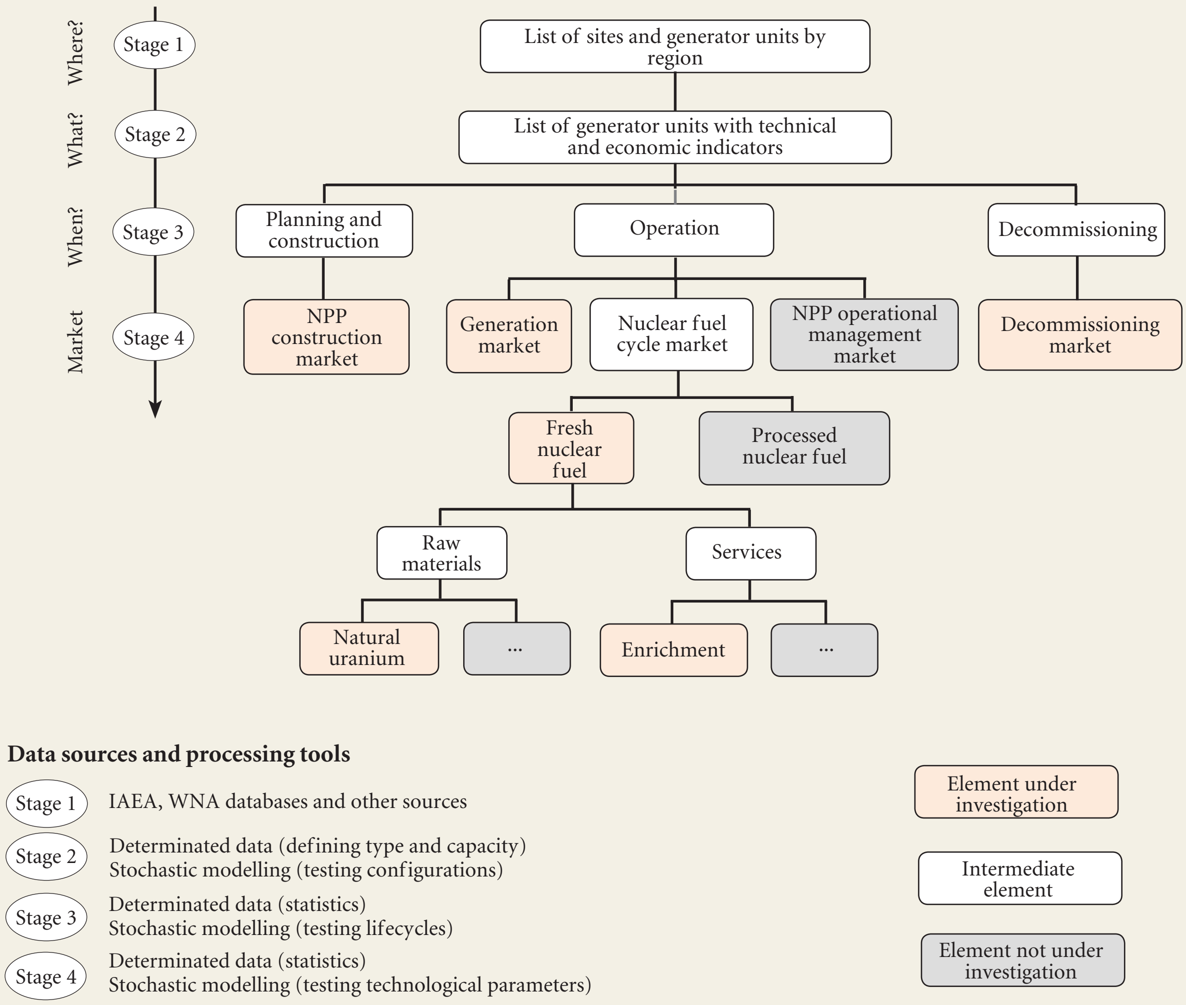
The *second stage* involves forming a database of the technical and economic performance for each NPP unit: the reactor type, its electricity and thermal capacity, average energy capacity factor (CF), fuel burnup, refueling enrichment, the mass and enrichment of the initial fuel loading, etc. Figures for planned to construction NPPs are modelled in the form of random values distributions based on existing designs.

The *third stage* takes into account and models the key temporal lifecycle parameters of power unit, such as start of construction, commercial operation and decommissioning dates. The planned lifecycle duration of generation III and III+ reactors under construction is generally at least 50–60 years.

The *fourth stage* (and subsequent stages) involves carrying out a probabilistic calculation of physical nuclear energy market volumes. The results can then be broken down according to certain criteria: by time, region, company, reactor type, etc.

