FORESIGHT
AND STI GOVERNANCE

ISSN 2500-2597

2020
Vol.14 No 4

JOURNAL OF THE NATIONAL RESEARCH UNIVERSITY HIGHER SCHOOL OF ECONOMICS

SPECIAL ISSUE

STRATEGIC MANAGEMENT IN THE CONTEXT OF DYNAMIC COMPLEXITY

ABOUT THE JOURNAL

Foresight and STI Governance is an international interdisciplinary peer-reviewed open-access journal. It publishes original research articles, offering new theoretical insights and practice-oriented knowledge in important areas of strategic planning and the creation of science, technology, and innovation (STI) policy, and it examines possible and alternative futures in all human endeavors in order to make such insights available to the right person at the right time to ensure the right decision.

The journal acts as a scientific forum, contributing to the interaction between researchers, policy makers, and other actors involved in innovation processes. It encompasses all facets of STI policy and the creation of technological, managerial, product, and social innovations. *Foresight and STI Governance* welcomes works from scholars based in all parts of the world.

Topics covered include:

- Foresight methodologies and best practices;
- Long-term socioeconomic priorities for strategic planning and policy making;
- Innovative strategies at the national, regional, sectoral, and corporate levels;
- The development of National Innovation Systems;
- The exploration of the innovation lifecycle from idea to market;
- Technological trends, breakthroughs, and grand challenges;
- Technological change and its implications for economy, policy-making, and society;
- Corporate innovation management;
- Human capital in STI;

and many others.

The target audience of the journal comprises research scholars, university professors, post-graduates, policy-makers, business people, the expert community, undergraduates, and others who are interested in S&T and innovation analyses, foresight studies, and policy issues.

Foresight and STI Governance is published quarterly and distributed worldwide. It is an open-access electronic journal and is available online for free via:
https://foresight-journal.hse.ru/en/

The journal is included into the 1st quartile (Q1) of the Scopus Cite Score Rank in the fields:

- **Economics, Econometrics and Finance** (miscellaneous)
- **Decision Sciences** (miscellaneous)

INDEXING AND ABSTRACTING

WEB OF SCIENCE™ CORE COLLECTION EMERGING SOURCES CITATION INDEX

SCOPUS™

RePEc RESEARCH PAPERS IN ECONOMICS

SSRN

ProQuest

GENAMICS™ JOURNALSEEK

EBSCO

Academic Search Premier

OAJI .net Open Academic Journals Index

ECONSTOR

DOAJ DIRECTORY OF OPEN ACCESS JOURNALS

FORESIGHT AND STI GOVERNANCE

National Research University
Higher School of Economics

Institute for Statistical Studies
and Economics of Knowledge

Address:
National Research University Higher School of Economics
20, Myasnitskaya str., Moscow, 101000, Russia
Tel: +7 (495) 621-40-38
E-mail: foresight-journal@hse.ru

http://foresight-journal.hse.ru/en/

Periodicity — quarterly

ISSN 2500-2597
ISSN 2312-9972 (online)
ISSN 1995-459X (Russian print version)

Publisher:
National Research University
Higher School of Economics

NOTES FOR AUTHORS

Before submitting your article, please prepare your manuscript using the following guidelines:

Articles should be topical and original, should outline tasks (issues), describe the key results of the author's research and his/her conclusions;

Manuscripts are to be submitted via e-mail: foresight-journal@hse.ru

Format

All files should be submitted as a Word document.

The text should be in Times New Roman 14 pt, 1.5 spaced and fit to the width, all margins should be 20 mm.

Article Length

Articles should be between 20000 and 60000 characters (incl. spaces). Optimal size is 40 000 characters.

Article Title

To be submitted in native language and English. A title of not more than eight words should be provided.

Author Details (in English and native language)

Details should be supplied on the Article Title Page, including:

- Full name of each author
- Position, rank, academic degree
- Affiliation of each author, at the time the research was completed
- Full postal address of the affiliation
- E-mail address of each author

Abstract

An abstract should be: informative (no general words), original, relevant (reflects your paper's key content and research findings); structured (follows the logics of the results presented in the paper), concise (between 250 and 300 words).

- Purpose (mandatory)
- Design/methodology/approach (mandatory)
- Findings (mandatory)
- Research limitations/implications (if applicable)
- Practical implications (if applicable)
- Social implications (if applicable)
- Originality/value (mandatory)

It is appropriate to describe the research methods/methodology if they are original or of interest for this particular research. For papers concerned with experimental work describe your data sources and data processing techniques.

Describe your results as precisely and informatively as possible. Include your key theoretical and experimental results, factual information, and any interconnections and patterns shown. Give special priority in your abstract to new results and data with long-term impact, important discoveries and verified findings that contradict previous theories as well as data that you think have practical value.

Conclusions could be associated with recommendations, estimates, suggestions, and hypotheses described in the paper.

Information contained in the title should not be dublicated in the abstract . Try to avoid unnecessary introductory phrases (e.g. 'the author of the paper considers…').

Use language typical of research and technical documents to compile your abstract and avoid complex grammatical constructions.

The text of the abstract should include the key words of the paper.

Keywords

Please provide up to 10 keywords on the Article Title Page, which encapsulate the principal topics of the paper.

Headings

Headings must be concise, with a clear indication of the distinction between the hierarchy of headings.

Figures

All figures should be of high quality, legible, and numbered consecutively with arabic numerals. All figures (charts, diagrams, line drawings, web pages/screenshots, and photographic images) should be submitted in electronic form preferably in color as separate files, that match the following parameters:

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

CONTENTS

SPECIAL ISSUE

“STRATEGIC MANAGEMENT IN THE CONTEXT OF DYNAMIC COMPLEXITY”

System Theory Approach as a Basis of Strategic Management

Helena Knyazeva
Professor, School of Philosophy, hknyazeva@hse.ru

National Research University Higher School of Economics, 20, Myasnitskaya str., Moscow 10100, Russian Federation

Abstract

The introductory article to the special issue "Strategic Management in the Context of Dynamic Complexity" substantiates the claim that models and representations of the theory of complex systems are becoming the most relevant science-based foundation that allows one to respond to the challenges of our time. The increasing complexity of social and economic development processes, accompanied by uncertainties, instabilities, unexpected turns, the digitalization in the economy and the birth of Industry 4.0, the growing importance of network structures in business activity, and new environmental standards associated with the need to switch to circular processes in the economy - all these things require changes in the management strategies of firms and corporations. Unconditional advantages are received by those firms that embed the principles of systemic, holistic, and non-linear thinking into their business philosophy.

Keywords: non-linear dynamics; complex system; strategic management; scenario planning; foresight; digitalization; long-term strategies

Citation: Knyazeva H. (2020) System Theory Approach as a Basis of Strategic Management. *Foresight and STI Governance*, vol. 14, no 4, pp. 6–8. DOI: 10.17323/2500-2597.2020.4.6.8

An increasingly complex context and new development models require multi-level management systems of appropriate complexity. According to the Conant-Ashby principle, only under this condition will system regulators be sufficiently reliable. A variety of elements allows a complex dynamic system to remain stable, adaptable, and capable of multivariate development [*Ashby*, 1956]. The control systems must be sufficiently flexible, varied, and complex to not constrain the system and provide opportunities for its forward movement.

This special issue discusses important aspects of the complex self-developing systems theory which can enrich approaches to strategic management, foresight, and scenario planning to meet the current and emerging challenges.

The assumption that invested managerial efforts are directly proportionate to the results obtained (the linear management concept) in most cases is not confirmed by practice in the present-day context. The development of the economic, financial, business, and socio-cultural spheres is becoming increasingly complicated and nonlinear, accompanied by uncertainty, the emergence of extraordinary phenomena, and the passage of special points - singularities, after which the development path radically changes. The trial and error or extrapolation methods (the empirical projection of the current state of affairs onwards) turn out to be not very effective in such situations. The theory of systems focused on understanding complex self-organizing structures and the laws of their evolution offers a new level of productivity.

Mathematical (game and graph theory, nonlinear programming, dynamic analysis, etc.) and computer science methods are actively applied in economic and social sciences. Mathematical tools are finding new applications not only in economics but also in sociology, history, social organization and management theory, and other domains. In addition to statistical descriptions or probabilistic assessment, they help to simulate and better understand complexly interconnected communication networks and their potential effects [*Mainzer*, 2017]. Cliodynamics is actively used in historical analysis, which makes it possible to study retrospective processes in the scope of possible alternative scenarios for countries' and sectors' development based on the global system approach [*Wallerstein*, 2018].

The proliferation of information and digital technologies has led to the emergence of a new economic model, Industry 4.0. Its main aspects (cyber-physical systems, the Internet of Things, smart cities, smart infrastructure, etc.) can be viewed in terms of dynamic complexity as well. This principle also works well in another area currently seen as a priority: the extended environmental perspective which goes beyond the relationship between man and nature. The systems theory reveals the laws of coevolution: the sustainable, mutually consistent, and balanced development of the environment on a variety of scales. The transition to waste-free production and a circular economy is currently under way [*Wiesmeth*, 2020].

This process facilitated by the actively developing interdisciplinary research in network science previously associated with cybernetics, systems theory, and systems analysis [*Barabási*, 2014, 2018]. Network partnerships provide obvious advantages in organizing the economy and communities over the previous hierarchical structures, since they create a synergy potential by combining all kinds of participants' resources. The smart development model encompasses an increasingly wide range of areas including transport and urban infrastructure, healthcare, energy, and so on. Smart energy grids are designed for the use of renewable sources and the redistribution of energy across networks. Assessing complex socio-technological systems requires interdisciplinary approaches which merge natural science, technical, social, and humanitarian competencies. Scientific and technological progress should be considered in universal selectionism terms. The processes associated with Industry 4.0 are in many ways reminiscent of biological evolution: innovations play the role of mutations, markets prompt natural selection, while social institutions determine the development of trends, just as the ecological situation sets the vector for environmental and climatic changes. Uncertainty determines the variability of processes whose alternative development paths diverge farther and farther from one another the more remote the time horizon becomes. Different scenarios arise, which may significantly deviate from the basic one. The aforementioned processes are described in **Klaus Mainzer's** paper "Technology Foresight and Sustainable Innovative Development in the Complex Dynamic Systems View".

The nonlinear thinking logic sees uncertainty as a potential strategic management asset. Like chance, it should not be interpreted only as a form of ignorance. Both these factors are natural properties of the majority of real-life processes and they cannot be completely eliminated. Accordingly, one should not assume uncertainty can be overcome just by improving research tools and building development scenarios. However, a correlation between the degree of uncertainty and different futures described in scenarios can be established. **Andrzej Magruk's** paper "Uncertainties, Knowledge, and Futures in Foresight Studies — A Case of the Industry 4.0" presents various ways of efficiently handling the uncertain prospects common for those trying to reach a preferred future.

New knowledge created by "complexity science" changes the existing ideas about development processes accompanied by uncertainty, instability, and ambiguity. It allows one to see non-equilibrium in a new way: as a source of creative potential and as "enriched material" for designing alternative visions of the future. **Helena Knyazeva's** paper "Dynamic Complexity Management Strategies", shows how skillful complexity management based on holistic thinking helps actors painlessly survive crises, pass forks in the road, go through periods of turbulence, and reach the desired development paths, using the energy sector as an example.

Innovative circular production models are proliferating, focused on preserving the environment and based on higher environmental standards. Among the particularly important ones is the circular economy model which implies re-using products instead of recycling them through the application of new technologies and creative, ecological design. **Hans Wiesmeth's** article "Systemic Transformations for Businesses in the Context of the Transition to a Circular Economy" presents the basic trends in this area. The author describes less-than-obvious barriers hindering the proliferation of the new model, such as inertial linear production schemes which create "path dependencies" and limit development opportunities. The paper reveals complex multi-layered cause-and-effect relationships which complicate the transition to a waste-free economy driven by socially and environmentally responsible businesses.

The application of digital technologies increases uncertainty and complexity associated with the development of any sector. New standards are emerging, which require the production of personalized products (preferably using local production facilities) and their accelerated delivery. As a result, production networks become more complex, while the number of connections between their nodes increases. Various actors' relationships are becoming increasingly nonlinear. In some cases, synergies arise, in others, the connections weaken. Doing business under such circumstances requires flexible, context-dependent management and adequate strategies. The paper by **Marta Götz** and **Barbara Jankowska** "The Adoption of Industry 4.0 Technologies and Company Competitiveness: Case Studies from a Post-Transition Economy" shows how companies that have taken the digital economy path more rapidly than others are transforming their own and related industries. Harmonized, coordinated action taken by top managers jointly with IT department heads plays a significant role here, along with a focus on holistic thinking which helps build an effective network of manufacturers, suppliers, other partners, and consumers. Such connections are also important for strengthening cooperation between universities and industrial companies, which creates the basis for translating new knowledge, that is, transforming it into technological innovations.

Business success increasingly depends upon building cooperation networks between enterprises, suppliers, and customers. The scope and duration of knowledge sharing partnerships (on a regular, systematic, or ad hoc basis) are determined by the specific market situation of a particular industry or enterprise. All network structures' links are interested in innovations, while their operations fit into the "open model". The publication by **Vitaliy Roud** and **Valeriya Vlasova** "Cooperative Strategies in the Age of Open Innovation: Choice of Partners, Geography, and Duration" stresses that open nonlinear networked cooperation promotes innovation both by individual nodes and by the network structure as a whole.

Following the example of medicine, all science (including university research) is switching to the translational principle which implies the accelerated conversion of knowledge into technological and other innovations. The "science-education–business" triangle is emerging, promoting mutually beneficial partnerships with synergistic potential. Businesses' and society's demand for knowledge generated over the course of university research creates a feedback effect from the former, in the form of additional support for university research and educational programs. At the same time the implementation of science-based innovation by companies increases their competitiveness, which is demonstrated in the paper by **Selma Ottonicar, Paloma Arraiza**, and **Fabiano Armellini** "Opening Science and Innovation: Opportunities for Emerging Economies".

The network interaction model which became a feature of the modern context [*Castells*, 2015], is further developed in the article by **Vladimir Milovidov** "The Linked Prosperity Model as an Integrated Response to Corporate Management Challenges in a Network Society". Horizontal, decentralized connections between individuals and companies of different sizes are becoming no less important than hierarchical structures. Enterprises' integration into such an environment also has a network dimension. Their activities, including their environmental and social responsibility affect the future of the regions where they are based. In accordance with the principle of the system and its context impacting each other [*Casper*, 2019], the environment the company creates becomes the key factor for its own further development.

Thus, the studies presented in this special issue offered to the reader's attention illustrate the applicability of systemic, holistic, nonlinear, and network thinking principles as effective strategic management, foresight, and scenario planning tools.

References

Ashby W.R. (1956) *An introduction to cybernetics*, New York: Wiley.

Barabási A.-L. (2014) *Linked. How Everything Is Connected to Everything Else and What It Means for Business, Science, and Everyday Life*, New York: Basic Books.

Barabási A.-L. (2018) *Formula: The Universal Laws of Success,* New York: Little, Brown and Company.

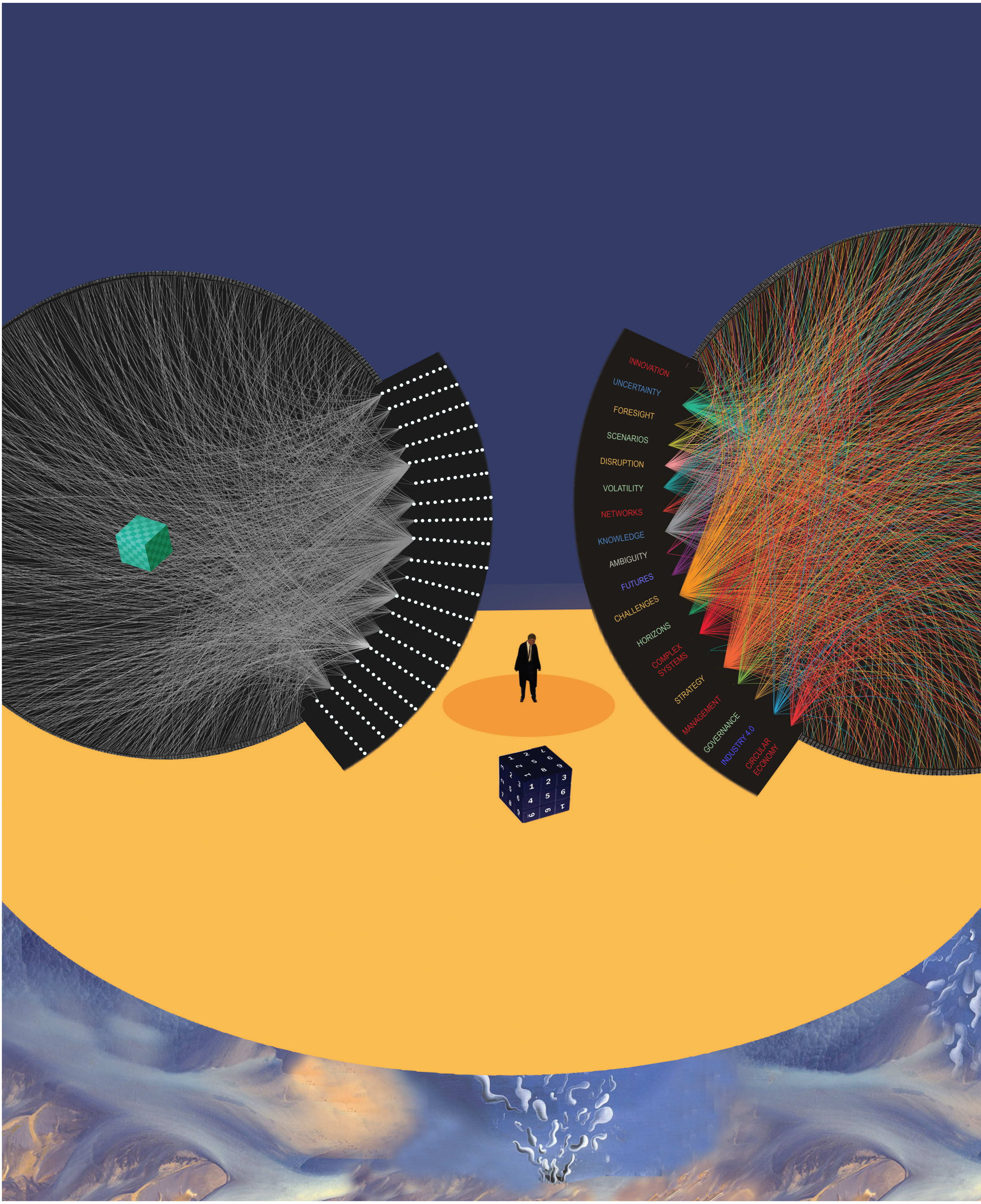
Casper M.-O. (2019) Social Enactivism: On Situating High-level Cognitive States and Processes. Berlin: De Gruyter.

Castells M. (2015) *Networks of Outrage and Hope: Social Movements in the Internet Age* (2^{nd} ed.), Cambridge (UK), Malden, MA: Polity Press.

Mainzer K. (2017) *The Digital and the Real World: Computational Foundations of Mathematics, Science, Technology, and Philosophy*, Singapore: World Scientific.

Wallerstein I.M. (2018) *Chaotic Uncertainty: Reflections on Islam, the Middle East and the World System*, Gaithersburg, MD: Kopernik Publishing.

Wiesmeth H. (2020) *Implementing the Circular Economy for Sustainable Development*, Amsterdam: Elsevier.


INNOVATION
UNCERTAINTY
FORESIGHT
SCENARIOS
DISRUPTION
VOLATILITY
NETWORKS
KNOWLEDGE
AMBIGUITY
FUTURES
CHALLENGES
HORIZONS
COMPLEX SYSTEMS
STRATEGY
MANAGEMENT
GOVERNANCE
INDUSTRY 4.0
CIRCULAR ECONOMY

Technology Foresight and Sustainable Innovation Development in the Complex Dynamical Systems View

Klaus Mainzer
Professor[a,b]; and President[c], mainzer@tum.de

[a] Technical University of Munich, Arcisstraße 21, 80333 München, Germany
[b] Carl Friedrich von Weizsäcker Center, Eberhard Karls University Tübingen, Geschwister-Scholl-Platz, 72074 Tübingen, Germany
[c] European Academy of Sciences and Arts, Sankt-Peter-Bezirk 10, 5020 Salzburg, Austria

Abstract

Information and communication technologies (ICT), which are transforming most areas, develop non-linearly. Failure to take into account the nonlinear principles of complex dynamic systems hinders the development of balanced innovation strategies. Companies and governments lose the ability to effectively respond to "grand challenges". The linear approach does not allow for covering a wide range of critical areas simultaneously in the scope of Foresight projects as it prevents one from applying an interdisciplinary approach to developing innovation strategies, correcting risk assessments, and making informed decisions.

This paper proposes a solution: management based on "cyber-physical systems" (CPS) built on dynamic complexity and nonlinearity principles. Such systems not only integrate computing and physical action but are embedded in the everyday environment. They are more than the sum of multiple intelligent computing devices. CPS transform into collective social systems, integrate information, energy, and material flows, and adapt to physical processes.

Cyber-physical systems can offer a sustainable information infrastructure which serves as a prerequisite for building up the innovative potential of a company, region, or country. They make it possible to analyze all stages of an innovation project from the technical and organizational points of view simultaneously, to cover all possible social consequences and challenges, and identify unexpected promising developments. CPS have a decentralized structure which allows one to solve complex problems and manage large and complex structures in real time, such as an energy grid, transport, smart city, healthcare, and so on.

Keywords: socio-technical systems; innovation strategies; foresight; complex dynamic systems; inter-disciplinary approach; management of complex structures; cyber-physical systems

Citation: Mainzer K. (2020) Technology Foresight and Sustainable Innovation Development in the Complex Dynamical Systems View. *Foresight and STI Governance*, vol. 14, no 4, pp. 10–19. DOI: 10.17323/2500-2597.2020.4.10.19

In the past, corporate strategies were often based on the assumption that digital technologies develop exponentially. This applies to growing computing power and data storage capacity, reduced size and cost of devices, and increased efficiency, among other things. Accordingly, it was believed that economic success would only be a matter of flexibly adapting to this context.

However, all of history shows that technological development has never been subject to rigid laws. Emerging innovation impulses often "pushed" this development in unforeseen directions. In the middle of the last century, computer pioneers relied on a few powerful mainframes. Then young entrepreneurs came up with small start-up companies producing many small personal computers (PCs) which have quickly spread all over the world.[1] Even the internet in its current version as the basis for worldwide communication was initially not on the screen when military communication networks were set up to secure command structures in the event of a nuclear strike. The exponential success of smartphones and their manufacturers was not envisioned in the long term either. Likewise, nobody knows today which developmental improvements can be expected in the coming decades and which trend reversals they could initiate. In a way science and technology development is similar to biological evolution [*Nelson, Winter*, 1982; *Nelson*, 2018]. In such a system, innovations play the role of mutations, markets make selections and social frameworks affect the development of trends – just like ecological conditions determine evolution. However, the algorithms of evolution remained "blind" for millions of years, while humans are (still) conscious of the course of technological development and can control and influence it, at least for short periods of time. In turn, visions of the future determine people's goals and aspirations and, through the awareness of cause-and-effect relationships, influence future development; this is called the "*normative force of the factual*" [*Bezemek*, 2019]. In other words, visions of technological development prospects can create ardent supporters of the corresponding trends. If these supporters happen to be executives at leading companies or prominent researchers, the relevant scenario will most likely be implemented.

Thus, a prediction becomes reality ("self-fulfilling prophecy") [*King*, 1973; *Pop*, 2015; *Biggs*, 2017]. The history of evolution shows that despite the fundamental "deterministic" laws, various possibilities exist for the implementation of various scenarios, but only a few become reality. That is, the laws of nature themselves make the future "open", so we should speak not about "a future" but of multiple "futures" [*Glenn, Gordon*, 2009; *Ringland*, 2010; *Godet, Roubelat*, 1996; *van der Heijden*, 1996]. Changes in economic, environmental, and social conditions and shifts in the technological landscape itself affect the vector of its further development. Therefore, an approach known as technological design[2] should be applied to developing new products and processes.

Applying Scenario and Delphi Procedures to Develop Corporate Strategies

While big data-based techniques analyze the future with powerful algorithms and quantitative methods, scenarios and Delphi procedures allow one to gain qualitative insights into the future. Unlike forecasts, they are not intended to accurately "calculate" the future, but to provide an idea of how events might develop. Scenarios are based on a deep and comprehensive understanding of events and rely on the knowledge, experience, and intuition of experts who assess possible scenarios for the future [*Häder*, 2002]. These approaches do not aim to forecast, but to assess potential futures. Scenarios describe the future context in the form of hypotheses whose analysis allows one to identify causal, logical connections and possible consequences, and to assess alternative future scenarios as more or less desirable. The starting point is analyzing the present and the past on the basis of empirical evidence. Then a baseline (trend) scenario is built, which is extrapolated into the future under the assumption of certain constraints remaining in place. As certain other conditions are assumed to change, alternative scenarios are proposed, which deviate further and further from the trend scenario as the distance from the present increases. A kind of funnel emerges, which, starting in the present, opens ever further around the time axis of the trend scenario. Extreme positive and negative scenarios are located at the margins.