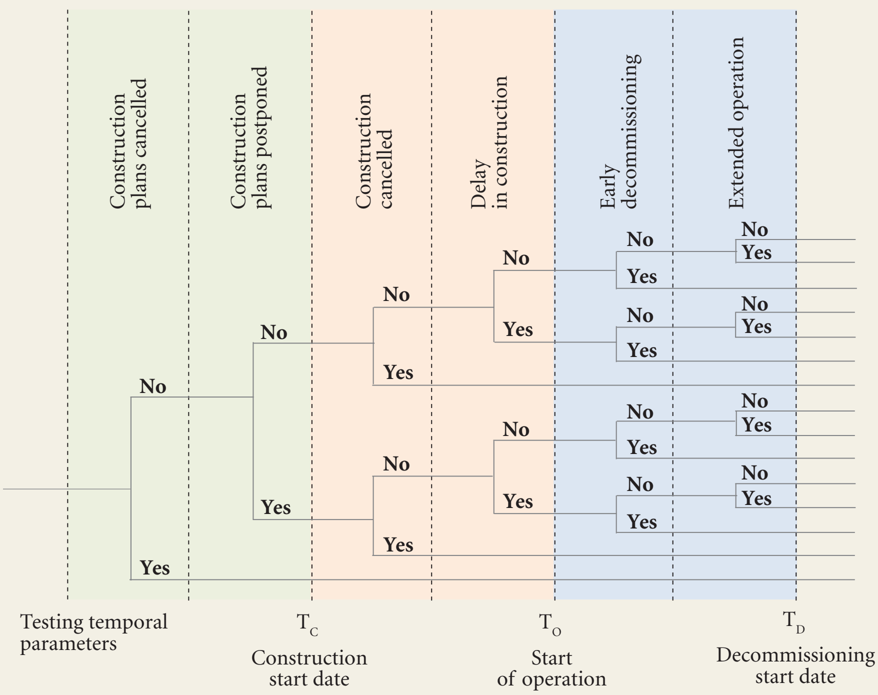
The key and most sensitive stage of the modeling is the third stage, which is linked to defining the temporal lifecycle parameters of NPP units (stage 3). The stated project time frames are practically never executed to the letter, so the method is based on probabilistic modelling of the duration of key stages of NPP lifecycle and several nuclear fuel cycle parameters. The most important stages of the lifecycle of each power unit [*Runte*, 2013; *Sholly*, 2012; IAEA, 2012] are modelled in the form of an event tree (Fig. 2). The 'yes' – 'no' branch probability depends on the region where construction is taking place, the time since the forecast was compiled, and the integrity of input data. The calculation also takes into account the fact that for each region in which a NPP is located the branch probabilities

Fig. 1. **Nuclear energy market probabilistic forecasting model diagram**



Source: compiled by the authors.

Fig. 2. **Power unit lifecycle temporal characteristics modelling diagram**



Source: compiled by the authors.

linked to planning the commissioning of new units correlate with one another in the same way as they do when units are decommissioned. Thus, for each branch of the tree, unique sets of random distributions of temporal power unit parameters are generated, where T_C is the probability distribution of the construction start date, T_O is the start of operation, and T_D is the start of decommissioning. The probability values of the temporal parameters are modelled using uniform and PERT distributions [*Davis*, 2008]. Since temporal power unit lifecycle parameters are dependent values ($T_O = f(T_C)$; $T_D = f(T_O)$), their probability distributions are consecutively defined, taking into account the duration of construction t_C and the duration of operation t_O:

$$T_C \rightarrow T_O = T_C + t_C \rightarrow T_D = T_O + t_O \quad (1)$$

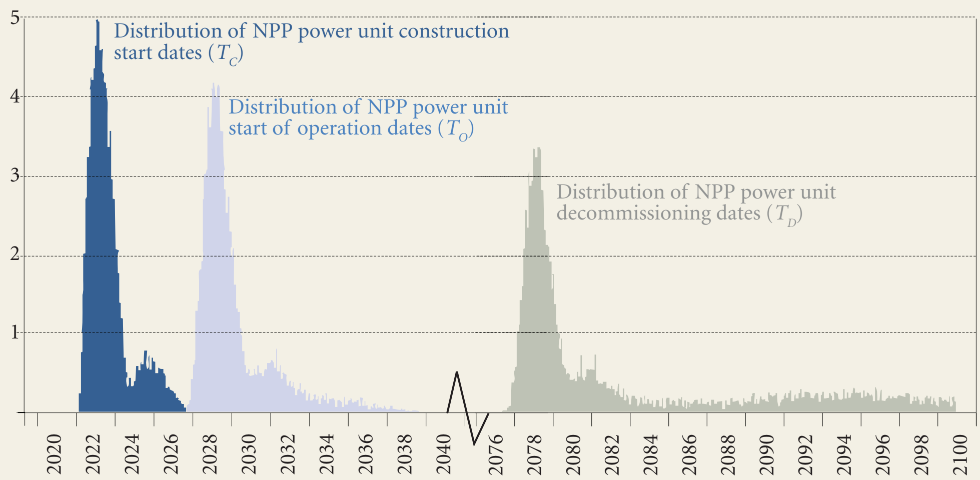
Probability distribution parameters are formulated on the basis of statistical, design and forecast data for the various types of nuclear reactors [IAEA, 2012, 2014a, 2014b, 2014d; WNA, WNA, 2013; *Emsley*, 2013; IEA, 2012, 2014; DOE, 2014; *Schneider et al.*, 2013; *Sholly*, 2013]. They take into account assessments of their reliability. As a result, the form of certain probability distributions (for instance, the minimum, maximum and mode values for the PERT distribution) are selected taking into account the location, time and specific characteristics of a particular power unit.

The result from modeling the temporal parameters of a single power unit's lifecycle can be presented in the form of a frequency histogram (Fig. 3).

The structure of the global nuclear energy industry can be modeled using the Monte Carlo method by reproducing the lifecycles and technical and economic performance of each specific power unit. The relations between the different random events is taken into account by the correlation coefficients and the introduction of stochastic control parameters, both in geographic and in temporal measurements. Using a correlations shows that decisions about building, extending or prematurely ceasing the operations of a NPP power unit are not made arbitrarily, but are influenced by developmental tendencies in the nuclear energy sector in a particular country, region or the world in a given time period. The correlation coefficient can serve as one of the control parameters of the model alongside distribution parameters reflecting the level of reliability of the input data, different technological and regional characteristics, scientific and technological progress in reactor construction, and other characteristics.

This theoretical model makes it possible, in principle, to take into account the impact of factors such as major accidents, economic crises, political decisions, as well as improvements in NPP construction and operation technologies, uranium enrichment, and nuclear fuel production.

Fig. 3. **Frequency distribution of NPP power unit lifecycle temporal characteristics** (%)



Source: authors' calculations based on data from [WNA, 2013].

Forecasting the number and capacity of NPPs

The database for the proposed model uses data and forecasts from the IAEA's Power Reactor Information System, the WNA, and other sources as of the end of 2013. It covers roughly 1,100 power reactors, of which 434 are operational in 31 countries (which are home to two–thirds of the Earth's population) and 72 are under construction in 14 countries. Alongside these, more than 600 reactors in almost 40 countries are at the development or planning stage for construction by 2030. Many of these are in China (almost 250 reactors), India (70), other Asian (117) and European countries excluding Russia (up to 60).

The annual t installed electricity capacity $W(t)$ of all operational NPP units, grouped together under the symbol Ω (geographic position, technical, economic or other parameters), is the sum of the capacity of each j reactor in this group:

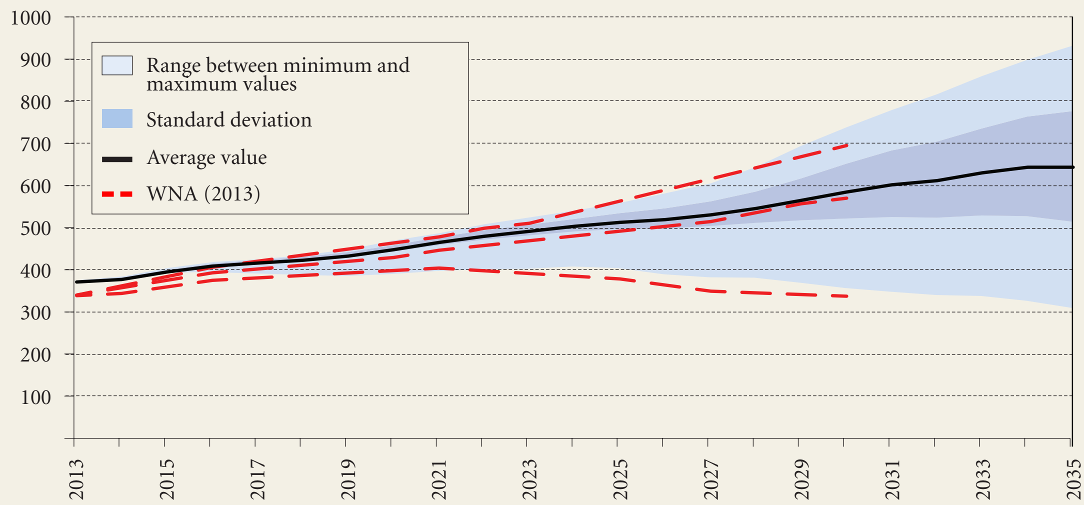
$$W_{\Omega}(t) = \sum_{j} W_{\Omega j}(t) \cdot [\eta(t - T_{O,j}) - \eta(t - T_{D,j})] \quad (2)$$

The expression in brackets is equal to zero over the entire temporal interval, except the period during which the unit is operated from $t = T_{O,j}$ to $T_{D,j}$; $W_{\Omega j}(t)$ is the installed electrical capacity of unit-j; and $\eta(t)$ is the Heaviside function, or the unit step function, which is zero for negative values in the argument and one for positive. When building the forecast, the time at which commercial operation of each reactor starts T_O is calculated by adding the construction duration t_c to the construction start date T_C, and the date on which operation ends T_D is obtained by adding the service life t_0 to T_O (1).

Thus, in the formula (2) above the start date $T_{O,j}$ and end date $T_{D,j}$ for commercial operation of unit-j assume random values according to the probability distribution within bounded intervals, in line with the method described above. The reproduction of the lifecycle (stages and technical and economic performance) of each power unit, including even those that do not yet exist, and where necessary their type, class and capacity, gives the annual t distribution of the installed electrical capacity of NPPs $W(t)$ in the segment under consideration Ω over the period up to 2035 (Fig. 4).

Under the baseline variant, the average installed NPP capacity globally will grow at a rate of roughly 2.5% per year, as also shown in the WNA's moderate scenario [IAEA, 2014a], and the minimum and maximum values are in line with the pessimistic and optimistic scenarios. At the start of 2014, the installed capacity of the world's NPPs was 374 GW (in Russia, roughly 25 GW with 34 reactors). The proximity of the model's results to the WNA's scenarios confirms the validity of selecting the frequency distributions of key events on the reactors' 'life tree'.

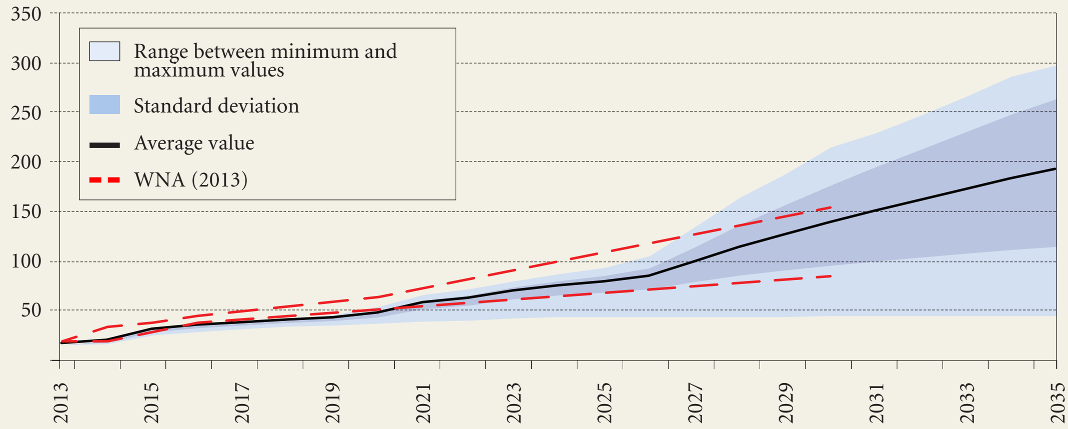
Fig. 4. **Installed NPP capacity dynamics globally** (GW)*



* The average value (solid line), band showing one standard deviation, and the maximum and minimum values of the model with 5,000 iterations (trajectories) are shown. The dotted lines represent the three WNA scenarios.