A good example of this is energy industry development scenarios. Most of them are based on the assumption that the demand for traditional energy resources will remain in place in the coming decades, so development prospects for alternative energy sources are assessed. Accordingly, scenarios describe various futures depending on the political decisions made.

Another tool widely used for the expert assessment of possible developments is the Delphi method

[1] See, e.g.://newsroom.intel.com/editorials/pc-evolution-from-mainframe-to-perceptual-computing/#gs.gqgpqe, accessed on: 26.09.2020.

[2] Technological design is an approach applied to develop most of the latest technologies. Like research, it is based on fact and evidence and implies taking a particular sequence of steps to solve problems or answer questions. Technological design includes the following stages: identifying a problem, investigating it, developing possible solutions, choosing the best one, creating a model, testing it, improving and retesting it if necessary, and making a final decision. For more see, e.g. [*Berg*, 1998].

[*Glenn, Gordon*, 2009; *Häder*, 2002]. Unlike scenarios, this involves collecting and iteratively processing the opinions of a large number of experts, which ultimately leads to building a certain shared vison of the future. Delphi is used by ministries and research organizations to support decision-making about investments in promising innovations. Experts' knowledge, experience, ideas, and visions are reviewed through a series of iterations. In the end, a single agreed upon vision of the future or a set of realistic, alternative options is formed. The customer receives recommendations on project implementation strategy. The effectiveness of this method depends upon the experts' qualifications and their abilities in interdisciplinary cooperation. As long as trends in a specific discipline are evaluated, problems usually do not arise. However, they do appear when a comprehensive, interdisciplinary assessment of a complex socio-technical system such as a "smart city" is in order.

When it comes to building infrastructure facilities such as power plants, airports, or transport interchanges, security systems are primarily based on the opinions of engineers. However, to assess how the new facilities will affect the quality of life, how convenient they would be to use, sociological surveys will be needed. No less important is a direct dialogue with the public, to involve it in decision-making. A complex assessment and communication process emerges during which not only interdisciplinary knowledge, but also people's opinions and attitudes must be taken into account. This makes assessing risks and making informed decisions even more complicated.

From Socio-Technical Systems to Intelligent Infrastructures

Digitization and artificial intelligence (AI) technologies are radically transforming socio-technical systems [*Mainzer*, 2019]. Classic computer systems clearly separated the physical and virtual worlds. Mechatronic control systems (such as those installed in modern cars and airplanes, with numerous sensors and actuators) [*Isermann*, 2009] no longer fit into this paradigm. They scan the environment, process the collected data and themselves can influence the physical environment in a coordinated way [*Hawkins, Abdelzaher*, 2005]. The next step in the development of mechatronic systems is the introduction of "cyber-physical systems" (CPS), which not only integrate computer control with physical action, but are embedded into the everyday environment (e.g., integrated intelligent power supply systems) [*Lee, Seshia*, 2016; NSF, 2008; *Giaimo et al*., 2020]. CPS consist of numerous networked components that independently coordinate their operations to accomplish a common objective. Thanks to networked embedding in system environments, CPS go beyond isolated mechatronic systems because they are more than the sum of multiple intelligent computing devices [*Rajkumar et al*., 2010].

Individual subsystems' intelligent functions are extended over the entire system. Like the internet, CPS transform into collective social systems which, in addition to information flows, also integrate energy, material, and metabolic flows (such as mechatronic systems and organisms). Historically, CPS research originated in the field of "embedded systems" and mechatronics [*Wayne*, 2008]. The integration of information and communication systems into everyday life has led to the emergence of new performance requirements such as fault tolerance, reliability, zero disruption, and secure access, with simultaneous implementation in real time. However, problem areas have become increasingly obvious over the course of embedding appropriate management and control processes, which affect the economic and environmental efficiency of the applied solutions. Examples include automatic traffic control systems designed to prevent congestion and shorten individual travel times [*Wedde et al*., 2007]. Powering electric vehicles with alternative energy sources, in particular solar panels or wind turbines, turned out to be no less difficult. This also applies to other renewable energy sources that are perceived as a sufficiently reliable and cost-effective alternative or backup energy source for power grids. These increasingly complex applications require highly adaptable control systems, flexible system architecture, the ability to quickly deal with failures, and scope for expansion and enlargement. Attempts to manage such systems centrally turned out to be a major obstacle to meeting these requirements. The need to process colossal amounts of data increases the required time and makes it difficult to take the necessary steps quickly. For example, large transport systems are highly dynamic. Therefore, even if traffic jam reports are transmitted to the traffic control center every two minutes, they cannot be analyzed and acted upon quickly enough to adapt to the actual traffic situation. As a result, specific vehicles' navigation systems calculate individual alternative routes. However, if all devices in the system used the same statistical algorithm, then in an effort to avoid traffic jams, all transport is directed along the same route, which only increases the chaos. Therefore, CPS aim to adapt control processes and information flows to the physical processes of the relevant applications [European Commission 2006] – just like the feats evolution has achieved over the course of organisms' and populations' development.

Top-down software structures superimposed on physical processes "from above" are not the solution. Distributed control, bottom-up management of layered control structures, highly autonomous software processes, and distributed learning strategies for agents are the benchmarks. One example is smart grids which, in addition to electricity, transmit data to ensure their normal functioning. Global and transnational network structures are emerging (similar to the internet), which include both combined heat and power plants for generating electricity from fossil fuel, and installations based on renewable sources (photovoltaic converters, wind farms) and biogas power generators.

Households also can generate energy using photovoltaic systems, biogas plants, or fuel cells, for themselves and other users [*Al Dakheel et al.*, 2020]. This implements the "local activity" principle: the input from a domestic energy source is fed into the grid and contributes to global distribution patterns. Thus, smart grids with integrated communication systems provide a dynamically regulated power supply [*Wedde, Lehnhoff*, 2007]. This is an example of large and complex structures operating in real time according to the cyber-physical systems' principles. Large power plants create a reserve supply of energy to deal with peak loads or voltage drops. The task of intelligent systems in this case is to flexibly redistribute accumulated energy reserves according to users' needs. The main problem with switching to renewable energy sources is the large number of limitations in terms of functionality, safety, reliability, timely delivery, fault tolerance, and adaptability. Cyber-physical systems with their decentralized bottom-up structure seem to be a solution, ensuring the functioning of our increasingly complex communication and supply systems. Central to this is the organization of data streams that control the energy supply like the nervous system of an organism.

Complex networks are an example of dynamical systems which can be modeled in the scope of the mathematical theory of complex systems and synergies [*Mainzer*, 2007]. From cellular automata[3] to neural networks and the internet, network structures are created in nature and in the technological domain, in which complex systems' elements interact according to local rules. Locally active elements (neurons, transistors, and nodes) form complex combinations and structures that affect the overall performance of the entire system. The same applies to the vital activities of organisms, cognitive functions of the brain, swarm intelligence [*Lozito, Salvini*, 2020], and the organization of technical infrastructures such as energy systems. Knowledge of network mathematics is required to calculate these systems' characteristics and relevant indicators. The first practical challenge in networking is the digitization of existing infrastructure, most of which was created separately with no coordination for their interaction. This is true for transport, energy, healthcare, administration, and education. The creation of the "Internet of Things" has led to the emergence of overlapping functional areas such as the smart home, smart production, smart city, and smart region. The intelligent networking of previously separate domains opens up new opportunities for greater efficiency and further development. However, new challenges also emerge: integrating technical, economic, legal, regulatory, political, and social aspects. Intelligent networks and services are created by linking classic infrastructures and augmenting them with artificial intelligence (autonomously operating, self-managing functions and components). Infrastructures' and networks' "intelligence" arises both "vertically" within a domain (e.g. healthcare or transport) and "horizontally" across domains [*Sa, Corke*, 2014; *Alegre et al.*, 2014; *Bassett et al.*, 2017].

Corporate Strategies in the Context of Industry 4.0

The ubiquitous penetration of internet technologies into industrial production marked the beginning of the next stage of industrialization, Industry 4.0 [*Schwab*, 2016]. The first industrial revolution (Industry 1.0) is associated with the invention of the steam engine. The second wave (Industry 2.0) came with the introduction of the assembly line-based production system first tested at Henry Ford's plant, essentially algorithmic in nature: the product is created step by step in line with a rigid program separating work operations. In Industry 3.0, industrial robots get involved in the production process; however, they remain stationary and always execute the same program to perform a specific task [*Tantawi et al.*, 2019]. In Industry 4.0, the manufacturing process is governed by the Internet of Things. The equipment, transport, and personnel "communicate" with each other in a flexible production process. Big data plays a key role here, which comprises not just companies' structured business indicators but also unstructured social networks data, sensor signals, audio, and video [*Dean*, 2014]. In Industry 4.0, products can be manufactured individually by a specified time, taking into account every nuance of the customer's preferences. Technology, production, and the market are integrated into a socio-technical system that flexibly self-organizes and automatically adapts to changing conditions. This is a vision of a cyber-physical system for industry [Acatech, 2011, 2012]. To set it up, data from machines and sensors must be traced, transmitted, analyzed, and integrated with text documents.

[3] A cellular automate is a discrete model used in a number of natural science disciplines including micromechanics. It is mainly applied to study the algorithmic solvability of certain problems and determine the starting points for building procedures to solve them. For more see, e.g. [*Schiff*, 2007].

Appropriate big data technologies aim to accelerate business processes and are expected to support rapid and efficient decision-making.

In the Industry 4.0 context, computer numerical control (CNC) machine tools are networked, communicate with parts and components via RFID chips, and take measurements on their own. Delivery systems are also automated. Thus, it becomes possible to use social cognition over the course of the human-machine interaction. Employees' workload is reduced, while productivity is increased. However, qualified personnel are required for adjusting and setting up the machines. In addition to customized flexible manufacturing, Industry 4.0 expands the possibilities for decentralized personalized energy supply. Across the spectrum, from industry to personalized medicine, there is a departure from mass standardized production a la Henry Ford. In recent decades, computing power doubled approximately every 18 months, while devices were getting increasingly smaller and more affordable. This trend is also observed for the number of sensors, the amount of data, and so on. Companies face the need to adapt their corporate structures to enable flexible, intelligent problem solving. Due to the application of ICT, the traditional material (physical) production is gradually turning into a "virtual" process, controlled by applications and software modules. Unmanned technology is penetrating increasingly more areas. For example, Google, a prime example of an exponentially growing IT company, is already building autonomous electric vehicles. Major prospects are associated with the large-scale application of 3D printing technology in the automotive industry; the latter could be radically transformed if vehicle parts and components are 3D-printed at a low cost. A lot will depend upon what kind of data is entered into these 3D printers, and by whom. IT companies are changing almost every business, but they also need to adapt. A good example is Microsoft which continues to produce Industry 2.0-style software for mass consumers with "standard" needs. Energy companies are increasingly focusing on the decentralized market and relying on individual advice to find the right solutions. New business models are emerging, such as "buy and build" [*Francis et al.*, 2013; *Bansraj et al.*, 2018]. A focus on deeper customization and personalization of needs is a hallmark of smart companies, for whom building consumer confidence is paramount. However, there is also some scepticism about "cloud technologies". Successful medium-sized companies will not be storing their data in the cloud, both because of fears of industrial espionage and the significant costs with uncertain payoff prospects.

Outdated security technologies are a weak point of Industry 4.0. Therefore, ensuring proper security will also require new solutions in order to safely store information and prevent unauthorized access to it. The data security issue also has a human dimension. Process automation is only possible because numerous sensors, cameras, photoelectric sensors, and other devices constantly record a huge amount of data. So, the question arises about who should have access to it, where and for how long it should be stored, and about its potential users. There is also an extensive debate under way about the impact of automation upon labor markets and the social implications of the proliferation of artificial intelligence. Smart factories are built to increase production efficiency and eliminate routine and mechanical operations, manual and intellectual alike. This approach is not at all new; it has accompanied industrialization since the 19th century. Despite the elimination of some jobs, it also generates demand for new ones. Customer service is of particular importance here, as communicating with clients and developing business models requires not only a wide range of business and management knowledge and skills, but also flexibility, experience in dealing with people, and knowledge of psychology. Most of the new professions are associated with mechatronics and robotics. Therefore AI-based automation does not create unemployment but helps cut production costs and thus contributes to the growth of the labor market for a wide range of skilled workers. This will allow countries with an educated and highly skilled workforce to "repatriate" production from low-wage countries. In the already highly automated Germany, the unemployment rate is significantly lower than in other European countries, where unemployment is associated with a lack of labor market reforms.

The popular assumption that in the future only highly qualified engineers with higher education will be in demand while everything else will be done by machines is groundless. Innovation will remain relevant in all areas. In engine development and production line design, engineers will need to master mechanical engineering-, electronics-, and information technology-related skills – disciplines which used to be outside their domain. Engineers will need to work on specialized teams to meet the complex challenges of Industry 4.0, so interdisciplinary collaboration skills are becoming a requirement. "Lathe operators" will remain in metalworking, but they will be managing networked CNC lathes. Accordingly, the requirements for their qualifications will change. In many areas the innovation cycle is already faster than training cycle. Therefore, the development of training programs requires particular attention, given the rapid obsolescence of software and many production tools. In the future, lifelong learning will become the norm, especially mastering new processes.

Criteria for a Responsible Approach to Building Intelligent Infrastructure

The integration of computer networks into social infrastructure, taking into account social, economic, and environmental factors is believed to be the most important condition for transforming socio-technical systems into platforms for the provision of various services.

These systems must be networked (e.g., via the internet), robust to disturbances, and be able to adapt and flexibly respond to changes [*Jones et al.*, 2013; *Behymer, Flach*, 2016; *van de Poel*, 2020]. They are already being implemented in offices, households, social institutions, and transport. As complex systems, intelligent infrastructures has to integrate various technological domains [*Geisberger, Broy*, 2012]. They must be controlled by common software which provides middleware tools for translating user instructions into machine language (e.g., smart homes, smart factories, smart hospitals or transportation systems). Intelligent infrastructure such as a city or an airport is considered a virtual machine.[4] The integrated client interface provides transparent and user-friendly interaction with the system. At a deeper level are certain domain-specific architectures such as the transport system, healthcare system, and industrial enterprises, where the work is actually done and services are provided to users. This model can be applied in a city management system covering transportation, healthcare, and industrial facilities including municipal power supply, garbage incinerators, and others. Common software ensures interoperability with specific user applications. The technical design of information infrastructure requires interdisciplinary cooperation between specialists in engineering and natural sciences and humanities (economics, physics, mechanical engineering, electrical engineering, computer science, cognitive psychology, communication sciences, sociology, and philosophy). This cooperation should be based on unique models integrating cognitive, knowledge, and mental aspects as well as approaches to problem solving based on advances in sociology and the philosophy of technology. Integrated design and the creation of information infrastructure will only work effectively if various aspects of the human factor are taken into account. Integrated hybrid systems, distributed digital control architectures, human-machine interaction mechanisms, integrated action models, and socio-technical networks should be developed using human-centered engineering methods [*Boy*, 2017].

This approach involves the step-by-step development of reference architectures, domain models, and application platforms for specific disciplines. They serve as prerequisites for conscious situational and contextual perception, process interpretation and integration, and, as a consequence, the efficient application and control of the relevant systems. The role of the human factor in information infrastructure needs to be studied on an interdisciplinary basis. A wide range of issues must be addressed, such as ergonomics, the integration of adaptive structures into the workflow, cause-and-effect relationships, and changes in social behavior due to the use of such systems. Despite the fact that these systems are multifunctional and provide a variety of services, interaction with them should be simple, reliable, and intuitive. Complex networks with an ever-increasing number of participants are becoming more difficult to control. Accordingly, the need to ensure these systems' reliability, safety, privacy and, as a consequence, users' trust, increases. The benchmarks here can be as follows:

- energy efficiency and environmental safety;
- know-how protection in open value chains;
- assessment and management of uncertain and distributed risks;
- appropriate and fair conduct in the event of a conflict of objectives, binding domain and quality models, rules, and policies (e.g., compliance)

Sustainable Innovation and the Expected Social Effects

Intelligent infrastructures develop in a changing context, and they themselves change the structure of the social system. Digital communications allow people to obtain information more rapidly. Due to their significant transformational potential, new socio-technical systems command increased attention from civil society and its institutions. Real-time access to information and the ability to actively respond to it against the background of growing network density and the related cascading effects, contribute to the emergence of new, "liquid" forms of democracy [*Blum, Zuber*, 2016]. Better-quality and more timely information encourages citizens become more involved in the decision-making process regarding the implementation of socio-technical systems. Thus, technology becomes important not only for professionals, but also for all of society. Greater participation by civil society responds to the demand for participatory democracy. Therefore, new technical solutions must have ecological, economic, and social dimensions. We are talking about sustainable innovation [*Schot, Geels*, 2008; *Boons, Lüdeke-Freund*, 2013]. However, greater participation alone will not be enough. Socio-technical projects must remain realistic so as not to endanger the territories where they take place. Also, sustainable innovation must be robust [*Roth*, 2015]. Socio-technical systems require sustainable information infrastructure as a prerequisite for

[4] For more see: https://uits.iu.edu/ii, accessed on 26.09.2020.

building up society's innovative potential. There is a growing need to create integrated research and education centers specializing in engineering and natural sciences, humanities, and social sciences [*van Kerkhoff*, 2014]. New university formats are emerging in these interdisciplinary research clusters. They leave behind the traditional distinction between the aforementioned scientific domains. They can be viewed as matrix structures, where disciplines are matrix lines, while matrix columns are complex research projects covering various elements of disciplines depending upon the objectives of the study. Such projects are not just a promising idea, they are already being implemented by universities on the basis of their experience. The author of this paper was directly involved in the creation of competence centers at the technical universities of Augsburg and Munich.[5]

All these approaches are based on the fundamental idea that science does not exist independently of society. Without taking into account social structures and processes, any technological or natural science-related innovations (especially in the AI field) are unlikely to become successful. For example, building a smart city requires an understanding of how to organize the effective coexistence of people and smart infrastructure. Smart supply chains designed to meet the needs of the world's growing population will not work without considering the context of developing countries. Robots will not be effective assistants for older people if there is no understanding of the latter's true needs. Ignoring the relevant social, economic, and environmental factors will prevent the harmonious integration of large-scale technology projects into the social structure.

Conclusions

Information and communication technologies are transforming most industries. According to the previously dominant belief, their development follows exponential laws, so to achieve economic success, it is enough to flexibly adapt to this logic. In reality though, technological development has never been subject to rigid laws. It is still not possible to accurately determine which promising development ideas may emerge in the future. Like all live systems, scientific and technological progress develops in dynamic complexity, but unlike biological evolution, it can be controlled by people who are able to influence its vector. This requires interdisciplinary thinking and an understanding of how production and educational strategies should be organized in the concept of complex, dynamic systems. Research results will only be practical if the objectives are set taking into account social sciences and humanities, choosing relevant criteria, going beyond the established notions, and learning from crises.

What would development strategies that take into account complex dynamic systems look like? Interdisciplinary issues should be addressed from the very start of any project, not during the subsequent "review".

Any scientific and technological project must involve researchers from the humanities: to study related social aspects, evaluate the results for compliance with economic, medical, environmental, and technological ethics, and develop new mechanisms for exchanging ideas between science and society. Empirical research should be interdisciplinary and project-oriented, while research results should be open for public discussion to serve as the basis for policy decisions.

In an increasingly informed society, the potential for people's involvement in decision-making on infrastructure and technology-related issues increases. Trying to regulate this process, countries develop clear step-by-step approval procedures: the project developer prepares a plan, next come consultations, a public presentation, a discussion, the presentation of its results, and the approval of the plan. However, public participation is often organized in the form of hearings, with project implementation remaining under the exclusive control of the authorities. The so-called "preclusion effect" [*Ketchum*, 2016] makes any appeals after a certain period of time impossible. While objective technical, social and economic conditions may change, this approach leaves no room for adaptive learning and adjustment. Such a "linear" legitimization procedure needs to be revised taking into account the ongoing global transformations. Boundaries for the application of a participatory approach must be established, to preserve the effectiveness of decision-making systems and maintain the social balance. Political structures are changing under the influence of technological and economic development and the emergence of new environmental trends. It is necessary to rethink the rules of the game to make coordinated, collective decisions in the context of a dialogue between all branches of government with the academic and business communities and the general public. For the future generations

[5] In 2012, as founding director of the Munich Center for Technology in Society (MCTS) at the Technical University of Munich as part of the Excellence Initiative 2012, and before that (in 1998) as founding director and the first head of the Institute for Interdisciplinary Computer Science of the University of Augsburg to analyze the societal impact of the internet.

of engineers, ICT professionals, and scientists, contact with the public will become an integral aspect of their work; therefore the skills required for such communication must be learned from the very beginning of their professional education. Taking into account the human factor should be seen as an important aspect of the technological design of human-machine interactions in the development of artificial intelligence. The big questions for the future of artificial intelligence can only be answered by interdisciplinary studies. Each project step should be examined at both the technical and the organizational level over the course of a dialogue with society, to cover and take into account all kinds of social consequences and challenges, and to see unexpected promising directions.

References

Acatech (2011) *Cyber-Physical Systems. Driving force for innovation in mobility, health, energy and production*, Berlin: National Academy of Science and Engineering (ACATECH). Available at: https://www.acatech.de/publikation/cyber-physical-systems/download-pdf?lang=wildcard, accessed 15.09.2020.

Acatech (2012) *Technology Futures. Anticipation – Creation – Assessment* (English Summary), Berlin: National Academy of Science and Engineering (ACATECH).

Al Dakheel J., Del Pero C., Aste N., Leonforte F. (2020) Smart buildings features and key performance indicators: A review. *Sustainable Cities and Society,* vol. 61, art. 102328. Available at: https://doi.org/10.1016/j.scs.2020.102328, accessed 19.09.2020.

Alegre H., Vitorino D., Coelho S. (2014) Infrastructure value index: A powerful modelling tool for combined long-term planning of linear and vertical assets. *Procedia Engineering*, vol.89, pp. 1428–1436. Available at: https://doi.org/10.1016/j.proeng.2014.11.469, accessed 06.08.2020.

Bansraj D.S., Smit H.T.J., Volosovych V. (2018) *Can Private Equity Act as Strategic Buyers? Evidence from Serial (Buy-and-Build) Strategies?* Paper presented at the 2019 FMA European Conference, 12-14 June 2019, Glasgow, Scotland. Available at: http://www.fmaconferences.org/Glasgow/Papers/Buy_and_Build_FMAEur_2019.pdf, accessed 04.07.2020.

Bassett M., Wilkinson S., Mannakkara S. (2017) Legislation for building back better of horizontal infrastructure. *Disaster Prevention and Management*, vol. 26, no 1, pp. 94–104. DOI: 10.1108/DPM-03-2016-0054.

Behymer K.J. Flach J.M. (2016) From Autonomous Systems to Sociotechnical Systems: Designing Effective Collaborations. *She Ji: The Journal of Design, Economics, and Innovation*, vol. 2, no 2, pp. 105–114.

Berg M. (1998) The politics of technology: On bringing social theory into technological design. *Science Technology and Human Values*, vol. 23, no 4, pp. 456-490. DOI: 10.1177/016224399802300406.

Bezemek C. (2019) The 'Normative Force of the Factual': A Positivist's Panegyric. *The Normative Force of the Factual. Legal Philosophy Between Is and Ought* (eds. N. Bersier-Ladavac, C. Bezemek, F. Schauer), Heidelberg, New York, Dordrecht, London: Springer, pp. 65–77.

Biggs M. (2017) Self-fulfilling prophecies. *The Oxford Handbook of Analytical Sociology* (eds. P. Bearman, P. Hedström), Oxford: Oxford University Press, pp. 294–314 DOI: 10.1093/oxfordhb/9780199215362.013.13.

Blum C., Zuber C.I. (2016) Liquid democracy: Potentials, problems, and perspectives. *Journal of Political Philosophy*, vol. 24, no 2, pp. 162–182. Available at: https://doi.org/10.1111/jopp.12065, accessed 07.04.2020.

Boons F., Ludeke-Freund F. (2013) Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, vol. 45, pp. 9–19. Available at: https://doi.org/10.1016/j.jclepro.2012.07.007, accessed 07.04.2020.

Boy G.A. (ed.) (2017) *The handbook of human-machine interaction: A human-centered design approach*, Burlington, VT: Ashgate Publishing.

Dean J. (2014) *Big data, data mining, and machine learning. Value creation for business leaders and practitioneers*, Hoboken, NJ: Wiley.

European Commission (2006) *European Technology Platform SmartGrids. Vision and Strategy for Europe's Electricity Networks of the Future*, Brussels: European Commission. Available at: http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf, accessed 30.07.2020.

Geisberger E., Broy M. (eds.) (2012) *Living in a Networked World. Integrated Research Agenda on Cyber-Physical Systems (agendaCPS)*, Berlin: National Academy of Science and Engineering (ACATECH). Available at: https://www.acatech.de/publikation/agendacps-integrierte-forschungsagenda-cyber-physical-systems/download-pdf?lang=en, accessed 19.09.2020.

Giaimo F., Andrade H., Berger C. (2020) Continuous experimentation and the cyber–physical systems challenge: An overview of the literature and the industrial perspective. *Journal of Systems and Software*, vol. 170, art. 110781. Available at: https://doi.org/10.1016/j.jss.2020.110781, accessed 27.08.2020.