Source: authors' calculations based on data from [WNA, 2013].

Fig. 5. **Installed NPP capacity dynamics in China** (GW)



Source: authors' calculations based on data from [WNA, 2013].

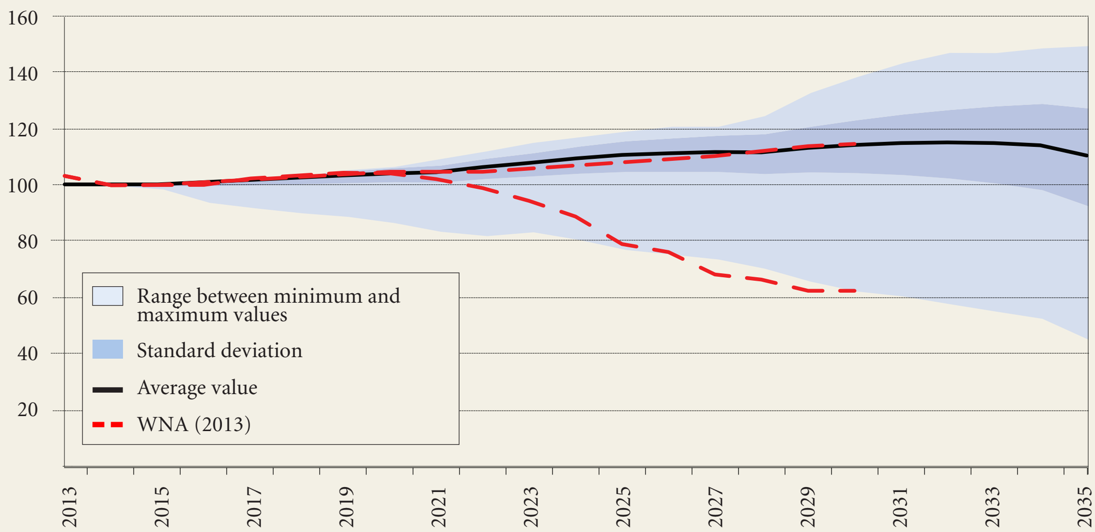
We forecast growth of roughly 11% in the Chinese nuclear energy industry (Fig. 5). By 2035, the number of reactors in the country will be almost double the number in the US (Fig. 6), the largest nuclear power in the world with an installed NPP capacity of roughly 100 GW and 103 reactors as of the end of 2013. For such a developed national industry, low growth is probable (0.6% per annum): there is even the possibility of a reduction in its total nuclear capacity by 2035.

Our calculations show that uncertainty significantly increases as the distance from the forecast starting point (2013) grows, in a similar as observed in the IAEA and WNA scenarios (Figs. 4–6). At the same time, the distribution dispersion is still acceptable in 2035. The increased uncertainty in the forecast is not a methodological defect: rather it is a measure of the uncertainty present in national nuclear energy development programmes. An annual review of the forecast that takes into account any newly commissioned or decommissioned reactors will make it possible to adapt the model to the industry's changing nature.

Forecasting NPP demand for fuel and uranium enrichment services

Forecasts of installed NPP capacity dynamics make it possible to assess the level of demand for nuclear fuel and uranium enrichment services. A particular power unit's annual fuel consumption depends on the thermal capacity of the reactor *Q* (GW),

Fig. 6. **Installed NPP capacity dynamics in the US** (GW)



Source: authors' calculations based on data from [WNA, 2013].

the fuel burnup B (GW·day/tU), and the capacity factor (CF). The mass of uranium M_f in the fuel to be fed in to a reactor (t/year) is defined by the widely accepted formula [*Kharitonov*, 2014; *Sinev*, 1987]:

$$M_j(t) = \frac{Q_j \cdot КИУМ_j(t) \cdot 365}{B_j(t)} \quad (3)$$

Currently, the average global NPP capacity factor is 0.75. The CF of some reactors is as high as 0.93. Fuel burnup is roughly 40–50 GW·day/tU, showing an upward trend to 60–80 GW·day/tU. Annual demand $P(t)$ for enriched uranium is defined as the sum of mass M_{Ok} for the initial fuel loading of commissioned reactors and mass M_j of the refueling for operational reactors:

$$P(t) = \sum\nolimits_{\Omega k} M_{ok}[\eta(t - T_{Ok} + 1) - \eta(t - T_{Ok})] + \sum\nolimits_{\Omega j} M_j[\eta(t - T_{Oj}) - \eta(t - T_{Dj})]. \quad (4)$$

Indices j and k take into account all types of reactors operating in year t and those commissioned the following year, as demand for fuel for initial loading arises roughly one year prior to commencing the commercial operation of a reactor. Purchases of fuel for this purpose are done in advance, so a lag of two years is applied when calculating market demand for enriched uranium. Likewise, when calculating capacity, the addition in formula (4) is done for all reactors in the database or for any particular group of interest Ω.