Glenn J.C., Gordon T.J. (eds.) (2009) *Futures research methodology — Version 3.0* (CD-ROM).Washington, D.C.: The Millennium Project. Available at: http://www.millennium-project.org/millennium/FRM-V3.html#toc, accessed 22.11.2019.

Godet M., Roubelat F. (1996) Creating the Future: The Use and Misuse of Scenarios. *Long Range Planning,* vol. 29, no 2, pp. 164–171. Available at: https://doi.org/10.1016/0024-6301(96)00004-0, accessed 22.08.2020.

Häder M. (ed.) (2002) *Delphi Interviews. A Workbook*, Heidelberg, New York, Dordrecht, London: Springer.

Hawkins W., Abdelzaher T. (2005) Towards feasible region calculus: An end-to-end schedulability analyzis of real-time multistage execution. *Proceedings of the 26th IEEE International Real-Time Systems Symposium (RTSS '05)*, Washington, D.C.: IEEE Computer Society, pp. 75–86. Available at: https://doi.org/10.1109/RTSS.2005.42, accessed 19.09.2020.

Isermann R. (2009) Mechatronic Systems – A Short Introduction. *Springer Handbook of Automation* (ed. S.Y. Nof), Heidelberg, New York, Dordrecht, London: Springer, pp. 317–331.

Jones A.J.I., Artikis A., Pitt J. (2011) The design of intelligent socio-technical systems. *Artificial Intelligence Review*, vol. 39, no 1, pp. 5–20. DOI: 10.1007/s10462-012-9387-2.

Ketchum B.J. (2016) Keeping tabs: When Will TTAB Decisions Have Preclusive Effect? Preclusive Effect of T.T.A.B. Likelihood of Confusion Decisions after B & B v. Hargis Industries. *Journal of Intellectual Property*, vol. 15, no 1, pp. 141–161.

King A.S. (1973) Self-Fulfilling Prophecies in Organizational Change. *Social Science Quarterly*, vol. 54, no 2, pp. 384–393.

Lee E.A., Seshia S.A. (2016) *Introduction to embedded systems: A cyber-physical systems approach*, Cambridge, MA: MIT Press.

Lozito G.M., Salvini A. (2020) Swarm intelligence based approach for efficient training of regressive neural networks. *Neural Computing and Applications*, vol. 32, no 14, pp. 10693–10704. DOI: 10.1007/s00521-019-04606-x.

Mainzer K. (2007) *Thinking in Complexity. Computational Dynamics of Matter, Mind, and Mankind* (5th ed.), Heidelberg, New York, Dordrecht, London: Springer.

Mainzer K. (2019) *Artificial Intelligence. When do Machines Take Over*?, Heidelberg, New York, Dordrecht, London: Springer.

Nelson R. (2018) *Modern Evolutionary Economics — An Overview*, Cambridge, MA: Cambridge University Press.

Nelson R., Winter S.G. (1982) *An Evolutionary Theory of Economic Change*, Cambridge, MA: Harvard University Press.

NSF (2008) *Cyber-Physical Systems. Program Announcements & Information*, Arlington, VA: National Science Foundation.

Pop O.-M. (2015) *Self-Fulfilling Prophecies and Innovation Success*. Available at: https://blog.hypeinnovation.com/self-fulfilling-prophecies-and-innovation-success, accessed 28.09.2020.

Rajkumar R., Lee I., Sha L., Stankovic J. (2010) Cyber-physical systems: The next computing revolution- Design automation. *Proceedings of the Design Automation Conference*, Piscataway, NJ: IEEE, pp. 731–737. DOI: 10.1145/1837274.1837461.

Ringland G. (2010) The role of scenarios in strategic foresight. *Technological Forecasting and Social Change*, vol. 77, no 9, pp. 1493–1498. DOI:10.1016/j.techfore.2010.06.010.

Roth S.(ed.) (2015) *Non-technological and non-economic innovations: Contributions to a theory of robust innovation*, Kiel (Germany): ZBW — Leibniz Information Centre for Economics.

Sa I., Corke P. (2014) Vertical infrastructure inspection using a quadcopter and shared autonomy control. *Field and Service Robotics: Results of the 8th International Conference* (Series: Springer Tracts in Advanced Robotics, vol. 92) (eds. K. Yoshida, S. Tadokoro), Heidelberg, New York, Dordrecht, London: Springer, pp. 219–232.

Schiff J.L. (2007) *Cellular Automata: A Discrete View of the World,* New Tork: John Wiley & Sons.

Schot J., Geels F.W. (2008) Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analyzis and Strategic Management*, vol. 20, no 5, pp. 537–554. Available at: https://doi.org/10.1080/09537320802292651, accessed 15.08.2020.

Tantawi K.H., Sokolov A., Tantawi O. (2019) Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration. *Proceedings of the 4th Technology Innovation Management and Engineering Science International Conference (TIMES-iCON 2019)*, art. 9024658. Available at: https://ieeexplore.ieee.org/document/9024658, accessed 30.05.2020.

van de Poel I. (2020) Embedding Values in Artificial Intelligence (AI) Systems. *Minds and Machines* (in press, first published online 01.09.2020). Available at: https://link.springer.com/article/10.1007/s11023-020-09537-4, accessed 14.08.2020.

van der Heijden K. (1996) *Scenarios: The Art of Strategic Conversation*, New York: Wiley & Sons.

van Kerkhoff L. (2014) Developing integrative research for sustainability science through a complexity principles-based approach. *Sustainability Science,* vol. 9, pp. 143–155.

Wayne W. (2008) *Computers as Components: Principles of Embedded Computing Systems Design*, Amsterdam: Morgan Kaufmann.

Wedde H.E., Lehnhoff S., van Bonn B., Bay Z., Becker S., Böttcher S., Brunner C., Büscher A., Fürst T., Lazarescu A.M., Rotaru E., Senge S., Steinbach B., Yilmaz F., Zimmermann T. (2007) Highly dynamic and adaptive traffic congestion avoidance in real-time inspired by honey bee behavior. *Mobilität und Echtzeit* (eds. P. Holleczek, B. Vogel-Heuser), Heidelberg, New York, Dordrecht, London: Springer, pp. 21–31. DOI: 10.1007/978-3-540-74837-3_3.

Uncertainties, Knowledge, and Futures in Foresight Studies — A Case of the Industry 4.0

Andrzej Magruk
Assistant Professor, a.magruk@pb.edu.pl

Bialystok University of Technology, 45A, Wiejska Street, 15-351 Bialystok, Poland

Abstract

The main purpose of this publication is an attempt to treat the phenomenon of uncertainty as one of the main research subjects in futures studies and not as the background for futures research – by answering the following research question: "What is the methodical relationship between the scope of the uncertainty phenomenon and the levels of knowledge and types of futures in the foresight approach?" This study uses the results of the analysis and criticism of the literature as the main research method. On this basis, deductive reasoning was carried out. The types of futures and the scope of uncertainty allowed to the author to define scale of knowledge levels. This paper has attempted to draw together three methodological fields: uncertainty, foresight, and knowledge. The author analyzed the complex relations among the above areas on the basis of their characteristics, which are extensions of existing concepts available in the literature. Conclusions from the results presented in this article can be a valuable contribution to the development of the area of futures management. In the management of complex systems (such as Industry 4.0), from the foresight methodological point of view, it seems relevant to determine which specific uncertainties can be managed by which classes of foresight methods, and which foresight methods are determined by what level of knowledge. The results of the research presented in this publication may be used for creating a research methodology for technological foresight projects and as a complementary element of research devoted to the issues of the development of modern technologies, which include Industry 4.0.

Keywords:
uncertainty; knowledge; futures; foresight; method; Industry 4.0

Citation: Magruk A. (2020) Uncertainties, Knowledge, and Futures in Foresight Studies — A Case of the Industry 4.0. *Foresight and STI Governance*, vol. 14, no 4, pp. 20–33. DOI: 10.17323/2500-2597.2020.4.20.33

At the beginning of the last century, it was noticed that efforts to make social life more rational generated unintended consequences such as increased uncertainty [*Poli*, 2017]. From the 1970s and 1980s, new perspectives appeared related to the phenomenon of uncertainty, especially in several areas that deal with human interactions and modern complex technologies (e.g., economics, large-scale processes and energy technologies, systems engineering, management science, computer science, and artificial intelligence) [*Smithson*, 1989].

Many of today's uncertainties (regional, national, global) are systemic in nature, being one of the most important features of many areas of social and economic life, especially in the context of futures management. Nowadays, one of the most popular approaches in many developed economies is the so-called Industry 4.0. In many respects, this idea, due to its modernity (its beginning dates back to 2011), innovativeness by transforming the way goods are designed, manufactured, delivered and paid for [*Hofmann, Rüsch*, 2017] and the systemic approach (of scale and dimensions, so far not used until now), is burdened with a high degree of uncertainty [*Magruk*, 2016]. For example, in the context of the development of a new kind of entrepreneurship, there is now a high level of uncertainty about what we can expect from the challenges and opportunities arising from the shifting of the border between human and machine tasks and algorithms [*Ansari et al.*, 2018]. Another area of uncertainty that is inherent to Industry 4.0 is the problem of the veracity of data, especially big data, that is generated throughout the whole process of managing Industry 4.0. Uncertainty exists in every phase of big data learning and comes from many different sources, such as data collection, concept variance, and multimodality [*Hariri et al.*, 2019].

The management of such systems enforces the use of complex and innovative research approaches (focusing on interdisciplinary fields and problems [*Sokolov, Chulok*, 2012]), as well as those in the futures context, generating new theories of management [*Shepherd, Suddaby*, 2017]. Such approaches undoubtedly include well-designed foresight methodologies, focusing on interdisciplinary fields and cross-issue problems, creating the ability to plan different futures based on specific needs or required outcomes [*Jemala*, 2010].

At the end of the 20th century, foresight became an important instrument for long-term problems related to risk and uncertainty [*Jenssen*, 2010; *Kononiuk et al.*, 2017] as a consequence of globalization and unprecedented technological progress [*Jemala*, 2010].

Despite the fact that foresight research tries to steer a course between the unsettling uncertainty and unpredictability of the future and the need for data, information, and knowledge to shape this future [UNDP, 2018], until now uncertainty was not main research object but acted as the background for futures research. The main purpose of this publication is an attempt to change this perspective – to treat uncertainty as the one of main research subjects in futures studies – by trying to solve a research problem related to the scope of uncertainty versus the level of knowledge and types of future shaping the methodology of foresight research. In the author's opinion, in complex systems (in this case this means Industry 4.0), from the foresight methodological point of view, it seems relevant to determine which kinds of future and levels of knowledge will be appropriate for the analysis of the scope of uncertainties.

Methodology

This study uses the results of an analysis and criticism of the literature as the main research method. Upon this basis, conceptual modeling was performed.

Both the human ability to understand the processes of change, the indication of cause-and-effect relationships, and plan for the future requires knowledge characteristic of foresight research. When uncertainty is expressed in connection with a desired outcome (this is very typical for foresight research) is it more positively evaluated than when it is expressed in terms of an undesired outcome [*Smithson,* 1989]?

Knowledge generated in foresight studies is characterized by a high degree of uncertainty and complexity. However, the quality of foresight knowledge is most often analyzed in terms of its reliability than the accuracy of the predictability of certain events [*Guimaraes et al.*, 2006].

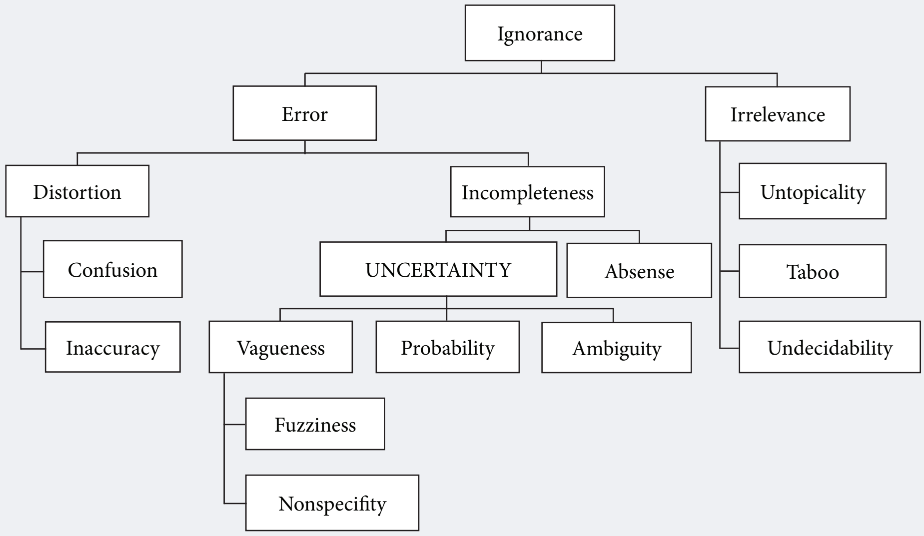
As mentioned in the introduction, it should be stated that in the foresight studies, the uncertainty phenomenon is most often the background for these studies and not its main subject. However, there are methodical areas of foresight in which the problem of uncertainty is being studied on a wider scale [*Magruk*, 2017a] through approaches such as scenario analysis [*Ringland*, 1998; *Kononiuk, Nazarko*, 2014], the cone of the future [*Amara,* 1974; *Hancock, Bezold,* 1994; *Kononiuk, Nazarko*, 2014; *Voros*, 2017], the cone of uncertainty [*Magnus*, 2012], and strategic foresight [*Courtney et al.*, 1997; *Courtney*, 2001]. The ideas mentioned above constitute a substantive basis for the study of uncertainty as the main object in foresight research.

Uncertainty in the modern era is the result of the complex interactions of forces of many kinds: technological, social, political, economic, and environmental [*Ringland*, 1998; *Chodakowska, Nazarko*, 2017].

Every theory of knowledge draws a distinction between knowledge and ignorance, and most do so between ignorance in the sense of incomplete knowledge and ignorance in the sense of erroneous belief [*Smithson*, 1989].

In the taxonomy of ignorance proposed by Smithson, uncertainty is only one of the types of ignorance (Figure 1) [*Smithson*, 1989]. In this article, a different

Figure 1. **Taxonomy of Ignorance**



Source: [*Smithson,* 1989].

perspective is used. Uncertainty is the subject of the study in relation to the levels of knowledge (as opposed to ignorance).

It should be stressed that uncertainty can be considered from a much larger number of points of view than shown in Figure 1. There are many definitions (Table 1) and typologies of uncertainty developed for various purposes [*Walker et al.*, 2003; *Lindley*, 2013; *Jalonen*, 2012; *van der Sluijs et al.*, 2004; *Funtowicz, Ravetz*, 1990; *Magruk*, 2016; *Bombola*, 2014; *Jędralska, Czech* 2011; *Wawiernia*, 2013]. In this article the author presents an innovative proposal to enlarge this spectrum with new scopes in relation to levels of knowledge and types of future.

In this publication, uncertainty is treated as a phenomenon that arises from two sources. The first source is subjective (epistemic) and results from self-knowledge (lack of knowledge) about the information on the basis of which decisions are formulated, but which (uncertainty) may be reduced by additional research [*Gaweł et al.*, 2015]. The second source of uncertainty is objective (ontological, aleotaric) and results from the stochasticity of the nature of the examined object and is irreducible [*Aven*, 2010]. The ontological nature of uncertainty refers to such categories as: existence and its ways, essence, subject and its properties, causality, time, space, necessity, and possibility [*Nja et al.,* 2017].

Self-knowledge about the decision situation in the context of uncertainty refers to three aspects important from the future research point of view of [*Kaivooja et al.*, 2004]: 1) knowledge, 2) predictability, and 3) time.

Knowledge, in the context to uncertainty, is the result of two components: awareness of self and knowledge of the world. It can be manifested in the following ways [*Atherton*, 2013; *Bojarski*, 1981] (Figure 2):

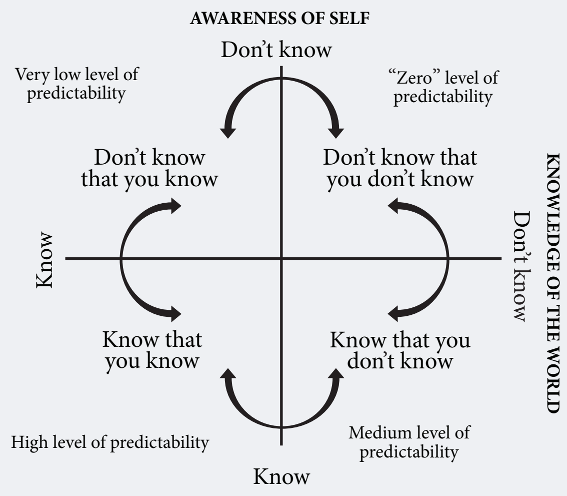
- the researcher knows of that which he is sure – corresponds to a high level of predictability;
- researcher knows that he does not have enough knowledge – corresponds to a medium level of predictability;
- the researcher does not know how he knows – or cannot express it– corresponds to a very low level of predictability;
- the researcher does not know that he does not have sufficient knowledge and is under the mistaken belief that he knows enough – corresponds to a "zero" level of predictability.

With the widening of the time horizon there is a correlation between the increase in the level of uncertainty and the decrease in predictability (Figure 3). In a short period of time, predictability is high, which determines the application of forecasting models (F). In the medium term, the level of predictability and uncertainty determines the use of scenario and simulation methods (S). In the very distant future, we are dealing with a very deep uncertainty, and all attempts at prediction can only be based on hope (H) [*Kaivooja et al.*, 2004].

For distant time horizons, the degree of complexity of the features, structures, and behaviors of the examined systems is increasing. Knowledge relating to these issues is becoming increasingly blurred, contributing to the deepening of uncertainty [*Magruk*, 2017b].

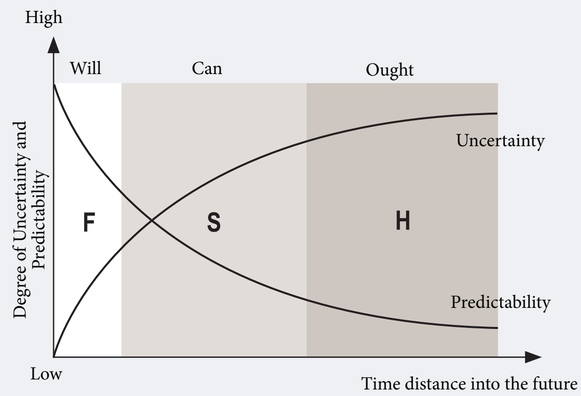
Industry 4.0 – the forerunner of the fourth industrial revolution – is such a complex system. It is a vision in which the real world will connect fully with the

Figure 2. **The Cycle of Knowing**



Source: [*Atherton*, 2013].

Figure 3. **Relation of Predictability to Uncertainty**



Sources: [*Kaivo-oja et al.*, 2004; *Magruk*, 2017a].

digital environment. Universality in the applications of Industry 4.0 including the Internet of Things, Big Data, cloud manufacturing, inter-machine communication, and cyber-physical systems, using interoperability, decentralization, and the full virtualization will certainly affect the course of many phenomena (economic, social, technological, etc.) [*Siderska, Jadaan*, 2018], while the direction, strength, and intensity of these changes are increasingly often becoming unpredictable (the not fully developed concept of Industry 4.0 is already a driving force for its new generations, i.e. Industry 5.0 [*Nahavandi*, 2019] or Industry X.0 [*Abood et al.*, 2017; *Schaeffer*, 2017]). The above facts mean that this vision is burdened with a high level of uncertainty in many aspects from the level of design to the level of use [*Magruk*, 2016].

The occurrence of the uncertainty phenomenon in the context of the future analysis of the development of such complex systems (as Industry 4.0) is broadly influenced by the following factors [*Bojarski*, 1981]:

Table 1. **Selected Interpretations of the Uncertainty Phenomenon**

Area of study	Definitions of uncertainty	чее есае
Theory of economics	Uncertainty is a subjective measure that correlates with objective risk; a measure of uncertainty is the probability of the occurrence of a specific event	Allan Willett, Frank Knight
Game theory	Uncertainty occurs when only a few alternatives of results are known, without the probability of their occurrence	Wiesław Samecki
Quantum physics	Uncertainty is determined by the principle of indeterminacy – there is a fundamental limitation of the possibility of simultaneous measurement with the infinite accuracy of specific dynamic quantities.	Werner Heisenberg
Systems theory	Uncertainty results from the inability to accurately determine all states of the elements of large dynamic systems and their relationships in the past and in the future	Wlodzimierz Bojarski, Jan Zieleniewski
Foresight	An important feature of foresight is accepting the fact of uncertainty, trying to understand it and making it a part of thinking about the future	Dana Mietzner, Guido Reger, Angela Wilkinson
Theory of decision making	The distinction between determinism (confidence), probability (objective uncertainty) and fuzzyness (subjective uncertainty)	Mirosław Bereziński, Jerzy Hołubiec
Cosmology	Uncertainty results from the singularity of the expansion of the universe and the collapse of massive stars	Albert Einstein, Andrew Strominger, Malcolm Perry
Theory of information	Uncertainty should be defined as entropy, resulting from information overload	Claude Shannon
Epistemology (researcher's perspective)	Uncertainty results directly from the ignorance of the researcher regarding the cognitive process and the measurement result	Kazimierz Ajdukiewicz

Source: compiled by the author based on [*Janasz*, 2009; *Wawiernia*, 2013; *Samecki*, 1967; *Bojarski*, 1981; *Kononiuk, Nazarko*, 2014; *Bereziński, Hołubiec*, 1981].

- the multiplicity of possible structures, their high complexity, and variability;
- number and strength of internal links of the system;
- insufficient knowledge of the surrounding environment;
- behavior of persons and institutions managing the system in the context of the potential to go beyond known rules;
- ignorance of new potential rules and their scope;
- length of the considered time horizon.

Factors that generate uncertainty in particular in the area of Industry 4.0 are [*Magruk*, 2016; *Cividino et al.*, 2019]:

- ignorance of new potential rules and their scope;
- the very large scale of mutual relations between all entities contributing to the ecosystem Industry 4.0
- creating new, previously unknown business models of cooperation and new value creation chains;
- the integration of new IT systems with old systems not designed for the Internet of Things;
- the creation of jobs by Industry 4.0 with new competences, e.g., for robots;
- the increase in the complexity of manufactured parts;
- the digitization of business processes goes beyond the boundaries of closed facilities (factories), e.g., virtual fleets, and includes everywhere and anytime.

According to P. Schwartz uncertainty is the "new normal" in today's rapidly changing times [*Schwartz*, 2012]. This is the level of decision and uncertainty that called "postnormal science" [*Funtowicz, Ravetz*, 1990]. Selected elements of this concept regarding the relationship of uncertainty to ignorance [*Aven*, 2013] are used in the main chapter of this article.

Research Findings

The author proposes to use the concept of the matrix of uncertainties, futures, and knowledge (Figure 4, which basic skeleton in the form of a "future cone" was developed by J. Voros [*Voros,* 2017] based on among others the work of Hancock and Bezold [*Hancock, Bezold,* 1994]) in the research of the future (in particular in foresight) and uncertainty. The other important ideas taken into account in the process of building the "cone of futures & possibilities" include the "cone of plausibility" [*Taylor,* 1990], the future cone, and ignorance and uncertainty matrix [*Sardar, Sweeney,* 2016], cone of possibility space [Candy, 2010], the idea of the "future light cone" [*Hawking*, 1988], and the "cone of uncertainty and possibilities" [*Magnus,* 2012].

The more distant time horizon, the worse the quality and resources of knowledge (the higher level of ignorance) and the greater the uncertainty (its scope and range). At the same time, with a larger area of uncertainty and an increase in the indeterminacy of the dynamics of changes in the structures of the observed system, we are dealing with different types of futures. In a completely deterministic system, if it was known what was going on during the initial state of uncertainty, it would be possible to predict with a high probability the future developments of the occurrences we would have to deal with [*Magruk,* 2017b]. In nondeterministic systems, the past and present events determine only the distribution of the probability of possible states in the future [*Heller,* 2016].

This approach (shown in Figure 4) makes it possible to identify (and, as a consequence, manage) selected types of uncertainty. Thanks to this approach, it is possible to change the research perspective in which the kinds of the future (types of alternative futures) characteristic of the "future cone" can become a background for uncertainty research.

Below are presented the characteristics of the types of uncertainties in relation to particular levels of knowledge corresponding to the particular types of the future.