To obtain value P of the enriched fuel x (mass concentration of uranium-235 in the fuel) at the isotope fractionation plant, natural uranium with a concentration of c=0.77% in value F is needed, forming depleted uranium with concentration y in value D [*Kharitonov*, 2014; *Sinev*, 1987]:

$$F = P\frac{x - y}{c - y}; \quad D = F - P \quad (5)$$

The uranium enrichment process is known to characterize *separative work R*, expressed in the same units as uranium spending (t/year etc.):

$$R = P\Phi(x) + D\Phi(y) - F\Phi(c), \quad (6)$$

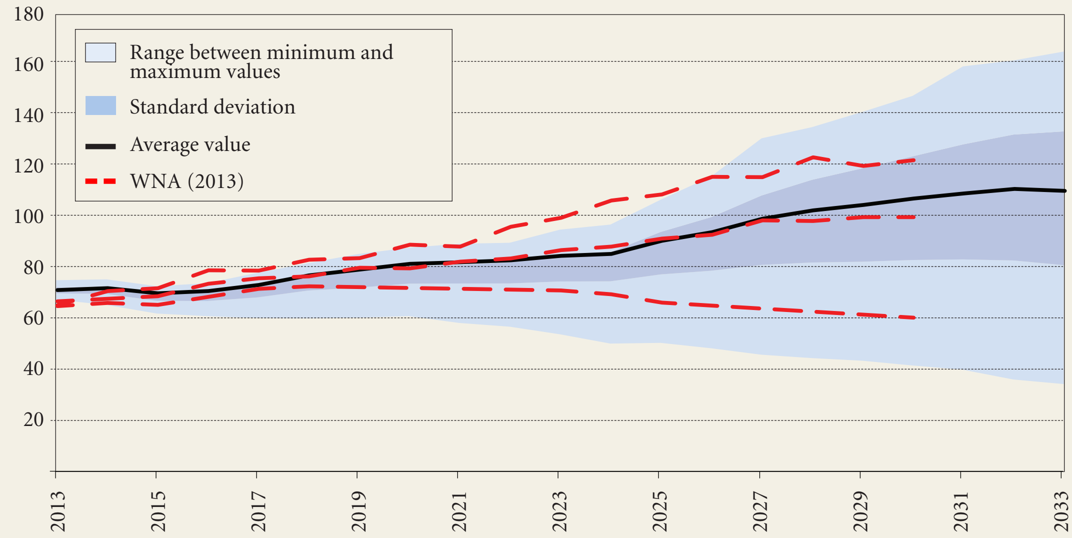
representing the difference between the 'values' of the obtained products P and D and the raw material input (feed) F. 1 kg of separative work is called a separative work unit (SWU). Separative work, like separative potential $\Phi(x)=(2x\text{-}1)\ln[x/(1\text{-}x)]$, characterizes the state of the gas mixture irrespective of the actual method used to separate the isotopes [*Borisevich et al.*, 2005].

Keeping the cost of uranium enrichment to a minimum allows for an optimal concentration y of uranium-235 in heaps ('enrichment tailings'), representing the relationship between the cost of natural uranium and separative work units. Currently, the optimal concentration of 'enrichment tailings' globally averages at roughly y≈0.22–0.25%. Over time, the price of natural uranium is expected to grow faster than the cost of separative work. This will entail a reduction in the optimal concentration of heaps to y≈0.15–0.18% or even lower. This uncertainty surrounding the y value causes additional dispersal in calculations of demand for natural uranium and separative work.

The demand of the global nuclear energy industry for natural uranium and isotope separative work will grow at a rate of 2–3% per year (Figs. 7–8). The dispersal of the calculation values characterizes the uncertainty risk: should the optimistic development scenario materialize in the nuclear energy industry, global demand for uranium enrichment services could surpass existing capacity at enrichment plants. Amid the stagnation in the industry, demand for natural uranium may be covered for a long time by stockpiled reserves (currently totalling 600 kt) with the inevitable landslide in uranium prices and closure of numerous extraction companies.

It is worth noting that roughly 40% of global uranium isotope separation production capacity is concentrated in Russia, all using the high-tech gas centrifuge method. Accordingly, Russia also accounts for roughly the same share (30–40%) of the global uranium enrichment services market.

Fig. 7. **Forecast of demand from the global nuclear energy industry for natural uranium** (*ktU/year*)



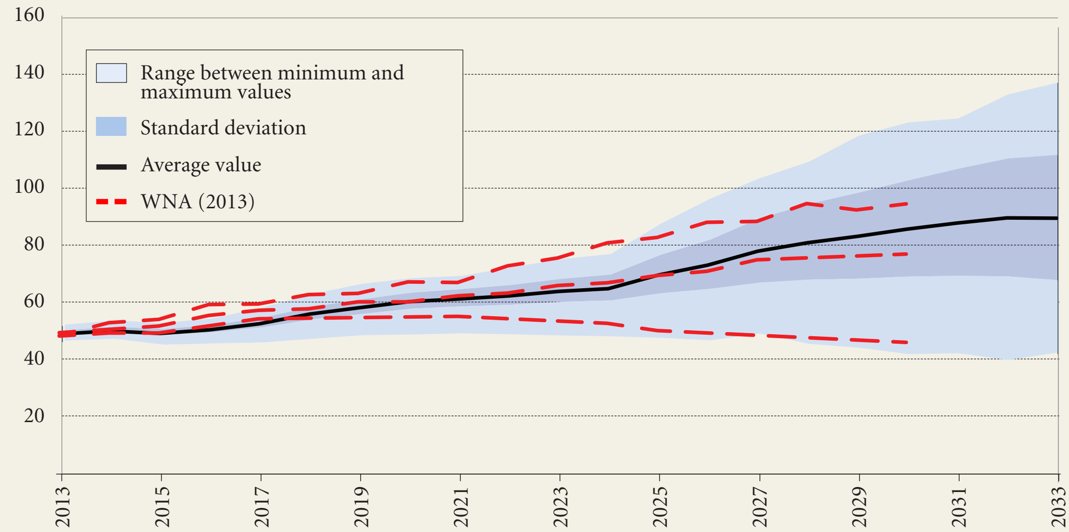
Source: authors' calculations based on data from [WNA, 2013].