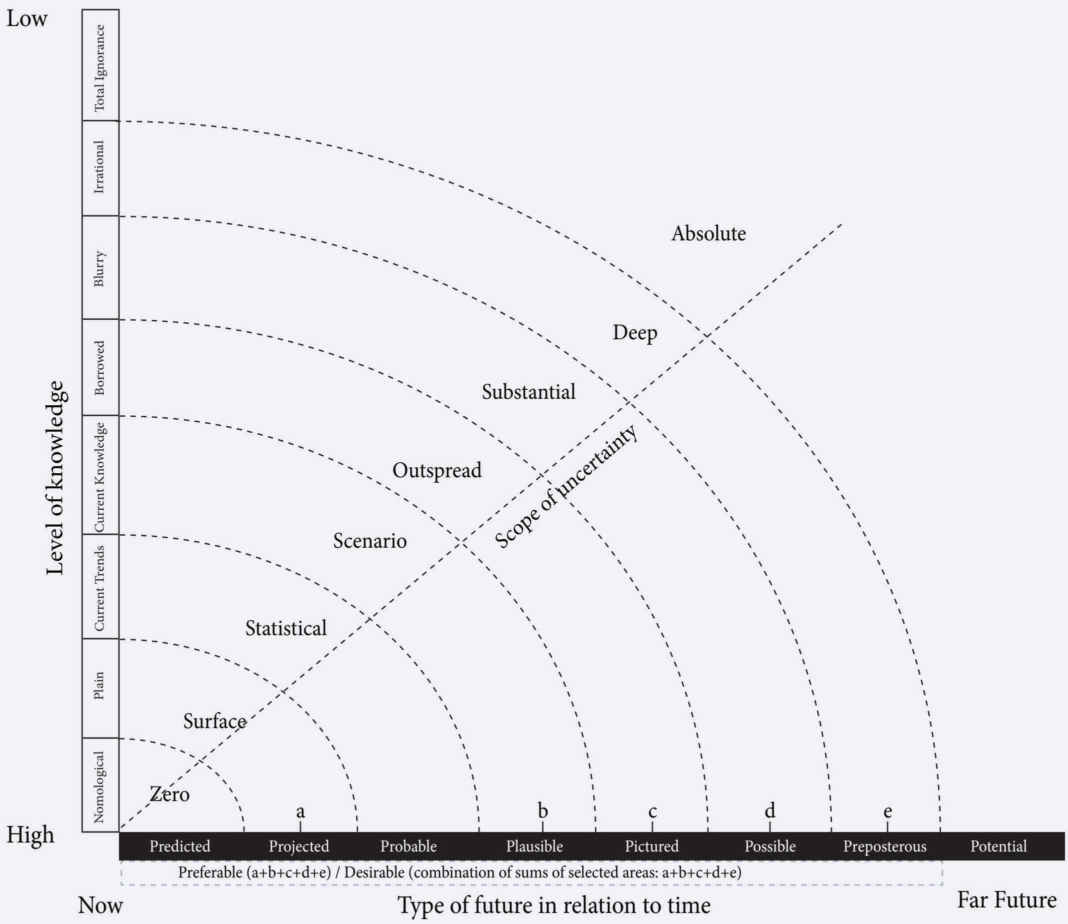
Zero scope of uncertainty with nomological knowledge vs. predicted future.

It is a very rare situation in which uncertainty is at a zero level, i.e., we can say with about 100 percent certainty, phenomena are based on total determinism. In this case, one can speak about a situation related to Laplace's doctrine of the nineteenth century, namely that the universe is completely determined [*Magruk*, 2017b]. It is the future that someone claims 'will' happen. This category of the future corresponds with the possibility of the occurrence of the "black elephants" [*Sardar, Sweeney*, 2016] – events which are extremely likely and widely predicted by experts. Knowledge in this case is based on total trust, it has a nomological character referring to the fundamental laws governing a given reality. There is a very high awareness of possessed and unqualified knowledge. This knowledge is based upon the relationship with dogmatic philosophers such as Plato or Locke who needed absolute certainty about knowledge [*Smithson*, 1989].

Surface scope of uncertainty with plain knowledge vs. projected future.

This uncertainty refers to a certain tendency that can be managed to some degree with adequate knowledge and foresight tools. Projected future is characteristic of simple prognostic studies in which the forecasting is based upon the extrapolation of historical data [*Pieriegud,* 2015]. Plain knowledge is single-person default knowledge. The awareness of knowledge is high – you know what you know, you know what you are not sure about, and what you do not know. Ignorance and uncertainty can be minimized through learning, research, appreciating the viewpoints of

Figure 4. **Matrix of Uncertainties, Futures, and Knowledge**



Source: compiled by the author.

others, and asking the right questions as well as by processing the available information to produce hypotheses that could shed some light on what we are seeing [*Sardar, Sweeney*, 2016].

Statistical scope of uncertainty with current trends vs. probable future

In this field we are dealing with statistical uncertainty, it means that uncertainty is based on well described functional relationships. The level of knowledge is closely related to the awareness of and knowledge about current trends and megatrends. Nevertheless, although megatrends are certainties, they always contain elements of uncertainty. All outcomes (expressed stochastically) and all probabilities are known [*Refsgaard et al.*, 2012]. This kind of future expresses what we know with great confidence about the future [*Larsen,* 2006]. An example of statistical uncertainty is the measurement of uncertainty associated with a sampling error, or an inaccuracy or imprecision in the measurements [*Walker et al.*, 2003];

Scenario scope of uncertainty with current knowledge vs. plausible future

Knowledge is based on our current understanding of how the world works [*Voros,* 2017]. In this case the whole range of outcomes of plausible futures and probabilities is unknown [*Refsgaard et al.,* 2012]. Plausible futures do not forecast what will happen in the future; rather they indicate what could happen [*Voros,* 2017; *Walker et al.,* 2003]. Scenario uncertainty is related to the external (often future) environment of a system and its effects upon the system. Scenario uncertainty implies that there is a range of discrete possible outcomes, but the mechanisms leading to these outcomes are not well understood without the allocation of their likelihood [*Walker et al.*, 2003].

Outspread scope of uncertainty with borrowed knowledge vs. pictured future

Knowledge is based on the conviction (or on the naïve assumption) that solutions proposed by someone will be analogous in reality. Uncertainty is focused on a broad range of alternatives (borrowed from advertising, corporate visions, popular 'futurology' and science fiction novels, films, television shows and projects from other places successfully completed). This range, despite its large capacity, is defined by limited numbers of key variables. The pictured future is similar to the "familiar future" [*Sardar, Sweeney*, 2016] and "used future" [*Inayatullah*, 2008] – one of the six basic concepts of futures thinking. It is someone's image of the future, someone's desired future or is it unconsciously borrowed from someone else from a scientific point of view, in the context of a literature review.

Substantial scope of uncertainty with blurry knowledge vs. possible future

Knowledge about the general direction of change cannot be achieved at present (it is very blurred – based on a broad range of alternatives and a plethora of possible avenues of development). This creates an awareness of what we do not know and what we must seek to know in the future. Uncertainty is due to common complexity, chaos, and contradictions of analyzed pieces of information. Uncertainty is related to a complex problem – we are aware that we do not have enough knowledge – we do not know what we do not know – but we can still grasp it to some extent [*Sardar, Sweeney,* 2016]. There is a thin line between pictured and possible future, but there is a difference based on the fact that in the pictured future we rely upon the already described (by someone) examples and imagined alternatives. In the example of possible future, we can come up with the future ourselves.

Deep scope of uncertainty with irrational knowledge vs. preposterous future

You do not know what you do not know, but you are under the mistaken belief (based on existing paradigms and modes of knowing, being, and doing) that you know enough. It is knowledge that goes beyond the framework of conventional thought, that does not allow us to focus on or think about. This knowledge requires radically new ways of thinking. Uncertainty is deep because it results from the unawareness of the direction, dimension, and impact of change, and also from the fact we are incapable of knowing what is happening to the system because our worldview or epistemology is totally inadequate. Sardar and Sweeney describe this preposterous future as "unthought future(s)". Is not unthinkable (or not expected or anticipated), but rather its horizon is populated with seemingly infinite alternative futures [*Sardar, Sweeney*, 2016].

Absolute scope of uncertainty with total ignorance vs. potential future

Knowledge has a zero level (total ignorance), it refers to issues that cannot be imagined. "Total ignorance" is an ignorance that cannot be classified into any type of ignorance described by Smithson [*Smithson*, 1989]. It is ignorance which is beyond the scope of scientific, logical, mathematical, or otherwise 'proper' analysis just because we cannot imagine a future does not mean it cannot happen [*Voros*, 2017]. Absolute uncertainty is due to inherent (ontological) variability. This uncertainty is non-reducible. This is the scope of uncertainty characteristic for Pyrrhonist or complete scepticism. Complete scepticism maintains that nothing can be certain, nor can anything be known because no one is justified or reasonable in their assertions about reality [*Smithson,* 1989]. The potential future is undetermined and 'open' and therefore not inevitable or 'fixed' [*Voros*, 2017].

It is not always easy to distinguish between these categories of uncertainty; it is often a matter of convenience and assessment related to the characteristics of the problem under study and the current state of knowledge or ignorance [*Walker et al.*, 2003].

The absolute future of the event under investigation is reflected by a set of all events (a or/and b or/and b or/and b/and c and/or d or/and e) with which the human being can (but does not have to) interact. The author proposes dividing the preferred future into sub-areas: a, b, c, d, e, characteristic for particular types of uncertainty and types of knowledge, which become preferable only with a specific configuration of factors as the future sum: from a to e, while in other combinations one receives a desirable form of future, characteristic of those found in foresight research.

The author used what is available in the literature in this study, a 10-class classification of foresight methods (Table 2) [*Magruk*, 2011].

In the author's opinion, in order to minimize the uncertainty phenomenon in predictive studies, it is necessary to take into account the properties of the methods selected for the study (Table 2), which are strongly reflected in the form of the explored type of the future and the level of knowledge they provide (Table 3). This selection was made on the basis of an analysis of the characteristics of individual foresight research methods and the author's experience resulting from his active participation in many foresight initiatives.

The most characteristic approach for foresight research methodology is the selection of appropriate research methods to create desirable futures [*Magruk*, 2013]. In the author's opinion, the results shown in Table 3 can be helpful for choosing appropriate foresight methods in a situation when we know with what type of future we are dealing with. Knowledge about the type of future may be a derivative of the formulated goals of research in a specific area (be-

Table 2. **Classification of Foresight Research Methods**

The name of classes	Foresight methods belonging to each class
Consultative	Voting, Polling, Survey, Interviews, Expert Panels, Essays, Conferences, Workshops, Citizen Panels, Brainstorming
Creative	Wild Cards, Mindmapping, Lateral Thinking, Futures Wheel, Role Play, Business Wargaming, Synectics, Speculative Writing, Visualization, Metaphors, Assumption Reversal
Prescriptive	Relevance Trees, Morphological Analysis, Rich Pictures, Divergence Mapping, Future Mapping, Backcasting, SRI Matrix, Science Fiction Analysis, Incasting, Genius Forecasting, Futures Biographies, TRIZ, Future History, Alternative History
Multicriterial	Key Technologies, Source Data Analysis, Migration Analysis, Shift-Share Analysis, DEA, Factor Analysis, Correspondence Analysis, Cluster Analysis, Sensitivity Analysis, AHP, Input-Output Analysis, Prioritization, SMART, PRIME, MCDM
Radar	Scientometrics, Webometrics, Patent Analysis, Bibliometrics, Technological Substitution, S-Curve Analysis Technology Mapping, Analogies
Simulation	Probability Trees, Trend Extrapolation, Long Wave Analysis, Indicators, Stochastic Forecast, Classification Trees, Modeling and Simulation, System Dynamics, Agent Modeling
Diagnostic	Object Simulation, Force Field Analysis, Word Diamond, SWOT, STEEPVL, Institutional Analysis, DEGEST, Trial & Error, Requirement Analysis, Theory of Constraint, Issue Management, ANKOT
Analytical	SOFI, Stakeholder Analysis, Cross-Impact Analysis, Trend Impact Analysis, Structural Analysis, Megatrend Analysis, Critical Influence Analysis, Technology Barometer, Cost-Benefit Analysis, Technology Scouting, Technology Watch, Sustainability Analysis, Environmental Scanning, Content Analysis, FMEA, Risk Analysis, Benchmarking
Survey	Web Research, Desk Research, Technology Assessment, Social Network Analysis, Literature Review, Weak Signals, Retrospective Analysis, Macrohistory, Back-View Mirror Analysis
Strategic	Technology Roadmapping, Technology Positioning, Delphi, Scenarios, Social Impact Assessment, RPM Screening, Technological Scanning, Multiple Perspectives Assessment, Causal Layered Analysis, MANOA, Action Learning

Source: [*Magruk*, 2011].

sides the many factors influencing the foresight research process) [*Magruk,* 2015]. Examples of specific technological areas are presented in the fourth row, based on research [*Watson, Cupani,* 2018] at Imperial Tech Foresight in the form of the "Table of Disruptive Technologies". Individual examples of technologies were selected on the basis of the time horizon postulated by Imperial Tech Foresight researchers and the availability of knowledge about them.

The first column of Table 3 refers to cryptocurrency technology. It is believed that for the fourth industrial revolution to be successful, an open, borderless, payment protocol in the form of bitcoin (one of the most popular cryptocurrencies) must be in place [*Gil-Pulgar,* 2016]. Postulated foresight research methods, which are possible to apply in this case are interviews, expert panels, genius forecasting, megatrend analysis, essays, and literature reviews. The use of the first three methods is reflected in the opinion of Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, which stated that "bitcoin's blockchain is the heart of Industry 4.0" [*Gil-Pulgar*, 2016]. The relationship "Zero scope of uncertainty in nomological knowledge vs. predicted future" with respect to the discussed technology seems to be a correct evaluation.

Key technological components of Industry 4.0 alongside wearables (e.g., smart glasses), augmented reality applications, distributed ledger systems (e.g., the blockchain), big data analytics as well as autonomous vehicles (including multi-agent systems) make up the second column. According to scientometrics and desk research (the recommended foresight methods in this group), autonomous vehicles are important in two dimensions of Industry 4.0: internal transport (within smart factories, e.g. via trailer unloading or piece picking robots) as well as external transport (e.g. via autonomous trucks, drones). Specific for this column, the surface scope of uncertainty refers to certain described tendencies in the literature [*Hermann et al.*, 2016; *Hofmann, Rüsch*, 2017; *Lom et al.*, 2016].

With regard to the third column in Table 3 (on the basis of web research), according to EIT Digital, a leading European digital innovation and entrepreneurial education organization (and other statistical studies), avatar companions (e.g., chatbots, assistants of engineers) are becoming increasingly widespread, both on the consumer market and in industrial applications. There is a growing interest in using chatbots to support collaboration between people and machines in industrial processes, and some industries, such as IBM, see this as a step towards Industry 4.0 [*Saracco*, 2018; *Jassova*, 2019]. In Industry 4.0, the data analysis performed by an avatar in the form of a chatbot can provide quick insight into emerging problems and easily translate them into a format that is understandable not only to machines but also to people [*Boker*, 2019].

Four-dimensional materials (fourth column) are a type of smart materials created (being at an early stage of development) as part of a process called additive manufacturing (current knowledge according to Table 3). In this case, 3D materials (now very popular in the development of Industry 4.0) are enriched with an additional dimension — time/memory. The implementation of this kind of material as part of

Table 3. **Methodological Foresight Matrix in Relation to Futures, Uncertainties, and Knowledge (with samples of technologies related to Industry 4.0)**

Time →

TYPE OF FUTURE	Predicted (a)	Projected (a)	Probable (a)	Plausible (b)	Pictured (c)	Possible (e)	Preposterous Future (e)	Potential Future	Preferable / Desirable Future
SCOPE OF UNCERTAINTY	Zero	Surface	Statistical	Scenario	Outspread	Substantial	Deep	Absolute	Combination of personal uncertainties
LEVEL (AWARENESS) OF KNOWLEDGE	Nomological	Plain	Based on Current Trends	Based on Current Knowledge	Borrowed	Blurry	Irrational	Total Ignorance	Combination of expert's knowledge
SAMPLES OF TECHNOLOGIES RELATED TO INDUSTRY 4.0	Cryptocurrencies	Delivery by autonomous vehicles	Avatar companions	4-dimensional materials	Swarm robotics	Transhuman technologies	Artificial consciousness	?	Innovative technologies
CLASSES OF FORESIGHT METHODS	SAMPLES OF FORESIGHT METHODS BELONGING TO EACH CLASS THAT CAN BE USED IN A SELECTED SCOPE OF UNCERTAINTY, TYPES OF FUTURE and LEVEL (AWARENESS) OF KNOWLEDGE								
Consultative	Expert Panels		Survey	Conferences	Interviews	Workshops	Essays	Expert Panels	A combination of selected methods from individual classes
Creative		Mind-mapping	Futures Wheel	Metaphors	Visualization	Wild Cards	Speculative Writing		
Prescriptive	Genius Forecasting	TRIZ	Morphological Analysis	Relevance Trees	Future Mapping	Rich Pictures	Alternative History, Science Fiction	Genius Forecasting	
Multicriterial		AHP	DEA	Key Technologies	Cluster Analysis				
Radar	Patent Analysis	Scientometrics	Webometrics	Technology Mapping				Analogies	
Simulation		Trend Extrapolation	Probability Trees, Stochastic Forecast	Classification Trees	Modeling and Simulation		Long Wave Analysis	System Dynamics	
Diagnostic		STEEPVL	Force Field Analysis	SWOT, DEGEST	Object Simulation				
Analytical	Megatrend Analysis	Cross-Impact Analysis	Trend Impact Analysis	Content Analysis	Benchmarking			Technology Watch, Environmental Scanning	
Survey	Literature Review	Desk Research	Web Research	Technology Assessment	Social Network Analysis	Weak Signals	Macrohistory		
Strategic		Technological Scanning	Delphi	Scenarios	Roadmapping	MANOA	RPM Screeening		

Source: own elaboration.

Industry 4.0 provides advantageous features like the reconfiguration of the printed structure and attaining the desired material property in time (current knowledge in relation to Table 3). Sectors which, within the framework of Industry 4.0's development, have plausible potential (with a scenario scope of uncertainty) to implement 4D materials including: medical engineering, clothing industry, and jewelry applications, power engineering, soft robotics, and the space industry [*Dilberoglu et al.*, 2017].

The concept of "swarm robotics" — fifth column — is based on the use of a large number (tens, hundreds) of simple machines for complex tasks. With simple rules and local interactions, swarm robots aim to design robust, scalable, and flexible collective behaviors to coordinate a large number of robots. The inspiration to explore the possibilities of swarm robot is most often provided by the self-organized nature (similarly as in the case of biomimicry [*Passino*, 2005]) in the form of colonies of ants, bees, birds, fish, and others (borrowed knowledge). The potential of "swarm robotics" in relation to the idea of Industry 4.0 lies in modular solutions, for example, in shape-changing machines (as in The Terminator movie) (pictured future) or programmable matter as an alternative to 3D printing. The advantage of swarm robots is their autonomy or cooperation in tackling a given task. The lack of operation of a small number of robots does not automatically mean the failure of the whole task. However, the described idea is also associated with a lot of difficulties of an algorithmic, technical, and financial nature. The fact that swarm robots do not have access to centralized control and/or to global knowledge [*Brambilla et al.*, 2013] is also a debatable issue in the context of the development of Industry 4.0 (outspread uncertainty).

Transhuman technologies (sixth column) will enable machines and living organisms to function at a high level of symbiosis (such as, e.g., by connecting human brains to global/internet databases). According to the visionaries, this integration is possible thanks to the achievements of genetics, cyber-technology, nanotechnology, biotechnology, artificial intelligence, and other areas [*McIntosh*, 2010]. In this case, the concept of Industry 4.0 strongly corresponds to the idea of the so-called "web of things" (web 4.0) [*Muller*, 2008]. This is the vision that will lead to [*Sarowski*, 2017]:

1) highly developed interactions taking place in symbiosis between man and machine;

2) integration into the network of almost all kinds of devices – through the full realization of the concept of the Internet of Things;

3) a new type of communication both in connecting people to objects and in connecting objects themselves to each other.

The substantial scope of uncertainty in blurry knowledge and potential future refers to the idea of creating a new generation of people (super-humans) by reaching a new level of their evolution. This idea is burdened with a high level of critical problems of security, which makes it necessary to apply such foresight methods as wild cards, rich pictures, and weak signals in this phase. It is an idea of the world in which man still plays a significant role despite the ubiquitous presence of technology, similar to the idea of Industry 5.0 [*Skobelev, Borovik*, 2017; *Guttman et al.*, 2017].

Artificial consciousness refers to the construction of intelligent machines that can compete with human intelligence. From today's point of view, it is a high-level science fiction idea. Therefore, we are dealing with a deep scope of uncertainty, in many aspects with irrational knowledge and a preposterous future. This approach raises the following philosophical questions: Can computers think? Is consciousness a human privilege? Can computer hardware replicate consciousness? (which is often regarded as the aspect of the mind that is least susceptible to artificial intelligence [*Chrisley*, 2008]). The answer to these questions is difficult because it requires a combination of information from many disciplines, including computer science, neurophysiology, philosophy, and religion [*Buttazzo*, 2001]. This requires the use of foresight research methods such as essays, speculative writing, alternative history, science fiction analysis, and macrohistory. In the context of the development of Industry 4.0, artificial consciousness strongly corresponds to the idea of the fifth generation of Internet development called the "web of thoughts" in the form of such technologies as: collective intelligence, artificial brain, digital aura – which allows for the intentional and adaptive behavior of autonomous robots — their body could be seen for itself as the morphologic apprehension of its material substrata [*Cardon*, 2006]. The role of the human element in this case is limited to a zero level.

In the last column, a combination of selected methods from individual classes depending upon the type of the desirable future can be created. The type of the desirable future depends upon the combination of the a, b, c, d, and e areas. A specific variation of the desirable future is the preferable future when we are dealing with sum of all areas (a + b + c + d + e). Other combinations (pairs, triples, fours) are desirable futures. The number of possible combinations of types of futures is 25. But the number of the possible combination of methods that we can use in research is very huge. For example, by combining any six methods (out of 116 methods identified by the author of this article) over three billion connections can be obtained [*Magruk*, 2013].

Discussion

The types of future (predicted, projected, probable, plausible, pictured, possible, preposterous, potential) and scope of uncertainty (zero, surface, statistical, scenarios, outspread, substantial, deep, absolute) proposed by the author based on the literature allow one to define the author's scale of knowledge levels in the form of: nomological, plain, based on current trends, based on current knowledge, borrowed, blurry — referring to future knowledge, irrational, and total ignorance.

The matrix of uncertainties, futures, and knowledge model has several modifications made by the author compared to the Voros model from:

- a new kind of future named the "pictured future";
- divisions of preferable future into sub-areas: a, b, c, d, e, characteristic for particular types of un-

certainty and types of knowledge, which becomes preferable only with a specific configuration of factors as the future sum: from a to e, while other combinations receive the desirable form of future, which is characteristic in foresight research.

Such a schematic approach, although simplified, was a good basis for achieving the main purpose of the article, that is, to answer the question: "What is the methodical relationship between the scope of the uncertainty phenomenon and the levels of knowledge and types of futures in the foresight approach?"

The methodological approach presented in this publication may be valuable from several perspectives. On the one hand, it allows one to develop basic research through in-depth theoretical analysis. On the other hand, it is a new contribution to the development of foresight research methodology. Thirdly, it allows one to better recognize new, complex, but not yet fully developed phenomena such as Industry 4.0. Other areas worthy of methodological analysis from the point of view of foresight, uncertainty, and knowledge are, for example, the Internet of Everything, Industry X.0, Industry/WEB 5.0, strong artificial intelligence, and others.

Conclusions

According to the author, thanks to specific foresight methods from different classes (and/or their combinations) related to selected types of the future, it is possible to manage selected ranges of uncertainty and not only treat uncertainty as a background for futures studies.

This paper has attempted to draw together three methodological fields: uncertainty, foresight, and knowledge. The author analyzed the complex relationships among the above areas on the basis of their characteristics which are the author's extensions of existing concepts available in the literature. By showing the strong relationships between the above fields, the research objective of this work was achieved.

The most characteristic aspect of the foresight research methodology is the selection of appropriate research methods to create a desirable future. In the author's opinion, the results showed in this paper can be helpful in choosing appropriate foresight methods in a situation when we know with which type of future, scope of uncertainty, and level of knowledge we are dealing.

References

Abood D., Quilligan A., Narsalay R. (2017) *Industry X.0 Combine and Conquer: Unlocking the Power of Digital,* Dublin: Accenture. Available at: https:// www.accenture.com, accessed 11.12.2019.

Amara R. (1974) The futures field: Functions, forms, and critical issues. *Futures*, vol. 6, no 4, pp. 289–301. DOI:10.1016/0016-3287(74)90072-X.

Ansari F., Erol S., Sihn W. (2018) Rethinking Human-Machine Learning in Industry 4.0: How Does the Paradigm Shift Treat the Role of Human Learning?. *Procedia Manufacturing*, vol. 23, pp. 117–122.

Atherton J.S. (2013) *Doceo. Knowing and not knowing*. Available at: http://www.doceo.org.uk/tools/knowing.htm, accessed 25.09.2019.

Aven T. (2010) On how to define, understand and describe risk. *Reliability Engineering and System Safety*, vol. 95, no 6, pp. 623–631.

Aven T. (2013) Practical implications of the new risk perspectives. *Reliability Engineering and System Safety*, no 115, pp. 136–145.

Bereziński M., Hołubiec J. (1981) Podejmowanie decyzji w warunkach niepewności informacyjnej [Decision making under conditions of information uncertainty]. *Metody modelowania i optymalizacji systemów energetycznych w warunkach niepewności* [Methods for modeling and optimization of energy systems in conditions of uncertainty] (ed. W. Bojarski), Wrocław: PAN, Ossolineum, pp. 64–78 (in Polish).

Bojarski W. (1981) Zagadnienia nieokreśloności wielkich systemów i niepewności [Indeterminacy issues of great systems and uncertainties]. *Metody modelowania i optymalizacji systemów energetycznych w warunkach niepewności* (ed. W. Bojarski), Wrocław: PAN, Ossolineum, pp. 7–28 (in Polish).

Boker A. (2019) *Industry 4.0: How Chatbot Data Analytics are Helping to Shape the Internet of Things within Telecommunications*. Available at: https://www.glassboxdigital.com/learn-about-chatbot-data-analytics/, accessed 01.10.2019.

Bombola P. (2014) Uogólniona niepewność zewnętrzna i wewnętrzna [General external and internal uncertainty]. *Ekonomia i Zarządzanie*, vol. 6, no 1, pp. 127–141 (in Polish).

Brambilla M., Ferrante E., Birattari M., Dorigo M. (2013) Swarm robotics: A review from the swarm engineering perspective. *Swarm Intelligence*, vol. 7, no 1, pp. 1–41.

Buttazzo G. (2001) Artificial consciousness: Utopia or real possibility?. *Computer*, vol. 34, no 7, pp. 24–30.

Candy S. (2010) *The futures of everyday life: Politics and the design of experiential scenarios*, Honolulu, HI: University of Hawaii at Manoa.

Cardon A. (2006) Artificial consciousness, artificial emotions, and autonomous robots. *Cognitive Processing*, vol. 7, no 4, pp. 245–267.

Chodakowska E., Nazarko J. (2017) Environmental DEA method for assessing productivity of European countries. *Technological and Economic Development of Economy*, vol. 23, no 4, pp. 589–607.

Chrisley R. (2008) Philosophical foundations of artificial consciousness. *Artificial Intelligence in Medicine*, vol. 44, no 2, pp. 119–137.

Cividino S., Egidi G., Zambon I., Colantoni A. (2019) Evaluating the Degree of Uncertainty of Research Activities in Industry 4.0. *Future Internet*, vol. 11, no 9, article 196, pp. 1–21. Available at: https://www.researchgate.net/publication/335765945_Evaluating_the_Degree_of_Uncertainty_of_Research_Activities_in_Industry_40/fulltext/5d7a43fca6fdcca980e1bbd6/Evaluating-the-Degree-of-Uncertainty-of-Research-Activities-in-Industry-40.pdf, accessed 24.01.2020.

Courtney H. (2001) *20/20 Foresight: Crafting strategy in an uncertain world*, Boston, MA: Harvard Business Press.

Courtney H., Kirkland J., Viguerie P. (1997) Strategy under Uncertainty. *Harvard Business Review*, vol. 75, no 6, pp. 67–79.

Dilberoglu U.M., Gharehpapagh B., Yaman U., Dolen M. (2017) The role of additive manufacturing in the era of industry 4.0. *Procedia Manufacturing*, vol. 11, pp. 545–554.

Funtowicz S.O., Ravetz J.R. (1990) *Uncertainty and quality in science for policy*, Heidelberg, New York, Dordrecht, London: Springer Science & Business Media.

Gaweł B., Rębiasz B., Skalna I. (2015) Teoria prawdopodobieństwa i teoria możliwości w podejmowaniu decyzji inwestycyjnych [Probability theory and possibility theory in investment decision making]. *Studia Ekonomiczne*, vol. 248, pp. 62–79 (in Polish).

Gil-Pulgar J. (2016) *Bitcoin: Welcome to the Fourth Industrial Revolution*. Available at: https://news.bitcoin.com/bitcoin-fourth-industrial-revolution/, accessed 15.10.2019.

Guimaraes Pereira A., von Schomberg R., Funtowicz S. (2006) Foresight knowledge assessment. *International Journal of Foresight and Innovation Policy*, vol. 3, no 1, pp. 53–75.

Guttman U., Papst J., Merlo R., Kane D., Bieser G., Grob O. (2017) Industry 4.0: What's Next. An SAP Point of View. SAP White Paper. Available at: https://www.sap.com/documents/2017/05/bae613d3-b97c-0010-82c7-eda71af511fa.html, accessed 23.01.2020.

Hancock T., Bezold C. (1994) Possible futures, preferable futures. *Healthcare Forum Journal*, vol. 37, no 2, pp. 23–29.

Hariri R.H., Fredericks E.M., Bowers K.M. (2019) Uncertainty in big data analytics: Survey, opportunities, and challenges. *Journal of Big Data*, vol. 6, no 1, article 44 (online). Available at: https://www.springerprofessional.de/content/pdfId/16778576/10.1186/s40537-019-0206-3, accessed 24.01.2020.

Hawking S.W. (1988*) A Brief History of Time*: *From the Big Bang to Black Holes*, New York: Bantam Dell Publishing Group.

Heller M. (2016) *Filozofia przypadku* [Philosophy of Chance], Kraków: Coperncus Center Press (in Polish).

Hermann M., Pentek T., Otto B. (2016) Design principles for industrie 4.0 scenarios. *Proceedings of the 2016 49th Hawaii international conference on system sciences (HICSS)*, Piscataway, NJ: IEEE, pp. 3928–3937.

Hofmann E., Rüsch M. (2017) Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, vol. 89, pp. 23–34.

Inayatullah S. (2008) Six pillars: Futures thinking for transforming. *Foresight*, vol. 10, no 1, pp. 4–21.

Jalonen H. (2012) The Uncertainty of Innovation: A Systematic Review of the Literature. *Journal of Management Research*, vol. 4, no 1, pp. 1–47. DOI: 10.5296/jmr.v4i1.1039.

Janasz K. (2009) Ryzyko i niepewność w gospodarce – wybrane aspekty teoretyczne [Risk and Uncertainly in Economy - Choosen Theoretical Aspects]. *Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania*, vol. 14, pp. 87–98 (in Polish).

Jassova B. (2019) *Chatbot Statistics Compilation 2019: The State of Market & Business Opportunities*. Available at: https://landbot.io/blog/chatbot-statistics-compilation/, accessed 29.09.2019.

Jędralska K., Czech A. (2011) O naturze niepewności i jej interpretacjach [The nature of uncertainty and its interpretations]. *Master of Business Administration*, vol. 19, no 3, pp. 9–18 (in Polish).

Jemala M. (2010) Evolution of foresight in the global historical context. *Foresight*, vol. 12, no 4, pp. 65–81.

Jenssen S. (2010) *Foresight between uncertainty and convention: An ethnographic study of research policy foresight at the Research Council of Norway* (PhD thesis), Oslo: University of Oslo.

Kaivo-oja J.Y., Katko T.S., Seppala O.T. (2004) Seeking convergence between history and futures research. *Futures*, no 36, pp. 527–547.

Kononiuk A., Nazarko J. (2014) *Scenariusze w antycypowaniu i kształtowaniu przyszłości* [Scenarios for anticipating and shaping the future], Warszawa: Wolters Kluwer (in Polish).

Kononiuk A., Sacio-Szymańska A., Gáspár J. (2017) How do companies envisage the future? Functional foresight approaches. *Engineering Management in Production and Services*, vol. 9, no 4, pp. 21–33.

Larsen S.C. (2006) The Future's Past: Politics of Time and Territory among Dakelh First Nations in British Columbia. *Geografiska Annaler: Series B, Human Geography*, vol. 88, no 3, pp. 311–321. Available at: https://doi.org/10.1111/j.1468-0459.2006.00224.x, accessed 19.01.2020.

Lindley D.V. (2013) *Understanding Uncertainty*, Hoboken, NJ: John Wiley & Sons, Inc.

Lom M., Pribyl O., Svitek M. (2016) Industry 4.0 as a part of smart cities. *Proceedings of the 2016 Smart Cities Symposium Prague (SCSP), 26-27 May 2016* (ed. M. Koukol), Piscataway, NJ: IEEE, pp. 22–27.

Magnus S. (2012) Exploratory or normative: New show. Adventure future. *Stephmag*, 27.02.2012. Available at: http://adventurefuture.wordpress.com/2012/02/27/exploratory-or-normative-new-show/, accessed 14.10.2019.

Magruk A. (2011) Innovative classification of technology foresight methods. *Technological and Economic Development of Economy*, vol. 17, no 4, pp. 700–716.

Magruk A. (2013) *Hybrid concept in foresight methodology*. Paper presented at The XXIV ISPIM Conference – Innovating in Global Markets: Challenges for Sustainable Growth in Helsinki, Finland, 16-19 June 2013. Available at: https://search.proquest.com/openview/bc729a2c014ecc2e2b45d0704766d8eb/1?pq-origsite=gscholar&cbl=1796422, accessed 16.01.2020.

Magruk A. (2015) The Most Important Aspects of Uncertainty in the Internet of Things Field – Context

of Smart Buildings. *Procedia Engineering*, vol. 122, pp. 220–227. DOI: 10.1016/j.proeng.2015.10.028.

Magruk A. (2016) Uncertainty in the sphere of the industry 4.0 – potential areas to research. *Business, Management and Education*, vol. 14, no 2, pp. 275–291.

Magruk A. (2017a) Concept of uncertainty in relation to the foresight research. *Engineering Management in Production and Services*, vol. 9, no 1, pp. 46–55.

Magruk A. (2017b) Phenomenon of Uncertainty in the Process of Holistic Anticipation of Non-deterministic Reality. *Procedia Engineering*, vol. 182, pp. 434–442.

McIntosh D. (2010) The transhuman security dilemma. *Journal of Evolution and Technology*, vol. 21, no 2, pp. 32–48.

Muller N. (2008) *The Web Expansion. From Web of Things to Web of Thoughts*. Available at: www.trendone.de, accessed 21.10.2019.

Nahavandi S. (2019) Industry 5.0 – A Human-Centric Solution. *Sustainability*, vol. 11, no 16, article 4371, pp. 1–13. Available at: https://www.researchgate.net/publication/335148344_Industry_50-A_Human-Centric_Solution, accessed 24.01.2020.

Njå O., Solberg Ø., Sverre Braut G. (2017) Uncertainty — Its Ontological Status and Relation to Safety. *The Illusion of Risk Control. What Does it Take to Live With Uncertainty?* (eds. G. Motet, C. Bieder), Heidelberg, New York, Dordrecht, London: Springer, pp. 5–21. Available at: https://link.springer.com/chapter/10.1007/978-3-319-32939-0_2, accessed 19.12.2019.

Passino K.M. (2005) *Biomimicry for optimization, control, and automation*, Heidelberg, New York, Dordrecht, London: Springer Science & Business Media.

Pieriegud J. (2015) Wykorzystanie megatrendów do analizy przyszłościowego rozwoju sektorów gospodarki [Using megatrends to analyse the future development of economic sectors]. *Megatrendy i ich wpływ na rozwój sektorów infrastrukturalnych* [Megatrends and their impact on the development of infrastructure sectors] (eds. J. Gajewski, W. Paprocki, J. Pieriegud), Gdańsk: Instytut Badań nad Gospodarką Rynkową – Gdańska Akademia Bankowa, pp. 8–25 (in Polish).

Poli R. (2017) *Introduction to Anticipation Studies,* vol. 1, Heidelberg, New York, Dordrecht, London: Springer International Publishing.

Refsgaard J.C., Arnbjerg-Nielsen K., Drews M., Halsnæs K., Jeppesen E., Madsen H., Markandya A., Olesen J.E., Porter J.R., Christensen J.H. (2013) The role of uncertainty in climate change adaptation strategies – A Danish water management example. *Mitigation and Adaptation Strategies for Global Change*, vol. 18, no 3, pp. 337–359.

Ringland G. (1998) *Scenario planning: Managing for the future*, Chichester: John Wiley & Sons.

Samecki W. (1967) *Ryzyko i niepewność w działalności przedsiębiorstwa przemysłowego* [Risks and uncertainties in the activity of an industrial enterprise], Warszawa: Państwowe Wydawnictwo Ekonomiczne (in Polish).

Saracco R. (2018) *Disruptive Technologies beyond 2030 for Human Machine Interactions*. Available at: https://cmte.ieee.org, accessed 18.10.2019.

Sardar Z., Sweeney J.A. (2016) The three tomorrows of postnormal times. *Futures*, vol. 75, pp. 1–13.

Sarowski Ł. (2017) Od Internetu Web 1.0 do Internetu Web 4.0-ewolucja form przestrzeni komunikacyjnych w globalnej sieci [From Internet web 1.0 to Internet web 4.0 – the development of the communication space forms in the global network]. *Rozprawy Społeczne*, vol. 11, no 1, pp. 32–39 (in Polish).

Schaeffer E. (2017) *Industry X. 0: Realizing digital value in industrial sectors*, Munchen: Redline Verlag.

Schwartz P. (2012) Winning in an Uncertain Future through Scenario Planning. *Delivering Tomorrow, Logistics 2050, A Scenario Study*, Bonn: Deutsche Post AG, pp. 27–33.

Shepherd D.A., Suddaby R. (2017) Theory building: A review and integration. *Journal of Management*, vol. 43, no 1, pp. 59–86.

Siderska J., Jadaan K.S. (2018) Cloud manufacturing: a service-oriented manufacturing paradigm. A review paper. *Engineering Management in Production and Services*, vol. 10, no 1, pp. 22–31.

Skobelev P.O., Borovik S.Y. (2017) On the way from Industry 4.0 to Industry 5.0: From digital manufacturing to digital society. *Industry 4.0*, vol. 2, no 6, pp. 307–311.

Smithson M. (1989) *Ignorance and uncertainty: Emerging paradigms*, Heidelberg, New York, Dordrecht, London: Springer-Verlag.

Sokolov A., Chulok A. (2012) Dolgosrochnyi prognoz nauchno-tekhnologicheskogo razvitiya Rossii na period do 2030 goda: klyuchevye osobennosti i pervye rezul'taty [Russian science and technology foresight – 2030: Key features and first results], *Foresight-Russia*, vol. 6, no 1, pp. 12–25 (in Russian).

Taylor C.W. (1990) *Creating strategic visions*, Carlisle: Strategic Studies Institute, US ArmyWar College, Carlisle Barracks.

UNDP (2018) *Foresight Manual. Empowered Futures for the 2030 Agenda*, Singapore: UNDP Global Centre for Public Service Excellence.

van der Sluijs J.P. (1997) *Anchoring amid uncertainty. On the management of uncertainties in risk assessment of anthropogenic climate change*, Den Haag: CIF-Gegevens Koninklijke Bibliotheek.

Voros J. (2017) Big History and Anticipation. *Handbook of Anticipation. Theoretical and Applied Aspects of the Use of Future in Decision Making* (ed. R. Poli), Heidelberg, New York, Dordrecht, London: Springer, pp. 425–464. DOI: 10.1007/978-3-319-31737-3_95-1.

Walker W.E., Harremoës P., Rotmans J., van der Sluijs J.P., van Asselt M.B., Janssen P., Krayer von Krauss M.P. (2003) Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment*, vol. 4, no 1, pp. 5–17.

Watson R., Cupani A. (2018) *Table of Disruptive-Technologies*, London: Imperial College. Available at: https://www.imperial.ac.uk/media/imperial-college/administration-and-support-services/enterprise-office/public/Table-of-Disruptive-Technologies.pdf, accessed 15.12.2019.

Wawiernia A. (2013) Taksonomia niepewności [Taxonomy of uncertainty]. *Zarządzanie i Finanse*, vol. 11, no 1/3, pp. 445–454 (in Polish).

Strategies of Dynamic Complexity Management

Helena Knyazeva

Professor, School of Philosophy, hknyazeva@hse.ru

National Research University Higher School of Economics, 20, Myasnitskaya str., Moscow 10100, Russian Federation

Abstract

The modern theory of complex systems changes our view of historical processes and is accompanied by uncertainties, instabilities, and ambiguities. The knowledge of this theory allows us to master a system or holistic thinking to understand the laws of functioning and growth of not just structural but dynamic complexity. Uncertainties and chaotic elements that indicate any state of crisis are not only negative factors that we should be aware of and are not without fear for us. We can learn to manage them and use them to renew our social systems thus producing innovations. The strategic vision of complex system evolution becomes an effective tool for decision making and scenario planning based on our participatory activities with alternative futures. The article examines the case of Shell Corporation, which has been using scenario thinking technologies since the early 1970s, which has given it incredible competitive advantages and incentives for rapid growth and transformation into an international energy giant.

eywords: foresight; non-linearity; uncertainty; participatory futures; synergy; complex system; holism; emergence; scenario planning; alternative futures

Citation: Knyazeva H. (2020) Strategies of Dynamic Complexity Management. *Foresight and STI Governance*, vol. 14, no 4, pp. 34–45. DOI: 10.17323/2500-2597.2020.4.34.45

Contemporary complexity theory or systems science (systemics) [François, 1999] provides a conceptual basis for understanding the nature of complex dynamic systems that are defined by several characteristics. First of all, they have a large number of elements; for example, the human body consists of 230 cell types, the brain has 80-90 billion neurons. Another key factor is complex connections between the elements. A system with particularly complex interconnections may be more complex than another, even if it has fewer elements. The example of two people with different world outlooks trying to communicate with one another shows that their relationship is often more complex than crowd behavior, where individuality is lost. The next attribute of complexity is systems' behavior, their functioning modes, and transformation over the course of development. This allows one to view the system as dynamically complex, displaying non-repeating patterns, plasticity, ability to adapt, learn, and change behavior to increase its chances of survival and of successfully functioning [*Godfrey-Smith*, 1996; *Mitchell*, 2009]. In other words, complex systems are distinguished by their non-trivial behavior, emergence, unpredictability, uncertainty, ability to self-organize, cyclical causality, feedback loops, and the ability of small changes to generate dramatic consequences [*Erdi*, 2008; *Bakshi*, 2017; *Deaton*, 2018; *Kok*, 2018; *Nandram, Bindlish*, 2017]. A system's dynamism implies its changing over time and switching between different operation modes. One of the more important phenomena associated with the dynamics of complex systems' behavior is holism, which has the following properties:

- dynamic interactions, which ensure the wholeness and integrity of the system;
- synergy, i.e., the possibility of obtaining an evolutionary benefit from the correct, resonantly organized interaction of elements or subsystems;
- the system cannot be separated from its environment; there are input and feedback loops between it and larger systems, and ultimately the Global System.

In addition to the above features, complex social systems are characterized by the interconnection of intangible (mental, cognitive, etc.) and material (economic, etc.) components.

Simple Complexity or Complex Simplicity

Complexity and simplicity, chaos and order are perceived as opposites only in a simplified, abstract outlook. In reality they are intertwined with numerous subtle ties. There is no perfect simplicity or exceptional complexity in natural or social systems, just as there is no pure chaos (disorganization) or total order. Systems tend to feature dynamic (or deterministic) relative chaos coupled with a certain degree of order (organization). A turbulent flow is perceived as chaotic, while possessing a subtle, invisible, ordered structure. On the contrary, order and symmetry are accompanied by small random deviations and aberrations. According to Arnaud Spire, a completely symmetrical system is sterile and devoid of the ability to develop. What is devoid of symmetry and remains in a state which is far from equilibrium is fruitful [*Spire*, 1999]. To describe the combination of complexity and simplicity, uncertainty and certainty, neologisms such as "simplexity" and "perplexity" are used.

Edgar Morin offers an etymological clarification of the concept of complexity, pointing out that "complex" (from Latin complexus) literally means "that which is woven, knit together" [Morin, 2002]. Hence the first basic aspect of complexity, holism, is namely the combination of parts or elements leading to the emergence of a wholeness, which acquires new emergent qualities that are not observed in its individual parts. In his book "The Quark and the Jaguar", the 1969 Nobel laureate in physics Murray Gell-Mann presents a paradoxical vision in which the complexity of the microcosm and the living world structures are comparable. The world of quarks (the smallest components that make up elementary particles; the author made a personal contribution to the proof of their existence) has much in common with the world of a jaguar wandering in search of prey. The two poles of the world, the simple physical and the complex biological, are closely interconnected. The quark symbolizes the basic physical laws that rule the universe, while the jaguar symbolizes the embodiment of the surrounding world in complex adaptive systems. Thus, the quark and the jaguar express two aspects of nature, "simple" and "complex" ones [*Gell-Mann*, 1995].

Gell-Mann coined the term "plectics" to denote a new transdisciplinary subject area that studies phenomena from various fields through the prism of integrating the simple and the complex. Chains of interconnections between simple basic laws governing the behavior of matter and complex phenomena in their diversity, individuality, and development are considered [*Gell-Mann,* 1996]. The concept of plectics ("to fold" in Greek) clearly demonstrates complex systems' property to make the whole look simpler (a single object instead of many elements), forming an intricately woven fabric. Alain Berthoz develops the concept of simple complexity or complex simplicity, symplexité [*Berthoz,* 2009], based on the principles of selection and anticipation on the basis of probabilistic estimates. In this respect it is close to the approaches to constructing **scenarios of the future**. The principle of meaningfulness plays a special role, since meaning determines the choice of a development goal. Mastering the mechanisms of simple complexity (*symplexité*) allows one to function and develop efficiently, since by its very nature it assumes that the future is not predetermined [*Berthoz,* 2009]. Most of the modern techniques for describing complex systems reduce complexity and thus turn it into simplicity. Laws are established to "order" diversity and variability; the repetitive behavioral patterns in diversity are identified. Whenever possible, complex nonlinear functions are presented in linear terms, while process dynamics is extrapolated to the future based on the current state or past experience. Hermann Haken, the founder of synergetics as a discipline, developed the heuristic order parameters, cyclical causality, and subordination principle model [*Haken,* 1977]. For a complex system, it is enough to determine just a few order parameters which describe the behavior of the system as a whole in dynamics and are linked by cyclical causality: they are generated by the behavior of elements or subsystems, but having emerged, assume control over them. Unambiguous, deterministic behavior of the system at certain development stages arises as a result of the choice of a path at the bifurcation point, where small influences, fluctuations at the level of elements can determine the further course of the system's development as a whole [*Prigogine,* 1989, 1997]. Along this path order arises from chaos, unity from diversity, and remain in place until the next bifurcation point. The course of nature's and society's history looks like a cascade of bifurcations; therefore, the future is fundamentally open and unpredictable. The attractor structures model developed by Sergei Kurdyumov describes the relatively stable structured states that complex systems can reach over the course of their evolution [*Knyazeva, Kurdyumov,* 2001]. Seeing attractors as possible future states simplifies the description of a complex system. The spectrum of attractor structures is not arbitrary but discrete, determined by the intrinsic properties of a complex system. Therefore, not all paths to the future are possible, while having a knowledge of the attractor spectrum reduces uncertainty, since it helps one to understand which options are realistic and achievable.

Self-Organization of a Dynamic System as a Basis for Scenario Planning in Companies

To self-organize, a system must first be disorganized due both to random factors and deliberate impact [*Ashby*, 1958]. A necessary condition for self-organization is a variety of system elements. This principle also applies to business activity: the more diversified the activities of a company or the national economy are, the more resilient it is to shocks. Reducing system diversity increases the risks of decay. Accordingly, a focus on narrow specialization increases the likelihood of a company leaving the market in the event of the latter's radical transformation. The dynamic stability of an enterprise as a system means maintaining integrity and stability in development. This is achieved through continuous creative destruction practices, by consciously abandoning the old framework to gain a new stable foundation. To characterize this quality of complex systems, researchers proposed definitions such as "moving equilibrium" [*von Bertalanffy*, 1932], "order from noise" [*Prigogine*, 1997], "organising randomness" [*Atlan*, 1979], and " multiple unity "(unitas multiplex) [*Morin*, 1977]. In addition, Morin introduced the concept of "pluriverse" reflecting a conceptual shift in understanding the nature of the Universe: from a single, unique, and monotonous world ("universe") to a variety of alternative **development scenarios** ("pluriverse").

The above terms present from different angles the idea that a share of chaos, a variety of elements, and processes with a certain degree of freedom support the life of companies, sectors, markets, and economies as complex systems. "Complicated" and "complex" systems are distinguished. The first include computers, technical devices, and production systems (sets of equipment) created according to given algorithms. Their organization is determined from the outside and how they would function is generally predictable. The second type includes biological systems, economic and social structures characterized by dynamic complexity and unpredictable evolution. Self-organization gives rise to new forms, new types of ordered processes and structures. Randomness and elements of disorder, the measure of which is entropy, multiply diversity. Nonlinear relationships between elements lead to a rapid increase in the complexity of their organization. There are certain conditions for the self-organization of complex systems:

- *Openness*. The ability to exchange matter, energy, and information with the external environment. On the contrary, in closed systems disorganization and entropy increase.
- *Non-equilibrium*. Most of the processes in complex systems are subject to homeostasis: a return, with minor deviations, to the initial state of equilibrium. It looks like self-organization on the verge of chaos, when the risk of the system's destruction increases, but at the same time it opens an opportunity for multiple complications, the emergence of cascades of new forms and content.
- *Nonlinear connections between elements*. In a "linear" outlook, systems behave predictably, follow a univariate course, and their prospects can be predicted by extrapolation. However, in reality they most often pass through states of instability and bifurcation points, near which even insignificant events, deviations, and fluctuations can determine the further path. At such "forks" the system "chooses a path" from a wide range of possible trajectories. Nonlinearity also means the rate of systems' evolution changes

(from rapid growth to stagnation or decline, or vice versa); there are different modes of operation and systems are sensitive to fluctuations in their unstable states. Emergent phenomena become possible: the emergence of new, previously unobserved, complexly organized structures.