Forecasting the size of the new NPP construction market

Nuclear power plants are among the most complex and high-tech facilities in industry. The construction and operation of a NPP are tied to numerous other sectors of the economy — construction, engineering, instrument-making, logistics, finance, insurance, science, education, etc. — and give rise to a significant multiplier effect on GDP dynamics [*Ivanter*, 2014]. On average, building a NPP takes 5 to 15 years and requires hundreds of thousands man-hours. Upon completing construction, the plant typically becomes a town- and structure-forming facility in a region for many decades. Forecasts of construction volumes in the industry help to appraise not only the prospects of local engineering, supply and construction markets, but also the markets of accompanying products and services. Below is a forecast of the new NPP construction market volume for the period 2015–2025, based on a database of reactors in various regions, compiled by the authors.

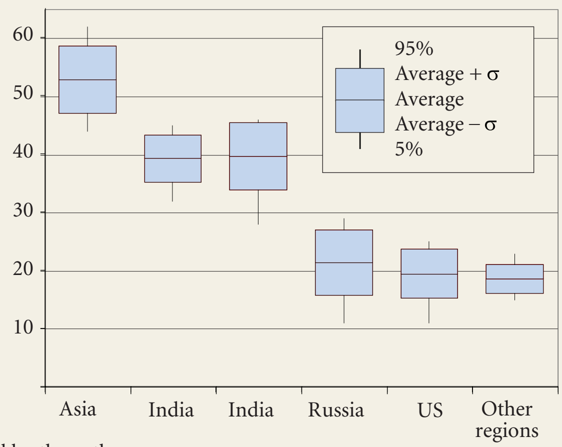
This study covers the following regions of the world and countries operating on the nuclear energy market: Russia, China, India, developed Asian economies, Japan and South Korea, other Asian states, Europe (excluding Russia), the US, and

Fig. 8. **Forecast demand from the global nuclear energy industry for uranium isotope separative work** (*millions of SWU/year*)



Source: authors' calculations based on data from [WNA, 2013].

Fig. 9. **Number of new NPP units globally (excluding China) which are expected to start being built in 2015-2025**



Source: compiled by the authors.

other regions, including Canada, South American and African countries. The total installed capacity of NPPs W_Ω and the number of power units N_Ω which are going to start construction in the next decade in region Ω is calculated as follows:

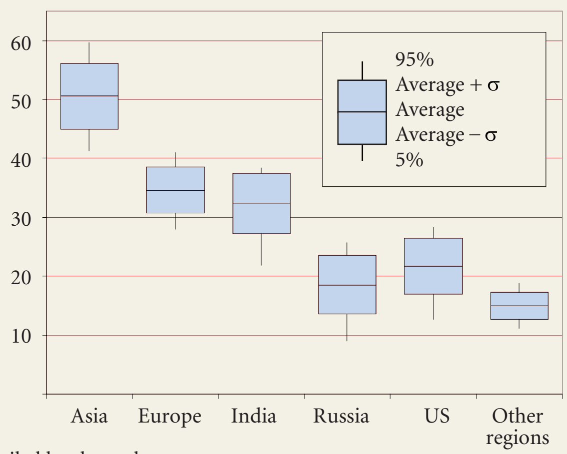
$$W_\Omega = \sum_{t=2015}^{2025} \sum_j W_{\Omega j} \cdot \delta(T_{Cj} - t); \quad N_\Omega = \sum_{t=2015}^{2025} \sum_j \delta(T_{Cj} - t). \qquad (7)$$

Where $\delta(t)$ is the delta function, which equals 0 everywhere, except t=0, where it equals 1. The number and capacity of the new reactors which are expected to start being built in 2015–2025 are relatively high in all regions examined: 17 and 53 reactors with a total capacity of 15 and 52 GW, respectively (Figs. 9–10).

Bearing in mind that the specific capital expenditure on construction of generation III and III+ reactors in various regions globally is currently 2,000–6,000 US dollars/kW [*Kharitonov*, 2014], the total investment in the industry could range from 34 to 370 billion US dollars between 2015 and 2025. The level of volatility on the market is confirmed by the dispersion analyses (Figs. 9–10).

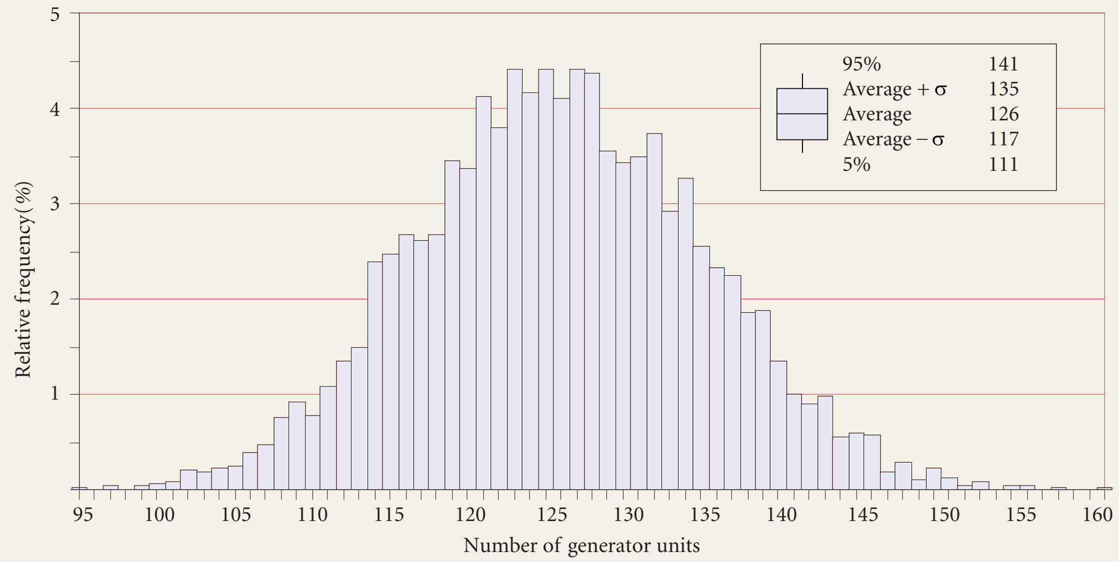
The forecast construction volumes for new NPPs in China significantly exceed those in other regions of the world (Fig. 11). The second group of countries after China with a high construction volume, referred to above as 'other Asian states', is at virtually the lowest limit of the Chinese market.