Dynamic Complexity and Emergence

Complex systems' development and self-organization are associated with the property of emergence [*Sartenaer,* 2016]. From an ontological point of view, "emergence" means the emergence of a new phenomenon, while epistemologically, it refers to the difficulty of understanding and predicting the behavior of a complex system. Emergence means the unpredictability of processes occurring in the system, for example, when events initially barely perceptible amplify to grandiose proportions and significantly affect the system's future (e.g., "black swans") [*Taleb,* 2010]. The unpredictability is due to unexpected turns in the system's development paths or a change in its functioning modes (from rapid growth to decline in activity, or vice versa). In this sense, emergence appears as an indeterminate randomness, the basis of an open future, complete with all the related problems associated with trying to foresee it. It has structural and procedural aspects which are inextricably linked. The structural dimension amounts to the newly emerged whole acquiring properties which have not been observed in its individual elements. In such a case one speaks of the emergent properties of the system that cannot be deduced from the characteristics of the elements. At the dynamic level, novelty emerges and the **holistic** effect becomes apparent, such as, for example, in properly organized executive teams, a well-coordinated orchestra, an adequately matched sports team, and so on.

According to the hierarchical principle, any system is an element of another, more extensive and highly organized system which also has emergent properties. Rising in the hierarchy increases the emergence. In terms of complexity, the more highly organized levels cannot descend to lower ones. But emergence also has the opposite effect: the emerging holistic structure transforms the elements in such a way that they begin to show properties they did not have previously. In this sense a part can be no less complex than the entire system. The integration of new elements transforms the system at different levels and the result of this transformation is not predetermined. The changes in the system are affected by internal and external factors, input and feedback loops connecting the organizational level in question with the higher and lower layers. The interaction of the system and the environment, the coordinated and interdependent emergence of both subjects' new qualities is called "dynamic co-emergence" [*Thompson*, 2007].

Managing Dynamic Complexity

New scientific knowledge about systems enriches our understanding of how dynamic complex processes can be managed and allows companies to effectively use *scenario planning* to flexibly revise development strategies, adapt them to the changing context and thus improve their prospects. This process is called "strategic reframing" [*Wilkinson*, 2014; *Ramírez, Wilkinson*, 2016]. Peter Senge recommends that companies and organizations master the systemic thinking principles as the "fifth discipline" [*Senge*, 2006], which does not fit into the classical disciplinary matrix and so goes to the interdisciplinary level. The merging of scientific disciplines leads to the emergence of a new culture of thinking [*de Rosnay*, 1975] and allows one to identify key conceptual transformations. There are numerous studies of approaches to managing dynamic complexity [*Gharajedaghi*, 2011; *Gonzalez,* 2013; *Hodgson*, 2020; *Jackson*, 2006, 2019; *Keatin, Katina*, 2019; *Nijs,* 2015; *Robinson,* 2005]. Here are the most relevant, in our opinion, provisions which can serve as a solid basis for management strategies.

New perception of chaos. Perceiving chaos as an undesirable element associated with high uncertainty and uncontrollability[1] still remains common. Since the days of Newton and Galileo, classical science looked at randomness as a form of ignorance. It was believed that a deep study of any complex phenomenon eliminates randomness and can produce its deterministic description. However, according to recent studies, randomness, variability, and volatility are deeply woven into the reality as objective properties of evolutionary processes [*Mainzer*, 2007a,b]. Variety is often achieved by randomly combining elements with unique characteristics. Maintaining it is considered a necessary condition for the balanced development of any system. A certain amount of chaos can be seen as complex systems' self-organization and self-building mechanism, which allows them to identify relatively simple attractor structures, development trends, and connect different elements or subsystems into a single whole. This, in turn, opens possibilities to adapt to changing environmental conditions, generate energy to overcome crises, and find ways out of evolutionary dead ends. The development rates of elements and substructures of a complex structure synchronize and new evolutionary wholes emerge. Elements of chaos

[1] Entropy is often seen as a measure of chaos and process disorganization in complex systems. However, the entropy approach has its limitations. The growth of complex structures and the system's structuring are typically accompanied by the emergence of order, macrolevel organization, and the maintenance of dissipation, dispersion, and microlevel disorganization processes.

serve as a mechanism for complex structures' and organizations' renewal and a source of innovation.

External organization vs spontaneity. In certain cases, systems, companies, or organizations which develop independently and spontaneously function better and remain more stable than structures built by external effort. In recent decades, a management model which considers companies and organizations as complex systems became more popular; it promotes self-organization, synergy, and diversity in order to find the best development paths.

Linearity vs nonlinearity. Rigid determinism is based on the belief in linear development. New scientific discoveries refute such an attitude, indicating that the world is organized in the form of complex systems which can go along multiple evolutionary paths matching their inherent nature. If it is possible to identify a limited set of viable development paths and create a mathematical model for them, the basis for scenario planning emerges. Also, the development of complex systems cannot be unidirectionally progressive; it is cyclical. Rapid growth and dynamic development are followed by periods of decline and stagnation, and sometimes degradation and simplification.

Entropy balance with external management. External management is not the only source of complex systems' sustainable development. It needs to be balanced with self-management, self-organization, spontaneity, and diversity. When the balance is upset in any direction, such as in the case of total domination of spontaneous market mechanisms, or, on the contrary, of state control, the risks of instability and crises increase. It is important to take into account that the shares of inner freedom and diversity (elements of chaos) must be regulated depending upon the evolutionary stage. In times of crises, they should increase to help the company as a complex system identify and take new development paths. Due to the nonlinear behavior of complex systems, extreme points inevitably arise along their evolutionary paths: singularities, or in other words, crises. In this context, crises are perceived as a natural component of complex systems' "life". Companies do tend to go through such periods from time to time, with the associated increased turbulence, chaotic movements, emergence of irrational social and cultural phenomena and processes. Understanding that it is inevitable helps one to proactively take such aspects into account in strategies and plan for creating new forms, structures, and various kinds of innovations.

Holistic thinking. Systems science emphasizes the importance of a holistic or systemic vision: the ability to see the whole behind the parts, recognize both the immediate context and remote configurations of possible developments, act locally on the basis of a global vision. A holistic view and scope are woven into the new rationality, becoming an intellectual and practical necessity. This cannot be comprehended with fragmented perception and thinking. Any informational facts acquire meaning only when placed in a certain context [*Morin*, 1999]. An equally important aspect of *holism* is understanding how to build dynamically stable holistic structures. The correct integration of parts into a whole leads to a situation where all elements begin to co-evolve (develop in a mutually consistent and harmonious way), which in turns accelerates the development of the newly emerged integral structures.

Small resonant impacts. The most relevant way to manage dynamic complexity is through small-scale but well-organized "soft management", which can trigger the necessary resonance at the right time in the right place. The nonlinear nature of the relationship between effort and effect should be taken into account. Major efforts can be fruitless, while on the contrary small and insignificant, but properly organized measures have the potential to be highly effective. The so-called "rule of leverage" [*Senge,* 2006] or "ephemerisation" [*Fuller,* 1997] works here, expressed as follows: "insignificant can cause significant, but great won't necessarily achieve something, even something small", which illustrates nonlinear relations between impacts and their results. Significant expenditures on managing a company as a complex dynamic system do not guarantee a proportional result. At the same time the correct and gentle influence applied at a certain point at the right time can "shake" the system and wake its dormant potential. Thus, it is not the force and intensity of action that play the decisive role, but rather its topology and "architecture". There are certain "situational configurations" in the company and other social environments under which small but targeted incentives are extremely effective. Knowledge of systems science helps one to act extremely efficiently, radically reduce costs, and generate the desired and (no less importantly) practical processes by making a resonant impact. Such actions tend to create synergies.

Instability as a resource. According to I. Prigogine, the way the system will go after passing the bifurcation point is not predetermined. This idea is presented in the study with the metaphorical title "To Die is not Cast" [*Prigogine*, 2000]. In turbulent times well-designed strategies play a decisive role. Playing on Einstein's metaphor of the "dice", Prigogine demonstrates the degree of chance's interference in evolution and the possibility of turning it into a targeted process. If according to Einstein all processes in the world can be perceived as deterministic if we reduce the probabilistic description to the one with no alternative outcomes, according to Prigogine randomness is deeply rooted in the world ontologically. As they develop, complex systems at different levels of the world's organization go through phases of instability and bifurcations when the choice of the further development path is made from a wide "fan" of possibilities and alternatives. It follows then that the future is not predictable in principle but is open. The new knowledge does not leave any ground for fatalistic beliefs and therefore the factor of "fate" remains a matter of individual perception but not a scientifically proven phenomenon. Complex systems' resilience depends upon their ability to pass bifurcations and identify new opportunities. Perceiving instability and randomness as assets helps one master the emerging new potential and turn the evolution in the preferred direction. A number of scientists believe that the course of time itself becomes nonlinear and has bifurcation points [*Dupuy*, 2010], which opens the possibility of choosing the future. By managing the instability near the bifurcation points, one can set the further development path. Passing through forks, the environment becomes sensitive to collective and individual actions that can lead to the emergence of new social, cultural, technological, and other patterns. At a new coil of the complex systems science, a strategic orientation arises based on the following premises:

- the future can be managed
- the future depends upon today's choices
- actions taken today are important for accomplishing a preferred vision of the future.

Building a Preferred Future

Leading experts adhere to a constructivist approach to understanding the world, stating that the external environment is not completely independent of our actions [*Le Moigne*, 1994; *Morin*, 1999; *Prigogine*, 2000]. The environment is created and transformed with the participation of people and reconstructed through interactions between objective reality and conscious creativity or projective action. The rule of objectivity, which remains a constant in scientific research, is supplemented by the prism of projectivity, i.e., different development directions are outlined and interpreted, and the probability of their implementation is estimated.

Constructivist epistemology involves not only discovery and learning, but also invention and creation. According to the constructivist approach, perceiving the future solely as an object of cognition looks unproductive. Building partnerships with it is much more effective. Constructing future scenarios implies making choices, and therefore "co-inventing" life. Constructivist practices are actively developing, moving into the mainstream and comprising various socio-cultural, socio-psychological, communicative, psychotherapeutic, and managerial tools, taking steps to strengthen security, making effective decisions in uncertain situations, and building development scenarios. Constructivism is currently understood not only as consciously constructing reality (including ordering and organizing society in accordance with the value preferences of the individual and collective subject), but also as promoting the creativity of social institutions, implementing and disseminating social innovations, managing development risks, going through crises and subsequently taking the desired development paths. Based on this understanding of complex systems, when they are unstable and possible development paths need to be identified, conscious attitudes and value preferences play a decisive role.

Instability can occur at two types of stages: bifurcation (branching of development paths), or extremum (culmination) of a complex structure's development. In both cases the system becomes sensitive to minor, microlevel fluctuations. Therefore, even a small impact can push it to one of the possible evolution paths, to a particular attractor in the spectrum. Resonant excitation of desired complex structures allows one to shorten the long and winding evolutionary path leading to a qualitatively new level. Having determined the parameters of complex systems' order, one can model, calculate, or qualitatively establish possible attractor structures for them, and using small but topologically correctly organized (resonant) impacts, turn the development process towards a desired path. It also becomes possible to actively intervene in the process of building complex structures from relatively simple elements over the course of their co-evolution, that is, joint, balanced development. One of the principles of evolutionary *holism* is a topologically optimal assembly of subsystems into increasingly complex, steadily evolving wholes in order to produce the necessary resonance, accelerate the progress of the emerged single complex structure, and achieve a preferred future. As a result, the new integrated system starts to develop at a higher rate than the most dynamic single structure did before the merger. The advantage of joint development is the saving of all kinds of resources. Furthermore, complex systems not only have a certain "memory depth" but can "attract" the future with the attractors inherent to these systems' internal properties. It becomes possible to constructively use the "attraction of the future" potential within the range of certain attractors.

Tools for Managing Dynamic Complexity

Achieving synergy. Synergy is the result of the **holistic** effect, when the emerging whole is greater than the sum of its parts. However, random connections between any system elements are not possible. Therefore, synergy is the result of a lucky self-organization. This phenomenon is a logical feature of evolutionary holism, regarded as a fundamental paradigm of the 21st century [*Laszlo*, 2012, p. 80].

In social terms, synergy becomes apparent in the emergence of integrity and cooperation, when 1 +

1 > 2, and in holistic individualization when the whole does not suppress or level the individuality but allows it to "flourish". In special forms of social holism, individuals' selfish actions paradoxically enhance social altruism and work for common interests [*Mandeville*, 1997; *Ruth*, 1961; *Luhmann*, 1987].

Synergy appears in the self-referential circle of human action: "I'll do what you want when you do what I want" [*Luhmann*, 1987]. Its social and ethical meaning reveals the "secret" of subjects' coming together in a social environment, when the division of labor or teamwork gives obvious advantages to a social group (or a state) and promotes it to leading market, political, or geostrategic positions. In optimal, correctly assembled high-synergy social structures the level of aggression tends to be reduced to a minimum, while the intensity of cooperation reaches a maximum. Such structures usually have a higher level of trust, internal diversity, decentralization, and responsibility. In the preferred social model based on self-organizing principles, each individual contributes to the collective behavior which acts as an order parameter. As a result, synergy mechanisms are triggered, involving ever more people in this process. Such models should be based on the responsibility principle broadly formulated by Hans Jonas [*Jonas*, 1984]. According to it, a self-organizing society would exist only to the extent that each member realizes they are responsible for the whole while carrying on with their individual activities [*Haken*, 1995].

Holistic and creative thinking as the basis of sustainable positions in the future. The abilities in highest demand increasingly often include creativity, "soft" innovation, visualization, narration, and holistic thinking. Today, against the background of constant bifurcations, a transition is taking place from the extensive consumption-based model to an intensive one, which relies on cohesion, communication, and awareness [*Laszlo*, 2012]. The arrival of the conceptual age is also mentioned [*Pink*, 2005] to replace the information one, with a radical shift in emphasis and a revision of values: from the dominance of purely analytical, linear thinking to nonlinear, visual, and symbolic. Cognitive skills such as holistic vision, intuition, emotional intelligence, and so on are of particular importance. Companies with access to a talent pool like this gain an edge. There is growing demand not just for professional abilities, but also for structuring and design skills. In addition to the ability to accumulate information, being able to critically comprehend it through the prism of holistic thinking is valued. Objective arguments alone may not be enough to substantiate one's position; it is important to present cases from personal experience. A serious attitude toward work must be combined with a gameplay approach [*Pink*, 2005]. High-tech skills are gradually giving way to "high-concept" ones (the ability to conceptualize) along with "high-touch talents" such as understanding aesthetic subtleties, immersing into narrative plots, adapting, and being tolerant of other cultures' ethical norms. Understanding complex systems allows one to flexibly adapt to change, successfully go through periods of turbulence and bifurcation points with a positive attitude, and take advantage of newly opened opportunities to turn the vector of development in a new direction. Large companies master the competencies in, and knowledge of, complex systems and set the trend for medium and small businesses by using the appropriate tools to operate in an increasingly complex and variable context through **scenario planning**.

Scenario Planning Practices

According to various estimates, in recent years scenario planning became a successfully mastered practice for 65% of companies [*Wilkinson, Kupers*, 2013]; it is being constantly updated and enriched with new approaches, which allow one to work with dynamic complexity and handle tasks on several levels while taking into account the global and local contexts with complex, multi-layered configurations. Scenario planning implies nonlinear, rolling coverage of possible prospects and effective "cooperation" with the future. The tendency to go beyond linear thinking can be detected in almost all fast-growing companies since linear thinking involves cognitive distortions (emphasis on familiar processes or neglecting weak signals with the potential to evolve into dominant trends and initiate a new development vector). Understanding that a complex system becomes susceptible to weak signals in instability states of two types, approaching a bifurcation point followed by the forking of possible development paths and in a state of culmination (maximum growth or decline), is crucially important. When a critical point (singularity) is passed, the regime changes: growth is replaced by decline, or, conversely, decline is followed by a rise, a recovery.

There are five approaches to perceiving the future: retroactive (focused on the past), inactive (focused on the present), pre-active (predicting the future), proactive ("creating" the future), and interactive, which implies collective "cooperation" with it [*Ramírez, Wilkinson*, 2016]. A shift in these attitudes is now taking place, from proactivity to interactivity. Predicting the future is difficult due to the complexity and disarray of economic and social processes. Therefore, the constructivist approach based on carefully working with trends turns out to be the most relevant one. Weak signals are taken into account, which might imply the emergence of new strong trends. Scenario planning is carried out through multiple iterations of probabilistic forecasts based on deep expert knowledge.

The World Business Council for Sustainable Development (WBCSD): case study

How the provisions of complex systems theory project on production processes can be illustrated by the example of the major project WBCSD Vision 2050 being implemented by the World Business Council for Sustainable Development (WBSCD) [WBSCD, 2010]. This association brings together about 200 leading companies from 36 countries specializing in 22 industries. The project's goal is to develop a set of measures that companies need to jointly implement to switch to a fundamentally new development model by 2050.

The measures were identified through scenario planning based on the complex systems theory. A strategic document "Vision 2050: The New Agenda for Business" [WBSCD, 2010] was produced with input from 29 leading international companies operating in 14 industries. Scenarios were used in combination with building a preferred vision of the future, retrospective analysis, and modeling, which allowed for preparing a roadmap specifying decision-making timeframes for large companies. Problems with expert evaluation arose over the course of research and the production of the document due to the still widespread linear approach to perceiving reality. These issues hindered the combined application of different methods and widening the focus to holistically cover and interpret global, regional, and industry-specific contexts. They were overcome by conducting retrospective analysis which allowed one to mentally move back in time, from the desired situation in 2050 to the present. As a result, 40 measures were outlined to advance to a new development level, along with more than 350 points on the roadmap implementation timeline.

The combination of scenarios allowed for rethinking the current situation and the traditional consumption-driven growth model. Typical linear projections of global megatrends for 2050 were identified at first followed by discrepancies with the planet's actual resource potential to support such development. Thus, the current views of growth prospects, barriers, and risks have been adjusted according to the actual state of affairs. As a result, nine areas for parallel implementation were identified, along with new "systemic" solutions based on intersectoral collaboration such as the transition to a **new waste-free** economy model, circular recycling design, and promoting cities' transition to sustainable development.

The WBCSD Vision 2050 strategy highlights approaches and practical tools suitable for application in an increasingly complex world, which helps one avoid problems by combining different solutions, involving a wide range of participants and widening the reach of all possible perspectives.

Valuable lessons from this case study include engaging experts who adhere to different viewpoints and applying a wide range of interpretational frameworks to build plausible scenarios. This allowed for exposing the fallacy of the existing beliefs in the linear nature of external changes and the possibility of maintaining continuous linear growth [*Wilkinson et al.*, 2013].

Building scenarios based on intuitive logic allows one not only to better assess the actual evolutionary potential of the extraordinarily complex world, but also to develop strategies for adapting to it to achieve a preferred future. Three types of complex systems need to be simultaneously addressed to accomplish this objective [*Spangenberg*, 2020]:

- *mental model (perceived reality)*: applied to understand the reality and build recommendations on this basis;
- *computerized model (virtual reality)*: allows one to quantitatively assess the assumptions generated by the mental model;
- *extraordinarily complex world (actual reality)*: disrupts the design of the first two systems by demonstrating unexpected behavior.

To prepare effective scenario recommendations, all three system types need to have a comparable complexity level. If this condition is not met, confusion and misperception of probability, uncertainty, and ignorance concepts arise, so the resulting scenarios and the recommendations based on them will be erroneous and misleading or, at best, useless for decision-making. Thus, ensuring that the mental models applied by developers of scenarios, strategies, and roadmaps adequately match the nonlinear development of the world is a key success factor in working with the future [*Spangenberg*, 2020].

Shell's Lessons

Many WBCSD member companies have used Vision 2050 to develop their corporate strategies. One of them is Shell, which has more than 50 years of unique experience in building scenarios to remain competitive and design the future. Shell perceives the future not as an object of research, but as a "partner" with whom it "interacts" in a participatory format [*Ramírez, Wilkinson*, 2016].

Shell's road to success began in the late 1960s when the company was regarded an outsider in the energy industry [*Laudicina,* 2012] and strived to find solutions to make a breakthrough to a new level. Shell was one of the first to pay attention to the results obtained by the leading research organizations RAND and the Hudson Institute, in particular the scenario planning technique [*Jefferson,* 2012]. The correct choice of strategic tools and their consistent application allowed it to survive the global shocks and crises (such as price fluctuations and the collapses of oil markets caused by geopolitical shifts in 1973, 1979, 1986, and 1991) with minimal losses and identify new opportunities.

Drawing on knowledge of complex systems, Shell applied this conceptual grid to scenario building, which allowed it to understand and interpret weak signals, identify critical uncertainties and non-linear turns in business cycles. Pierre Wack, the founder of Shell's scenario building practices, named the following key steps in this activity [*Wilkinson, Kupers*, 2013]:

- identifying the most important trends and breaking them down into predictable and unpredictable ones;
- identifying sources of uncertainty with the greatest impact upon the course of events;
- drafting a set of possible plots and their outcomes with an in-depth analysis of any scenarios whose credibility cannot be refuted by logical reasoning;
- iteratively refining the scenarios, with a focus on weak signals and wildcards.

The approaches to and emphases upon applying these principles were not always the same. At the early stages, in the 1970s, scenario building was based on iterative re-perception and seeing of the future: designing interpretive frameworks for decision-making. The success of scenario planning was predetermined by the fact that from the very start, scenarios were inbuilt into all organizational processes: strategy development, risk management, promotion of innovation, and the development of a leadership culture [*Wilkinson, Kupers,* 2013]. In the last decade, this activity was primarily focused on "seeding the future": selecting tools to support decision-making involving a wide range of specialists in different fields. Scenarios correlate with quantitative models and are coordinated with other corporate processes including the development of innovation strategies [*Wilkinson et al.,* 2013]. Scenario building at Shell has a number of specific features: scenarios remain unfinished ("open stories"), go through multiple iterations during discussions [*Bentnam,* 2014], and are sensitive to weak signals. This process is accompanied by unique staff training methods.

The nonlinear approach allowed Shell to accurately predict the fall in oil prices in the early 1980s and develop effective countermeasures. After the energy crisis of 1973 the company developed the "Boom & Bust" scenario which provided for the possibility of "vigorous recovery containing the seeds of its own destruction" [*Wack*, 1985]. Shell displayed a degree of flexibility that was rare at the time. Without trying to predict when the overall crisis will end and recovery will begin, the company chose to develop a set of preventive measures. The recovery in oil prices after the 1973 crisis occurred very quickly and was called the "released spring effect". Certain economies, including the United States, grew by 11-12% in 18 months, which is similar to an economy the size of Britain's springing up from scratch. Such a rebound does not mean outstanding achievements, but only reflects the depth of the "dent" the global economy received in 1973-1975. Positive feedback was the basis of this rapid nonlinear growth, when the initial increase in economic indicators contributed to the further acceleration of their growth. In the theory of complex systems such processes are called peaking regimes, when growth occurs not exponentially but even faster, according to the hyperbolic law. Actually, such surprises are not uncommon in business cycles [*Wack*, 1985].

The complexity theory points to the need to pay attention to the harbingers of radical change. When a certain value begins to change so that the cycles become increasingly shorter and the amplitude of change increasingly larger, this heralds a turning point: a crisis, a change in the development regime. Processes of this kind took place in the economy in the 1950s, when phases of increasing amplitude and decreasing duration were observed. From the outside, the state of the system still looks the same but its swing indicates increasing instability and the imminent arrival of a turning point in its development.

Shell's approach to solving the mental models problem is remarkable: overcoming decision-makers' indifference to information in the scenarios. It is not enough to simply paint a picture of uncertainties, outline a spectrum of possible development paths, and present model calculations. These results will not be recognized if they are not adapted to the recipients' mental models [*Wack*, 1985]. Therefore, the mental "soil" needs to be prepared for "seeding" nonlinear knowledge. For scenarios to be taken into account in decision-making, they must transform people's reality perception patterns, taking into account their personal cognitive characteristics. Shell has developed a phenomenological approach which explores the perception of reality through the prism of personal experience. Scenario planning is complemented by a critically important aspect: working with recipients' individual perceptual, mental, and practical experience using narrative methods which imply creating realistic future plots referencing personal experience and a strategic vision of development paths. This allows one to critically rethink the existing images of the future and the strategies based on them [*Cornelius et al.*, 2005]. This approach proved to be more effective in changing perceptions than simple comparative analysis of scenarios and working with digital data.

Another technique is "deep listening" to decision-makers during structured interviews. It allows for identifying the respondents' key problems and approaches to adapting their perception at a later stage.

Shell's exclusive toolset helped create a unique corporate climate with the right constructs, promoting freedom of discussion and acceptance of an "open-ended" future [*Wilkinson, Kupers*, 2013]. It is based on an approach which sees the company as a living organism whose development can be blocked or, on the contrary, facilitated by the environment. The environment created by Shell fosters the rapid development of skills required to capture weak signals, construct new trends, and develop a culture of synergistic discussion.

Another important problem is the fact that the external world (actual reality) is always more complex and unpredictable than the attempts to adapt mental and computerized models (perceived and virtual realities) to match it. The element of uncertainty and unexpectedness is invariably present in the objective reality and, moreover, it is very significant. Therefore, despite its colossal long-term scenario building experience, even Shell does not always manage to catch the changes in the outside world in time. At least three major events were not envisioned in Shell's global forecast models, namely the 2008 financial crisis, the shale gas boom in the United States, and Germany's decision to accelerate the transition to renewable energy after the Fukushima nuclear disaster [*Wilkinson, Kupers*, 2013]. Nevertheless, Shell managed to find ways out even of these situations with relatively small losses, thanks to a timely and well-thought-out response policy.

Shell is currently developing scenarios not only until 2050 but also until the end of this century. Based on the latest advances in the development of evolutionary, holistic, systemic, and network approaches, and on the need to have knowledge of a wide cultural context for doing business effectively, the company builds scenarios not only for the energy market, but also for the economy, geopolitics, environment, and resource conservation. Geopolitical confrontation is currently increasing on various levels along with the pressure on oil companies due to the need to solve environmental and social problems. Taking into account the present and emerging challenges, Shell strives to make its business more flexible and customer-oriented, responsive to the social and cultural changes taking place in the world, and environmentally friendly.

Conclusions

The effectiveness of strategic foresight and scenario planning practices is due to their focus upon the advances of systems science. Representatives of this discipline show varying degrees of optimism about the future. Their positions are based on two key arguments. An individual with the appropriate competencies can consciously influence the choice of further development paths during periods of instability when passing bifurcation points. Fluctuations, minor changes (in historical terms, the actions of individuals) can become significant and turn the course of events in a new direction. The degree of optimism about the future may differ from one scientist to another, but there is hardly any doubt that one can actively participate in its creation. Experts describe such a model of the future using four main characteristics: possible, probable, preferable, and participatory future, or more generally, 4P futures. Shell analysts point to the need to radically change the attitude toward the future. Scenario building is not an attempt to predict the future, but to "cooperate" with it. The future can be "grasped" only through joint action, participatory activity, perceiving a plausible scenario as a personal experience embedded in global context. Long-term development options can be calculated and choosing the path to the most favorable vision of the future, designing trends in accordance with humanitarian values is the responsibility of each member of society.

References

Ashby W.R. (1958) Requisite Variety and its implications for the control of complex systems. *Cybernetica*, vol. 1, no 2, pp. 83–99.

Atlan H. (1979) *Entre le cristal et la fumée. Essai sur l'organisation du vivant*, Paris: Editions du Seuil.

Bakshi V. (2017) *Forward-looking Manager in a VUCA World*, Los Angeles: SAGE.

Bentnam J. (2014) The scenario approach to possible futures for oil and natural gas. *Energy Policy*, vol. 64, pp. 87–92. Available at: https://doi.org/10.1016/j.enpol.2013.08.019, accessed 29.08.2020.

Berthoz A. (2009) *La Simplexité*, Paris: Odile Jacob.

Cornelius P., van der Putte A., Romani M. (2005) Three Decades of Scenario Planning in Shell. *California Management Review*, vol. 48, no 1, pp. 92–110. Available at: https://doi.org/10.2307%2F41166329, accessed 29.08.2020.

de Rosnay J. (1975) *Le Macroscope. Vers une vision globale*, Paris: Éditions du Seuil.

Deaton A.V. (2018) *VUCA Tools for a VUCA World: Developing Leaders and Teams for Sustainable Results*, Glenn Allen, VA: DaVinci Resources.

Dupuy J.-P. (2010) Le future bifurque-t-il? Vers une nouvelle science de la future. *Bifurcations. Les sciences sociales face aux ruptures et à l'événement* (eds. M. Bessin, C. Bidart, M. Grossetti), Paris: Éditions La Découverte, pp. 373–386.

Erdi P. (2008) *Complexity Explained*, Heidelberg, New York, Dordrecht, London: Springer.

François C. (1999) Systemics and Cybernetics in a Historical Perspective. *Systems Research and Behavioral Science*, vol. 16, pp. 203–219. Available at: https://doi.org/10.1002/(SICI)1099-1743(199905/06)16:3<203::AID-SRES210>3.0.CO;2-1, accessed 29.08.2020.

Fuller R.B. (1997) *Synergetics: Explorations in the Geometry of Thinking,* New York: Macmillan.

Gell-Mann M. (1995) *The Quark and the Jaguar. Adventures in the Simple and the Complex*, London: Abacus.

Gell-Mann M. (1996) Let's Call It Plectics. *Complexity*, vol. 1, no 5, p. 96.

Gharajedaghi J. (2011) *Systems Thinking. Managing Chaos and Complexity: A Platform for Designing Business Architecture,* Burlington, MA: Morgan Kaufmann.

Godfrey-Smith P. (1996) *Complexity and the Function of Mind in Nature*, Cambridge: Cambridge University Press.

Gonzalez W.J. (2013) The Sciences of Design as Sciences of Complexity: The Dynamic Trait. *New Challenges to Philosophy of Science. The Philosophy of Science in a European Perspective* (eds. H. Andersen, D. Dieks, W.J. Gonzalez, Th. Uebel, G. Wheeler), vol. 4, Heidelberg, New York, Dordrecht, London: Springer, pp. 299–311.

Haken H. (1977) *Synergetics. An Introduction,* Berlin: Springer.

Haken H. (1995) *Erfolgsgeheimnisse der Natur. Synergetik: Die Lehre vom Zusammenwirken,* Berlin: DVA. ISBN 9783548342207.

Hodgson A. (2020) *Systems Thinking for a Turbulent World: A Search for New Perspectives,* New York: Routledge.

Jackson M.C. (2006) Creative Holism: A Critical Systems Approach to Complex Problem Situations. *Systems Research and Behavioral Science*, vol. 23, no 5, pp. 647–657. Available at: https://doi.org/10.1002/sres.799, accessed 29.08.2020.

Jackson M.C. (2019) *Critical Systems Thinking and the Management of Complexity: Responsible Leadership for a Complex World*, Hoboken, NJ: Wiley.

Jefferson M. (2012) Shell scenarios: What really happened in the 1970s and what may be learned for current world prospects. *Technological Forecasting and Social Change*, vol. 79, no 1, pp. 186–197. Available at: https://doi.org/10.1016/j.techfore.2011.08.007, accessed 29.08.2020.

Jonas H. (1984) *The Imperative of Responsibility: In Search of an Ethics for the Technological Age*, Chicago: University of Chicago Press.

Keating C.B., Katina P.F. (2019) Complex System Governance: Concept, Utility, and Challenges. *Systems Research and Behavioral Science*, vol. 36, no 5, pp. 687–705. Available at: https://doi.org/10.1002/sres.2621, accessed 29.08.2020.

Knyazeva H., Kurdyumov S.P. (2001) Nonlinear Synthesis and Co-evolution of Complex Systems. *World Futures*, vol. 57, pp. 239–261. DOI: 10.1080/02604027.2001.9972831.

Kok J. (2018) *Leading in a VUCA World*, Heidelberg, New York, Dordrecht, London: Springer.

Laszlo E. (2012) *The Chaos Point. The World at the Crossroads*, London: Piatkus.

Laudicina P.A. (2012) *Beating the Global Odds: Successful Decision-making in a Confused and Troubled World*, New York: Wiley.

Le Moigne J.-L. (1994) *Le constructivisme*, vol. 1. Paris: ESF éditeur.

Luhmann N. (1987) *Soziale Systeme. Grundriß einer allgemeinen Theorie*, Frankfurt: Suhrkamp.

Mainzer K. (2007a) *Der kreative Zufall: wie das Neue in die Welt kommt*, München: C.H. Beck.

Mainzer K. (2007b) *Thinking in Complexity: The Computational Dynamics of Matter, Mind, and Mankind* (5th ed.), Heidelberg, New York, Dordrecht, London: Springer.

Mandeville B. (1997) The Fable of the Bees, and Other Writings, Indianapolis, IN: Hackett Pub.

Mitchell M. (2009) *Complexity. A Guided Tour. Oxford*, New York: Oxford University Press.

Morin E. (1977) *La methode. La nature de la nature*, Paris: Editions du Seuil.

Morin E. (1999) *Les sept savoirs nécessaires à l'éducation du futur,* Paris: UNESCO.

Morin E. (2002) Le complexus, ce qui est tissé ensemble. *La Complexité, vertiges et promesses* (ed. R. Benkirane), Paris: Le Pommier, pp. 5–35.

Nandram S.S., Bindlish P.K. (eds.) (2017) *Managing VUCA through Integrative Self-management,* Heidelberg, New York, Dordrecht, London: Springer.

Nijs D.E.L.W. (2015) Introduction: Coping with Growing Complexity in Society. *World Futures*, vol. 71, no 1, pp. 1–7. DOI: 10.1080/02604027.2015.1087223.

Pink D. (2005) *A Whole New Mind: Moving from the Information age to the Conceptual Age*, New York: Riverhead Books.

Prigogine I. (1989) The Philosophy of Instability. *Futures*, vol. 21, no 4, pp. 396–400. Available at: https://doi.org/10.1016/S0016-3287(89)80009-6, accessed 29.08.2020.

Prigogine I. (1997) *The End of Certainty – Time's Flow and the Laws of Nature,* New York: The Free Press.

Prigogine I. (2000) The Die is not Cast. *Futures. Bulletin of the World Futures Studies Federation*, vol. 25, no 4, pp. 17–19.

Ramírez R., Wilkinson A. (2016) *Strategic Reframing: The Oxford Scenario Planning Approach,* Oxford: Oxford University Press.

Robinson K. (2005) Towards a Metaphysics of Complexity. *Interchange*, vol. 36, pp. 159–177. Available at: https://doi.org/10.1007/s10780-005-2352-0, accessed 29.08.2020.

Ruth B. (1961) *Patterns of Culture*, Boston: Houghton Mifflin.

Sartenaer O. (2016) Sixteen Years Later: Making Sense of Emergence (Again). *Journal for General Philosophy of Science*, vol. 47, no 1, pp. 79–103. Available at: https://doi.org/10.1007/s10838-015-9312-x, accessed 29.08.2020.

Senge P.M. (2006) *The Fifth Discipline: The Art and Practice of the Learning Organization*, New York: Doubleday/Currency.

Spangenberg J. (2020) *System Complexity and Scenario Analysis*. Paper presented at the Ninth Biennial Conference of the International Society for Ecological Economics "Ecological Sustainability and Human Well-Being", December 15-18, New Delhi, India. Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.543.4782&rep=rep1&type=pdf, accessed 13.09.2020.

Spire A. (1999) *La pensée – Prigogine, suivi de trois entretiens avec Gilles Cohen-Tannoudji, Daniel Bensaïch et Edgar Morin*, Paris: Desclée de Brouner.

Taleb N.N. (2010) *The Black Swan: The Impact of the Highly Improbable* (2nd ed.), New York: Random House.

Thompson E. (2007) *Mind in Life. Biology, Phenomenology and the Sciences of Mind,* Cambridge, MA: Harvard University Press.

von Bertalanffy L. (1932) *Theoretische Biologie*, vol. 1, Berlin: Gebrüder Borntraeger.

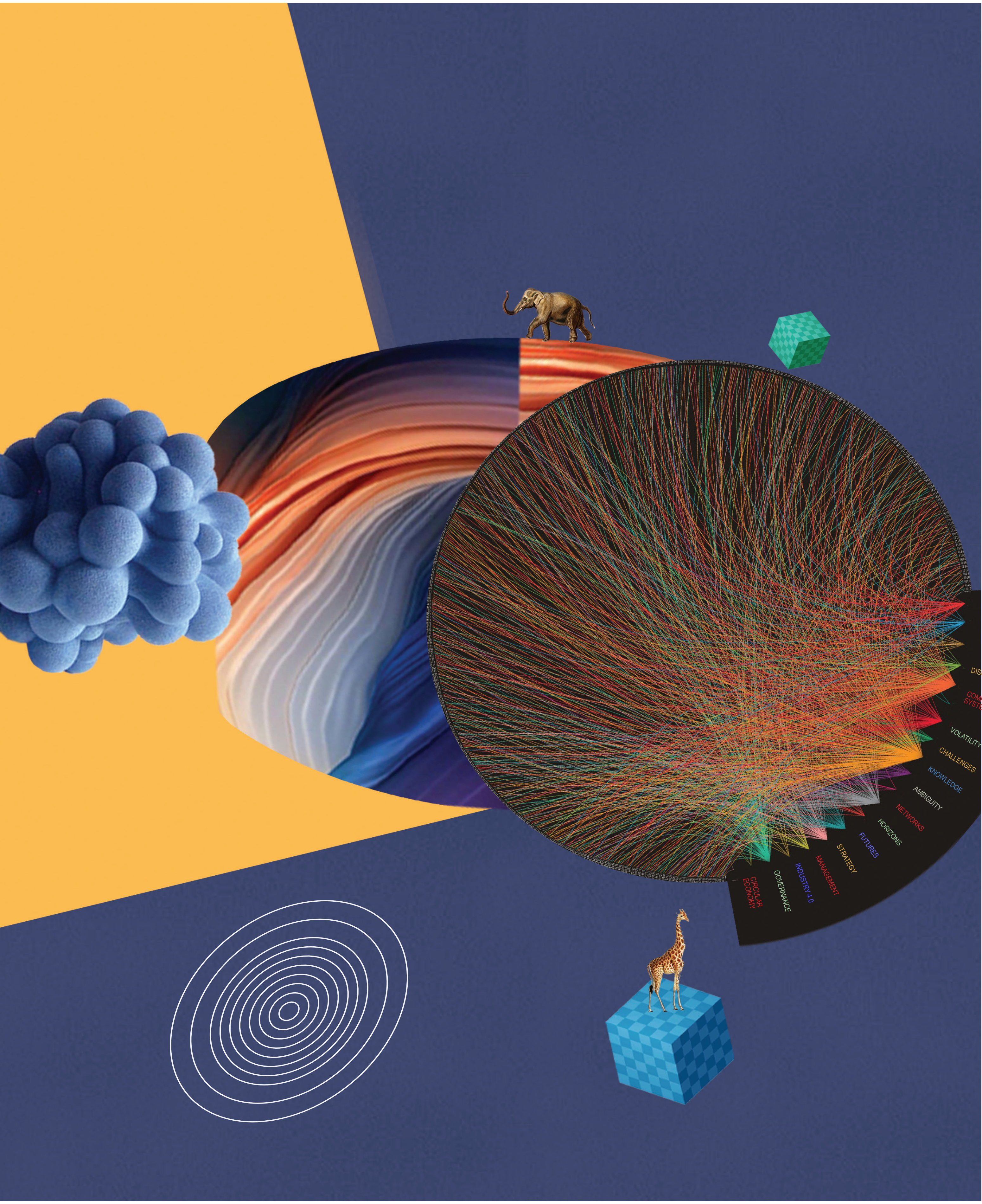
Wack P. (1985) Scenarios: Shooting the Rapids. *Harvard Business Review,* November-December Issue, pp. 139–150.

WBSCD (2010) *Vision 2050: The New Agenda for Business*, Geneva: World Business Council for Sustainable Development.

Wilkinson A. (2014) *The Essence of Scenarios: Learning from the Shell Experience,* Amsterdam: Amsterdam University Press.

Wilkinson A., Kupers R. (2013) Living in the Futures. *Harvard Business Review*, vol. 91, no 5, pp. 118–127.

Wilkinson A., Kupers R., Mangalagiu D. (2013) How Plausibility-based Scenario Practices are Grappling with Complexity to Appreciate and Address 21st Century Challenges. *Technological Forecasting & Social Change*, vol. 80, no 4, pp. 699–710. Available at: https://doi.org/10.1016/j.techfore.2012.10.031, accessed 29.08.2020.



VOLATILITY
CHALLENGES
KNOWLEDGE
AMBIGUITY
NETWORKS
HORIZONS
FUTURES
STRATEGY
MANAGEMENT
INDUSTRY 4.0
GOVERNANCE
CIRCULAR ECONOMY

Systemic Change: The Complexity of Business in a Circular Economy

Hans Wiesmeth
Professor Emeritus, Department of Economy[a], hans.wiesmeth@tu-dresden.de; President[b]; and Research Supervisor, Laboratory of International and Regional Economics[c], hans.wiesmeth@urfu.ru

[a] Dresden Technical University, 01062 Dresden, Germany
[b] Saxon Academy of Sciences and Humanities (Sächsische Akademie der Wissenschaften), Karl-Tauchnitz-Str. 1, 04107 Leipzig, Germany
[c] Graduate School of Economics and Management, Ural Federal University, 19 Mira Street, Yekaterinburg, 620002, Russian Federation

Abstract

The transition to a circular economy is often associated with appropriate business models, which should, among other things, help to replace the conventional "end-of-life" concept regarding commodities with restoration and environmental design. This systemic change appears to be closely linked to the waste hierarchy: the prevention of waste, the reuse of old commodities, and the recycling of waste. Thise paper shows that there are various problems facedfor businesses when attempting to maintain the waste hierarchy in the context of a circular economy. The intrinsic nature of environmental commodities and, in particular, societal path dependencies present some challenges. These societal path dependencies are related to the benefits of decentralized decision-making in a market economy. In the short term, appropriate environmental policies can help alleviate some of these problems, but in the long term, these societal path dependencies need to be reoriented. The paper contains practical examples of all the issues raised.

Keywords: circular economy; technological innovation; waste hierarchy; societal path dependencies; decentralized decision-making; new business models

Citation: Wiesmeth H. (2020) Systemic Change: The Complexity of Business in a Circular Economy. *Foresight and STI Governance*, vol. 14, no 4, pp. 47–60. DOI: 10.17323/2500-2597.2020.4.47.60

According to the Ellen MacArthur Foundation, "applying circular economy principles could unlock up to EUR 1.8 trillion of value for Europe's economy" and "business plays a central role in creating the systemic change required to reap the financial benefits of this transition" [MAF, 2020]. The Foundation refers to the benefits of a "new system" and provides many examples of viable business models, often of a disruptive nature, supporting the implementation of a circular economy. Case studies referring to single-use food packaging, saving clothes from landfills, and developing electric mobility systems, to name but a few, show the potential for doing good business in a circular economy.

Similarly, the Circular Economy Action Plan of the European Union (EU) emphasizes that "the transition to the circular economy will be systemic, deep and transformative" and "building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and foster business creation and entrepreneurship among SMEs." Moreover, "a whole new range of sustainable services will bring about a better quality of life, innovative jobs and upgraded knowledge and skills" [EU, 2020].

Industrial ecology, one of the roots of the concept of a circular economy, assigns a special role to business regarding the potential for environmental improvement with technological innovations. Proponents of industrial ecology consider the heightened role for business "a necessary component of a shift to a … more effective approach to environmental policy" [*Lifset, Graedel,* 2002]. The question here is whether the transition to a circular economy should not be left entirely to business – with a steady stream of suitable environmental technologies that improve the environmental situation. Such a "technology-leadership" would certainly create excellent business opportunities. But would it also meet the objectives of a circular economy?

These "business-centered" views on the implementation of a circular economy are by no means limited to industrialized countries. China is one of the countries that could be seen as a leader in the introduction of circular economy strategies [*Wiesmeth,* 2020, Ch. 4]. In fact, the concept was proposed by scholars in China in 1998 [*Yuan et al.,* 2006; *Zhu,* 1998] and thereafter promoted by government agencies with a variety of activities, such as the establishment of eco-industrial parks. Corresponding projects "should focus on improving resource productivity and eco-efficiency in a comprehensive way, especially optimizing the structure of industry/product, developing and applying new technology, upgrading equipment, and improving management" [*Yuan et al.,* 2006, p. 5]. Not surprisingly, most researchers in China who were working on this subject at that time had a background in technology.

As far as developing countries are concerned, the recommendations are similar, although there should be other priorities for business, such as in the agricultural sector. Preston et al. [*Preston et al.,* 2019] are convinced that the circular economy "could provide new opportunities for economic diversification, value creation and skills development" and that "developing countries are in a strong position to take advantage of the new economic opportunities" and in view of the required "circularity in international value chains" the developing countries are well-advised to grasp these opportunities.

These are the optimistic prospects for business and business opportunities in a circular economy. In general, it can obviously be said that most countries seeking to implement a circular economy are likely to emphasize these potential economic opportunities, probably in order to gain broad support from the local population. Stressing the role of business also helps to avoid the impression that a transition to a circular economy requires substantial resources from public sources, which is a similarly controversial issue. It is therefore not surprising that circular economy strategies in Russia focus also on the development and implementation of appropriate business models [*Plastinina et al.,* 2019; *Wiesmeth,* 2020].

However, it is not only "between the lines" of this brief overview that it becomes clear that the transition to a circular economy is more often than not accompanied by disruptive changes in business that various industrial branches will have to reduce their activities or even cease to exist. In this context, Wilts [*Wilts,* 2016] refers in particular to those business companies that "understandably wonder about the future of their business model if there is no longer to be any waste" (see p. 19).

In addition, current business activities do not always meet the objectives of a circular economy. We are seeing questionable exports of old electronic equipment to developing countries with "recycling" activities in these countries harming both human health and the environment. We are seeing similarly problematic exports of plastic waste to developing countries and emerging economies. Here, too, recycling with outdated technologies leads to the pollution of air, soil, and groundwater. We moreover monitor the sale of second-hand cars for reuse to customers in countries without sufficient opportunities to properly maintain these cars. The resulting air pollution is characteristic of many large cities in developing countries. Furthermore, developed countries are also violating their commitments to mitigate climate change and car producers are using "defeat devices" to cheat on the actual emissions of their cars. In addition, "green washing" and moral self-licensing are used with environmentally friendly behavior in one context to justify less environmentally friendly behavior in other contexts. Finally we observe questionable avoidance strategies with regard to the "polluter pays" principle.

These thoughts and observations lead us to the research question of this paper: what are the relevant features of the systemic change that is obviously deemed necessary for the transition to a circular economy and, even more importantly, what precisely is the role of business in achieving this systemic change? Moreover, referring to the title of the paper, what makes businesses in a circular economy complex? After all, "many actors also profit very well from the existing linear system" [*Wilts,* 2019, p. 19], from the extraction of natural resources, for example. So why should a company turn to circular economy strategies?

The research question is therefore embedded in a rather complex network of incentives, with some stakeholders supporting the objectives of a circular economy but others not.

In order to address the research question, the following section introduces the concept of a circular economy and discusses briefly its perception in the literature and in practice – with reference to the systemic change often associated with it and including some guidelines for its implementation. Since in any economic system the allocation of resources and commodities has to be solved, it is interesting to compare a circular economy to a regular market economy in terms of aspects of the allocation mechanism. This comparison will allow for some insight regarding the research question. This is further explored in more detail in the next section on business activities with a potential impact upon the environment.

Beyond the well-known fact that environmental commodities are characterized by public good properties and external effects, societal path dependencies seem to pose real obstacles for a smooth transition to a circular economy. The practical relevance of these path dependencies will then be investigated in the context of the waste hierarchy. The analysis will be illustrated by examples taken from various areas closely related to the implementation of a circular economy. The need to redirect these societal path dependencies could be interpreted as the necessary systemic change. The paper closes with some summarizing comments on the systemic change and on the complexity of business in a circular economy.

The approach taken in this paper is descriptive. This article's goal is to draw attention to the challenges regarding the transition to a circular economy. The emphasis is upon societal path dependencies, which indicate the need for systemic change. This systemic change refers to the market economy, the role it can and should play, but also the limits of this widespread framework for businesses in the context of a circular economy. Of course, the goal cannot be to replace the market economy, but there is a need to establish some new social norms for doing business in a circular economy. Therefore, this paper should contain some guidelines for implementing a circular economy, highlighting aspects of systemic change.

The Concept of a Circular Economy

The following two subsections briefly review the definition of a circular economy and its perception in the literature and practice, refer to features of a new system, and provide basic guidelines for its implementation.

Definition and Perception of the Circular Economy

The circular economy emerged from various roots, with rising environmental awareness paving the way in the years following the release of "The Limits to Growth" by the Club of Rome in 1972. From an economic point of view, Pearce and Turner [*Pearce, Turner,* 1989] introduced the concept, which points to the fundamental functions of the environment in an economic system that must be sustained: the environment serves as a supplier of natural resources, as a recipient of all kinds of waste, and provides direct utility through attractive surroundings and beautiful landscapes.

If the environment is no longer able to perform these functions, this has immediate consequences for many business activities: a shortage of natural resources can disrupt production and exceeding the assimilative capacity of the environment as a receptable of waste necessitates costly efforts to clean up the environment and can severely impair all kinds of economic activities. Moreover, uncontrolled landfilling of waste can contaminate soil and groundwater and thus endanger the health of humans and other living beings. The current pollution from plastic waste, with microplastics already appearing in the food chain, is proof of this. Similarly, the global anthropogenic emission levels of greenhouse gases exceed the assimilative capacity of the atmosphere and oceans and further contribute to climate change.

Countries and regions differ in terms of the availability of natural resources, in terms of the assimilative capacity of the environment, but also in terms of the level of environmental awareness. The economic situation, geographic, climatic, and demographic characteristics of the countries lead to these differences. The circular economy should, of course, comply with these particular framework conditions. For this reason, it is better to refer to the implementation of "a" circular economy, adapted to the concrete situation in a country. At first glance, this seems simple, but it can have enormous consequences for businesses in a circular economy, for example, when this business affects countries with different characteristics, such as developed and developing countries. Here, too, the trade in plastic waste and global greenhouse gas emissions are examples, pointing to difficult aspects of a systemic change.

From a more practical point of view, the concept of the circular economy originated from different technical "schools of thought" [MAF, 2020]. One of them, industrial ecology, "focuses on product design and manufacturing processes": already in the design of a product are relevant environmental aspects taken into account, thus revealing systemic thinking [*Lifset, Graedel,* 2002].