Fig. 10. **Installed capacity of new NPP units globally (excluding China) which are expected to start being built in 2015–2025** (*GW*)



Source: compiled by the authors.

Fig. 11. **Probability density distribution of the number of new NPP units in China which are due to start construction in 2015–2025**



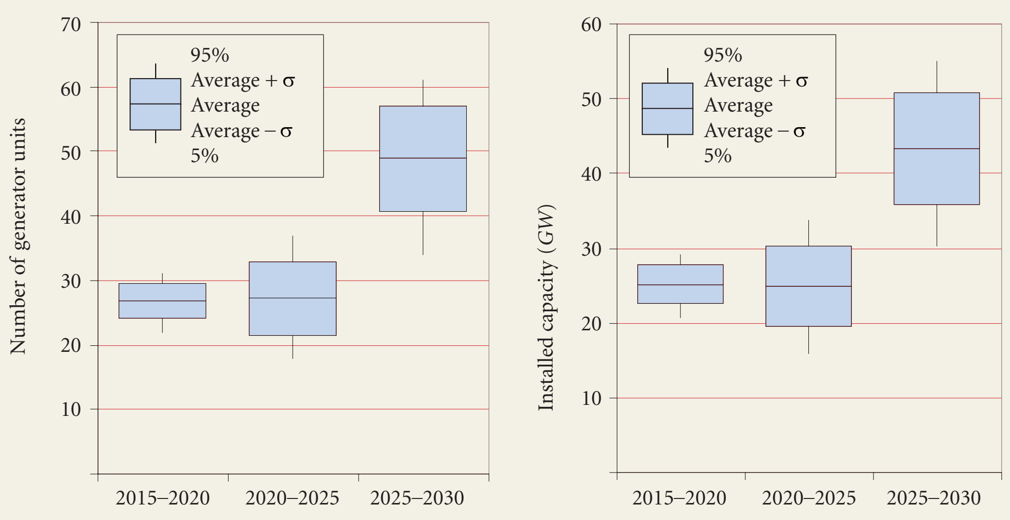
Source: compiled by the authors.

This method forms the basis for studying market prospects for NPP construction contractors. As an example, we will look at the expected export construction volume of Russian-designed reactors over the next three five-year periods: 2015–2020, 2020–2025 and 2025–2030 (Figs. 12, 13). In this case, the temporal interval changes and the condition 'Russian-designed reactor' is added to Ω in formula (7). Currently, Russia accounts for roughly 20% of the global NPP construction market.

The analysis shows that the variance of the share of Russian-designed power units exceeds the variance of the total number of reactors globally, and this in turn can be explained by the uncertainty in constructing Russian-designed power units affecting the instability of industry development parameters on a global scale. Existing capacity makes it possible to export from five Russian-designed NPP units in 2015–2020, and nine in 2025–2030. However, at present, the engineering infrastructure allows for only four reactors to be built per year.

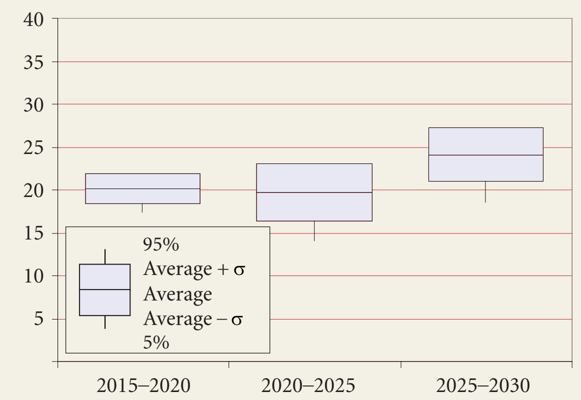
According to WNA analysts, the share of nuclear energy in EU countries over the coming decade could drop to critical levels due to the lack of internal development of next-generation reactors and restrictions on the construction of Russian-

Fig. 12. **Russian-designed NPP unit construction volumes in 2015-2030**



Source: compiled by the authors.

Fig. 13. **Share of Russian-designed NPPs in the total number of NPPs built globally (%)**



Source: compiled by the authors.

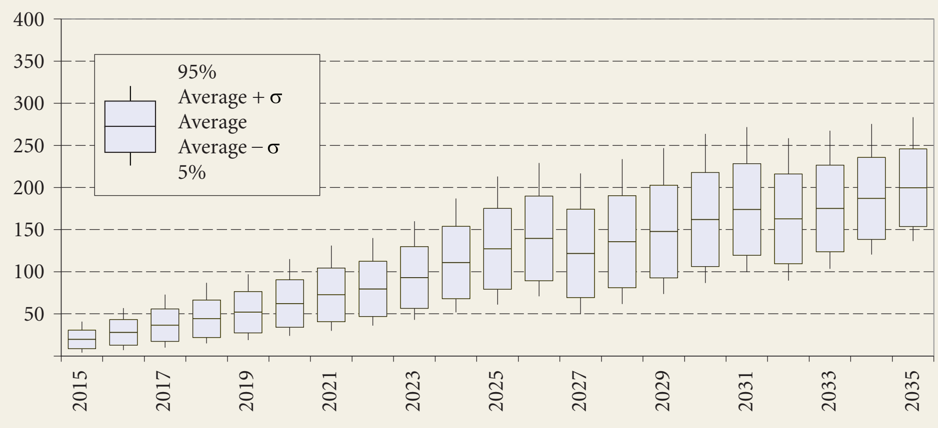
designed power units [*Tarlton*, 2014]. In those European countries where such restrictions do not exist, in our opinion the volume of power generation at NPPs will not suffer such a serious slump.

Forecasting NPP decommissioning

The planned service life of the majority of operational power reactors is 30–40 years. Life extension the service life of a NPP by 10–15 years is almost always considered economically advantageous and admissible from a safety perspective. This is primarily because of the low cost of electricity produced by NPPs which have already repaid its capital expenditure costs. The declared service life of generation III and III+ reactors does not generally fall below 60–80 years, meaning that these reactors will not be decommissioned under the temporal horizon that we have adopted up to 2035. The decommissioning process itself is a specific and labour-intensive procedure that last decades. Currently, the NPP decommissioning market is underdeveloped in the majority of regions, since demand for decommissioning services has been rare in recent years. However, in the medium term, a significant increase in the size of this market expected, due to ageing of the global NPP pull (Fig. 14). To calculate the retirement of power units on an accrual basis, we use a formula similar to (7), where in place of the construction start date used date T_D, and in place of the delta function $\delta(t)$ used a step function $\eta(t)$.

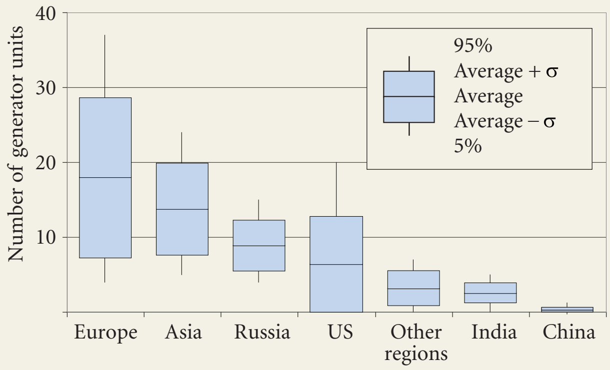
The high variety of our estimates is caused by inconsistent information about policies of several countries regarding whether to extend the service life of current reactors (Figs. 14–15). By 2035, over 200 power units with extended service

Fig. 14. **Number of power units which will cease operations (on a cumulative basis since 2015)**



Source: compiled by the authors.

Fig. 15. **NPP decommissioning volumes in various regions globally over the period 2015–2025**



Source: compiled by the authors.

lives are expected to be taken out of operation. Therefore, over the next decade, a capital-intensive NPP decommissioning market will start to form: this market will be extremely varied in terms of the distribution of its volumes between certain states and groups of countries (Fig. 15).

The most promising markets for NPP decommissioning services seem to be in Europe, where the largest number of reactors are in operation (over 160), and in Asia (excluding China) (Fig. 15). It is characteristic that the distribution forms differ significantly across regions: the possibility of extending the life of operational power units depends upon the type of reactor, technical capabilities and national strategies. In particular, in the US, despite the large number of operational reactors (roughly 100), the expected size of the NPP decommissioning market is proportionate to the Russian market but does not surpass the upper quantile of the latter.

In China, where the nuclear industry is relatively young, the number of spent NPPs is small. However, in regions with 'old' nuclear plants, companies will — by 2025 — have had time to accumulate experience in decommissioning NPPs and will be able to begin exporting their services to new markets.

Conclusions

This article presented the results of a forecast of expected global nuclear energy market volumes up to 2035 based on stochastic modeling, which makes it possible to analyse the economic risks of market players. The model's database included all types of existing, planned and built thermal-neutron generation III and III+ reactors. The model did not take into account 4th generation closed-cycle breeder reactors, as they are not expected to commence commercial operation until 2035 or later.

The data analysed confirm that over the next 20 years, the average annual growth in the global energy market will be roughly 2%. China, India and other Asian countries will see the highest market values in new NPP construction. The size of the industry in Russia is roughly on par with that in the US, but has a higher volatility. Meanwhile, the likely construction volumes for Russian-designed NPP units in the world by 2030 could increase both in absolute and relative terms.

This study has shown that the share of nuclear energy production from NPPs in EU countries over the coming decade risks dropping to critical levels due to the lack of internal development of next-generation nuclear reactors and the lack of quotas to construct equivalent Russian products. However, several European countries have projects to construct Russian reactors of the latest generation in place or at the planning stage.

Over the coming two decades, we expect to see growth in the number of spent reactors (increasing to 250). This will lead to the formation of a new science- and capital-intensive NPP decommissioning market. The largest volume is expected in Europe, the region with the oldest stock of nuclear reactors. In China, as in other countries with a young nuclear energy industry, the NPP decommissioning market is virtually non-existent.

The dynamics of launching new reactors (and stopping old ones) significantly impact on the status quo of regional natural and enriched uranium and uranium enrichment markets. In light of these tendencies, the current policies of several countries to diversify and allocate quotas for energy generation resources and equipment supplies may yet undergo significant revisions. F

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