In view of the relevance of local conditions, it is not surprising, that there is a large variety of perceptions of a circular economy in the literature and practice. Kirchherr et al. [*Kirchherr et al.,* 2017] have more than 100 different approaches to the concept. The consequence is that a circular economy is usually understood differently in different countries. The main differences relate to the role of various groups of stakeholders, the interpretation and relevance of the waste hierarchy, but also the importance of business models.

Given the research question, the role of business models for a circular economy as perceived in the literature and practice needs to be investigated more carefully. Kirchherr et al. [*Kirchherr et al.,* 2017] define a circular economy as follows: "A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (see p. 224). This replacement of the "end-of-life" concept obviously characterizes an important feature of the "new" system.

As has already been indicated, many practical approaches to implementing a circular economy relate to appropriate business models. This holds for the Ellen MacArthur Foundation [MAF, 2013, 2020], for the Circular Economy Action Plan of the EU [EU, 2020], the Green Economy of the UN [UN, 2020], and others (see also [*Wiesmeth*, 2020, Ch. 4]). Moreover, there have been attempts in many countries to establish "smart cities", a concept that is closely related to sustainable development and circular economy in cities [*Albino et al.*, 2015], which promises a lot of money (Frost & Sullivan, 2019), an El Dorado for business.

However, if there seem to be so many interesting business models in the context of a circular economy, why are they not yet visible on a larger scale? The following sections attempt an explanation of this observation and also provide examples of business activities that are questionable in terms of a circular economy. First, however, we look at the basic guidelines for the implementation of a circular economy.

Guidelines for Implementing a Circular Economy

In order to restore and sustainably maintain the fundamental functions of the environment in an economic system, especially the prevention of waste has to get sufficient attention. Preventing waste helps to save natural resources, but also protects the assimilative capacity of the environment as a recipient of waste. Moreover, less land-filling and less extracting natural resources supports the environment as a direct provider of utility. As there is generally a lack of information on the actual capacity of the local environment to assimilate waste, the prevention of waste should be and has to be a priority goal.

Of course, waste can also be prevented by extending the lifespan of products through reuse. Second-hand markets and markets for used cars have long been in existence and are now garnering increased support from online services. Finally, the recycling of collected and separated waste items allows for at least a partial recovery of resources including energy and reduces the volume of waste that needs to be landfilled. This, of course, is also important for protecting the assimilative capacity of the environment.

This brings us to the basic "3R" version of the waste hierarchy, which must be continuously and sustainably respected for the implementation of a circular economy – obviously an important aspect of the necessary systemic change.[1]

How can the waste hierarchy be implemented, in particular, the priority goal of preventing waste? How can this systemic change be encouraged? What role can businesses play? One important tool in this context is the "Design for Environment" (DfE): manufacturers should make their products environmentally friendly in order to simplify the recycling of waste products and save natural resources through appropriate designs and/or higher resource efficiency. Observe that this corresponds perfectly to the vision of industrial ecology and emphasizes once more the close relationship between the aims of a circular economy and industrial ecology [*Lifset, Graedel,* 2002].

Thus, in summary, a circular economy must continuously focus on waste prevention. This has a significant impact upon maintaining the fundamental functions of the environment for sustainable development. DfEs help to implement the waste hierarchy. Of course, additional measures can be applied to save natural resources or to extract these resources in an environmentally friendly way. This points in particular to mining practices in some developing countries and emerging economies.

With this basic outline on what needs to be done in a circular economy – with various hints to business activities and the "new" system, the next step consists of considering the framework conditions for business and relating them to the context of a circular economy. These are the conditions, which usually guide business – the conditions offered by a market economy.

Allocating Commodities in an Economic System

One of the main tasks of any economic system is the allocation of resources and commodities, the task of solving the allocation problems: which commodities should be produce and how many units? How does one produce them (labor-intensive, environmentally friendly, …)? For whom does one produce them? These fundamental problems are important for any economic system and are resolved in any economic system – in one way or the other. A systematic approach to solving the allocation problems is provided by the market or price mechanism in the context of a market economy.

Allocating Commodities in a Market Economy

The market or price mechanism is characterized by the decentralization of economic decisions by means of the price system. The undeniable advantage of this mechanism is the fact that it motivates consumers and producers to use their individual knowledge to make their economic decisions on scarce resources and commodities. These individual decisions are coordinated by the price system leading to a market equilibrium, which is characterized by efficiency properties, at least under certain conditions.

Of course, these nice properties do not come without a price. Very importantly, there must be appropriate feedback for one's action: if I put some effort or money into some activity, buying a commodity, for example, then I want to be sure about a more or less exclusive feedback, an individually "perceived" benefit. This is the "utility" or "profit" derived from the consumption or production of these commodities. Therefore, utility maximization and profit maximization characterize decentralized decision-making of consumers and producers in a pure market economy. The "business models", emphasized in all kinds of contexts for implementing a circular economy, have to

[1] For more extended versions of the waste hierarchy with up to 9Rs see, for example, [Kirchherr et al., 2017]

be embedded into this framework. But what are then the challenges of solving the allocation problems in a circular economy? What is the role or what can be the role of appropriate business models?

Allocating Commodities in a Circular Economy

The first question is, of course, whether we can simply extend the market mechanism to cover the circular economy. This would perfectly correspond to the role assigned to business models to implement a circular economy – both in the literature and in practice. Unfortunately, however, there are some issues, which prevent such a simple extension.

There is, first of all, the intrinsic nature of the commodities of relevance in a circular economy. "Waste", for example, is a "commodity" as it obviously affects human wellbeing, as it touches the human sphere. But how does one deal with waste or, rather, how can one facilitate the prevention or reduction of waste in a market economy? There likely is a scarcity of the (environmental) commodity "absence of waste." However, if I reduce waste with some individual effort, is there necessarily feedback from my action, if others continue to generate waste, perhaps even more than before? In addition, if others reduce waste, I will also benefit from their efforts. The consequence is that without any augmentation, the market system cannot adequately handle these "environmental" commodities characteristic of a circular economy.

At the international level, the scarcity of certain environmental commodities, such as the reduction of the emissions of greenhouse gases, need not in all countries be perceived in the same way. As already indicated, some countries could consider other environmental issues, such as clean air or access to clear water, which are more important for the time being than climate change. Thus, these differences in perceived scarcity of certain global environmental commodities can create difficulties with respect to their allocation. In addition to this, missing perceived feedback from one's own actions, again in the context of climate change, may also pose challenges, even for industrialized countries: with 2% of global greenhouse gas emissions, Germany's efforts to reduce these emissions will make no difference without the efforts of other countries.

These considerations, which are of course well-known in environmental economics, are but one aspect of solving the allocation problems in a circular economy. There is, however, another issue, which is at least as important. As already indicated, a significant share of publications on the implementation of a circular economy refers to appropriate business models. But is it straightforward to identify viable business models for waste prevention? Is waste prevention really in the interest of recycling companies? Is an extended lifespan of products, electronic equipment, for example, always the priority goal of manufacturers? Similarly, differences in the levels of environmental awareness can induce international trade in environmental commodities such as waste, plastic waste, for example. Will it be possible to reconsider existing regulations in the context of the World Trade Organization (WTO)?

These remarks point to so-called societal path dependencies, which seem to interfere with the role of business regarding the systemic change, the transition to a circular economy. So far, most societies seem unwilling to accept the fact that there are limits to how far we can go with the market economy for implementing a circular economy. Discussions regarding the required systemic changes need to be intensified in order to address this important issue. The fact is, however, that the shortcomings of various policies in the context of the implementation of a circular economy are, at least to some extent, the consequence of such societal path dependencies.

Doing business in a circular economy is thus becoming increasingly complex! The following section will investigate consequences of these structural differences between a regular market economy and a circular economy by examining business activities, which in one way or another involve environmental commodities. Table 1 shows the differences and commonalities between these two economic systems with respect to the waste hierarchy.

The Complexity of Business Potentially Impacting the Environment

Most business activities are related to environmental commodities: in the simplest case there is the generation of waste, emission of pollutants, or trade in certain kinds of waste. What are the implications for doing business in the context of a transition to a circular economy?

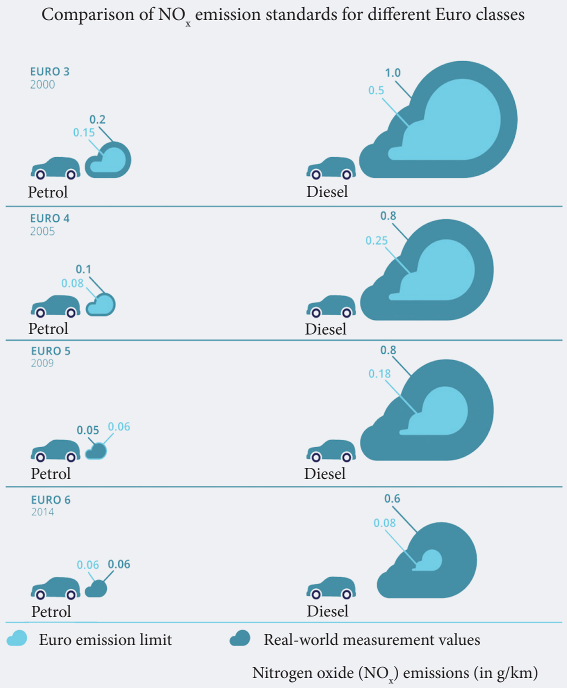
Of course, we know how to augment the market system to cover environmental commodities, to "internalize" the environmental effects. The usual "market-oriented" policies include in particular pollution taxes and tradable emission certificates. These policies are in use in different countries to motivate companies to restructure their business activities to reduce pollution and, thus pay fewer pollution taxes and spend less on emission allowances.

However, what seems so simple, requires a few thoughts. In the context of the "price-standard approach", these taxes are meant to reduce pollution to the level of a given environmental standard, and also the total quantity of certificates available in a given period of time corresponds to such a standard, a so-called "cap". These standards are proxies for the generally unknown efficient levels of environmental commodities. Of course, due to new scientific insight, it is necessary to adjust these standards. This is, for example, also the case for waste management activities in Russia, with increasing "utilization rates" for various types of waste [*Starodubets, Wiesmeth,* 2020, Table 4]. Although

Table 1. **The Nexus between a Market Economy and a Circular Economy**

<table>
<tr><td colspan="2">Market Economy</td><td rowspan="2">Information asymmetries characterize contexts without decentralized decisions</td></tr>
<tr><td rowspan="2">Societal path dependencies related to decentralized decisions determine business models</td><td>Waste Hierarchy
Waste prevention?
Profitable recycling?</td></tr>
<tr><td colspan="2">Circular Economy</td></tr>
<tr><td colspan="3">Source: compiled by the author.</td></tr>
</table>

Figure 1. NO_x Emission Standards and Real-World Measurement Values



Source: European Environment Agency (EEA). Available at: https://www.eea.europa.eu/media/infographics/comparison-of-nox-emission-standards/view, accessed 16.06.2020.

companies are in general accustomed to ever-changing conditions, the more problematic issue is: how and to what extent are standards raised?

Raising Environmental Standards

As it is usually the manufacturers who know what could be done to further reduce pollution in the context of their production activities, there are information asymmetries and the challenge for policymakers is finding the right time and adequate levels for the adjustment of the environmental standards. In view of the Prisoners' Dilemma, producers will voluntarily make use of their knowledge only if it is in their legitimate business interests.

The nitrogen oxide (NO_x) emissions of vehicles provide a good example of this situation. In the EU, the emission standards have been reduced over the last several decades: for diesel cars, for example, from 0.5 gr/km in 2000 to 0.08 gr/km in 2014. Figure 1 shows in addition the differences between the emission standards and the real-world measurements. These discrepancies have led to new testing procedures, which better indicate the real emissions. Nevertheless, it remains a challenge for car manufacturers to achieve these standards because customers also continued to ask for heavier vehicles, increasing the fleet averages with respect to the consumption of gasoline and diesel and, thus, the emission of noxious gases. The development of so-called "defeat-devices", which were then used to manipulate emission tests, eventually led to "Dieselgate".

What were the reasons for this result? Obviously, car manufacturers had the technical solutions for reducing NO_x emissions, for example, by adding AdBlue. However, they either did not want to burden drivers with additional stops to replenish this substance or they were not satisfied with this end-of-the-pipe technology. Anyway, there was a mixture of issues, which came together to produce this result. Customers' preferences for heavier vehicles were certainly among them: the changing demand outperformed technological efforts to sufficiently reduce emissions.

These considerations show that the regulatory acts of governments, even if they are foreseeable, can have a significant impact upon doing businesses in a circular economy. In particular, as has been indicated, business will not always voluntarily contribute to the necessary systemic change with appropriate DfEs. Moreover, if efforts to reduce NO_x emissions meet efforts to mitigate climate change, and if this is, above all, happening in times of COVID-19 coronavirus, then the disaster is ready.

Environmental Standards and International Trade

International trade is increasingly impacted by environmental regulations in both export and import countries creating another level of complexity due to the possible interference of governments with trade in a variety of ways. A first assessment of environment-related trade barriers by [*Fontagné et al.*, 2001] shows that 88% of world trade is potentially affected. Figure 2 reveals the growth of the environment-related notifications in recent decades.

Governments can use environmental standards as tools to prevent or restrict market entry and thus reduce the competitive pressure on the national industry. It is not always easy to find out whether a particular standard is used for environmental protection or, rather, for economic reasons – or both. In addition, differences in environmental awareness may distort the picture: regarding the possible pollution of the environment, what might be acceptable in one country need not be acceptable in another – and this attitude is likely to change over time.

China used to import significant volumes of plastic waste: more than 1.6 million tons in 2015. After China's import ban on highly contaminated waste, in particular plastic waste in 2018, this volume dropped to less than 65,000 tons. This regulatory change likely resulted from a combination of economic and environmental issues: growing economic welfare raised environmental awareness but made the recycling of this type of waste also increasingly expensive. Nevertheless, not only was the business of companies trading and handling waste severely impacted, but also that of companies providing certain environmental technologies, thus pointing out the risks of doing business in a context that is vulnerable to regulatory intervention.

However, there is another aspect that should be examined more closely. Due to the increasing number of regulatory measures, environmental technologies are a major business in some countries, especially in the US, Japan, and Germany. According to the US Department of Commerce, the global markets for environmental technologies (goods

Figure 2. **Environment-Related Notifications in 1997-2018**

Source: World Trade Organization (WTO). Available at: https://edb.wto.org/, accessed 16.06.2020.

and services) reached $1.05 trillion in 2015 with US exports of $47.8 billion [ITA, 2017, Fig. 1]. Similar to the US, Germany's global trade share in Greentech products amounted to 16% in 2016 and is expected to continue to rise in the near future [GTAI, 2019].

These numbers point to the growing importance of exporting these technologies, in particular to developing countries and emerging economies. However, these exports and the future export potentials depend first of all on the environmental regulations in the import countries. If these regulations change, then markets can break away – as they did recently after China's import ban. Finally, with regard to the transition to a circular economy, many regulations need to be changed.

An additional comment in this context relates to export promotions of certain technologies, such as e-mobility or green hydrogen in Germany. Hydrogen technologies shall secure Germany a "global leadership role", according to a recent press release of the German Federal Ministry for Economic Affairs and Energy.[2] The critical issue is that these attempts to achieve a leading role globally may create technological path dependencies in particular in Germany. Alternative environmentally friendly technologies may be driven out of the market, just by such a combination of environmental standards and regulations on the one hand and export promotions with their focus on economic aspects on the other. The following subsection provides an example: the recent promotion of e-mobility in Germany.

Promoting E-Mobility in Germany

The promotion of e-mobility began with the aim of gaining a leading role in the related technologies. With regard to Germany, it was also an attempt to strengthen the business of electric vehicles in China. China supported the purchase of electric cars and the expansion of the necessary infrastructure such as charging stations. As Chinese car manufacturers lag behind their competitors from abroad regarding conventional vehicles, the support for e-mobility also aimed at developing a domestic industrial sector, which is competitive on a global level [*Heymann,* 2020, p. 8]. Thus, in order to achieve this goal of a market entry in China, Germany first had to establish e-mobility "at home" in a credible way. The high environmental standards for emissions of vehicles have proved to be helpful in this respect and stimulated the development of the corresponding technologies in Germany.

As has already been indicated, various developments, in particular with regard to customers' preferences for heavier vehicles, have made it increasingly clear that it will be difficult, if not impossible, to achieve the emission standards with conventional petrol and diesel engines. Thus, the government introduced "super-credits" for e-vehicles: each e-vehicle sold counts for two vehicles with, by definition, 0 gr/km emissions, thus reducing average fleet emissions. These super-credits will be gradually reduced and abolished in the next few years, but there are further significant subsidies: for a couple of years, the purchase of an e-vehicle will be supported by up to EUR 6,000.

For the time being, it is still unknown whether sales of e-vehicles will increase sufficiently in the years to come. After all, there are still some handicaps: the not yet adequately developed infrastructure, the limited range, and, despite of all the subsidies, the still rather high price of e-vehicles.

Interestingly, China cut subsidies for electric cars at the end of 2019, which led to an immediate decline in demand for e-vehicles [*Heymann,* 2020, p. 8]. The question is now, how will Germany react to the latest developments both in China and in Germany regarding e-mobility? Is perhaps the recent switch of the German government to hydrogen technology the answer?

[2] https://www.bmwi.de/Redaktion/EN/Pressemitteilungen/2020/20200610-securing-a-global-leadership-role-on-hydrogen-technologies.html

In order to return to the topic of this paper, in the context of the implementation of a circular economy, governments must play an increasingly large role regarding environmental standards and other regulatory measures. However, this poses a certain risk to all types of business activities which, in one way or another, are related to environmental issues, i.e., virtually all business activities. For managers of these companies, this implies taking into account not only the usual actual and potential market developments in their decisions, but also possible, often unexpected, changes in the environmental framework conditions at both the national and international levels.

This increases the level of complexity of doing business in a circular economy, in particular in export-oriented countries and once again highlights the necessary systemic change that seems to go beyond traditional business models with their focus on decentralized decision-making. Are there widely functioning business models of the circular economy?

Societal Path Dependencies

With regard to the typical perception of the circular economy in the literature and practice, its implementation is usually considered under the framework of a market economy. The design of business models for a circular economy has attracted much interest among practical-minded organizations, such as the Ellen MacArthur Foundation [MAF, 2020]. Lewandowski [*Lewandowski,* 2016] points to the interest of major global companies in a circular economy due to "the huge financial, social and environmental benefits", but also to the "limited transferability" of existing business models for the circular economy and the missing "comprehensive framework supporting every kind of company in designing a circular business model." So, there is again the above question: are there widely functioning business models for the circular economy?

If we continue to tie the implementation of a circular economy to the context of a market economy, then we have to accept that companies usually have the knowledge to identify appropriate business models. They for sure would not need much external advice and they would also protect their business ideas and their knowledge. Thus, the approach mentioned above is uncommon for a market economy, although the idea itself seems to come from industrial ecology with its technology leadership regarding the road to a circular economy [*Lifset, Graedel,* 2002].

This section will investigate this issue more carefully and will link it in particular to the role of societal path dependencies and their importance for implementing a circular economy. To make one point clear: the characteristics of a market economy, such as decentralized decisions, making use of the individually available knowledge and information, is an asset also for a circular economy. Thus, the aim of this section is not to discredit the market economy in the context of implementing a circular economy. Rather, the aim is to draw attention to certain obstacles and the need to deal with them in a considered manner.

Moreover, technological innovations, for environmental technologies in general and designs for environment (DfEs) in particular, are of great importance for sustainably implementing a circular economy. However, as already indicated, not all companies are likely to have an intrinsic motivation to "voluntarily" introduce such innovations, as Lifset and Graedel expect them to have [*Lifset, Graedel,* 2002]. In this context, Gupt and Saray point to the relevance of the market situation, which must be in favor of a DfE [*Gupt, Saray,* 2015]. Thus, in general, appropriate environmental regulations are required to motivate producers to a DfE regarding their products.

The Nature of Societal Path Dependencies

The concept of the (technological) path dependency originated in the 1980s with various publications on "alternative theories of the firm" [*Stack, Garland,* 2003]. Increasing returns to scale can lead in one way or another to the selection of suboptimal technologies, which then can be become locked in as industry standards. This can also happen in the context of environmental technologies: the choice of a particular waste management system usually leads to technological path dependencies with respect to subsequent updates of the system. And, as already indicated, export policies of governments can also create these path dependencies in both the export and the import countries.

Societal path dependencies are a little bit more complicated. They comprise not only technical and technological issues, but also cultural and institutional aspects, including the way people perceive certain issues, how they tend to think about certain issues. Of course, these societal path dependencies come from different societal roots such as historical events, religion, and probably depend upon the local situation, the geographic, climatic, and the economic conditions of a country. Also, the way business is organized in a country can mean a societal path dependency in the sense that "existing business models hamper transitions by reinforcing the current system's stability." On the other hand, however, "business models drive transitions by facilitating the stabilization process of technological innovation" [*Bidmon, Knab,* 2018].

It is interesting to learn in this context that if the innovation process is a stable feature of businesses, then the existing business models may nevertheless be part of a transition. Regarding the transition to a circular economy, it thus remains to establish innovations, in particular DfEs, as such a stable feature. But, as we know already, there is the issue of a possible lack of incentives due to asymmetric information.

With respect to the implementation of a circular economy, societal path dependencies play a role not only regarding environmental innovations, but also in all areas of waste management, in all aspects of the waste hierarchy. This is examined in the following subsections, focusing on the waste hierarchy.

As outlined above, doing business in a circular economy depends to a significant extent upon the sustainable implementation of the waste hierarchy with waste prevention as a priority goal. What are the challenges with respect to this issue?

The Perception of Waste and its Prevention

Kirchherr et al. [*Kirchherr et al.,* 2017] in investigating the core principles of a circular economy found that among the 114 definitions of a circular economy, some 35%-40% refer to the reduce, reuse, recycle (3R) framework of the waste hierarchy. However, practitioner definitions "are found to feature reuse and recycle as often as the 3R framework (25% of definitions)". The explanation is that promoting reduction "may imply curbing consumption and economic growth", if no other shifts in the existing business models are undertaken [*Kirchherr et al.,* 2017, p. 226] thus pointing to societal path dependencies: the societal necessity of economic growth, which in this case seems to interfere with the required systemic change.

Wilts [*Wilts,* 2012] is convinced that "defining the prevention of the waste as the top priority of the waste hierarchy … is much more than a simple amendment of ways of dealing with waste, but means nothing less than a fundamental change of the socio-technical system of waste infrastructures." In particular, he refers to "the relationship between physical waste infrastructures, actor constellations in waste governance and incentives for waste prevention." In fact, the waste management infrastructure in Germany and in most other countries, usually consists of waste collection and various levels of waste separation and in particular of a multitude of activities in waste recycling, which is not really geared toward waste prevention.

There are various reasons for this observation, for this obvious lack of attention paid to the "priority goal" of waste prevention. First of all, there are different definitions of waste prevention. Quite often, as in Germany, the reduction of waste is considered equivalent to waste prevention. Although the concepts are certainly close, they are not identical. The volume of municipal solid waste in Germany decreased significantly in the years after 2000. However, this decrease was mainly due to a smaller quantity of construction and demolition waste, whereas production and commercial waste increased, and household waste stayed more or less at the same level [Germany, 2018, Fig. 1]. Thus, the volume of waste was reduced, but probably not so much due to serious efforts made with regard to household and commercial waste. In fact, packaging waste in Germany increased by 19% between 2000 and 2017, and plastic packaging by 74%.[3] The volume of construction and demolition waste may have been reduced by less construction activity or for other reasons.

Of course, waste prevention starts on a different level. It is an active effort to change your behavior regarding the generation of waste. Corvellec [*Corvellec,* 2016] refers to three "main types of actions: raising awareness about the need to prevent waste, increasing material efficiency, and developing sustainable consumption". Although Wilts [*Wilts,* 2012] cites various indicators, it is a fact that waste prevention is difficult to measure, in contrast to the reduction of the waste volume.

Another reason for this neglect of waste prevention is the perception of waste, the way that waste is understood in large parts of society. "Waste" is usually something to get rid of. Once waste "disappears" in a landfill or elsewhere, in a recycling plant, for example, it is out of sight and is "prevented" from affecting or even harming the individual comfort zone. Only a few people are interested in the fate of "waste" once it is collected. It seems rather that waste separation is kind of a "moral self-licensing": by separating waste I did what I could to protect the environment [*Engel, Szech,* 2017].

This sounds simple, but that is how waste management has developed in recent decades, and so it is still in the DNA of many societies, documenting a societal path dependency that is only gradually changing. Currently, recycling takes on the role that landfilling played a few decades ago.

This is then another reason why waste prevention is falling behind waste recycling. The recycling of waste obviously helps to "prevent" waste from harming the environment and, moreover, helps us recover some resources. The structure of our waste management systems is also focused on this issue. Of course, it is and has to be in the interest of waste management companies to collect and recycle as much waste as possible. That is their business and they have to show the results at the end of the year, and what is better in this regard than to continuously increase collection and recycling rates? Thus, these structures also point to societal path dependencies [*van Ewijk, Stegemann,* 2016]. This issue will be reconsidered in the context of doing business with recycling waste.

Are There Business Models for Waste Prevention?

What does all this imply for doing business in a circular economy, for the role business plays in creating the systemic change "required to reap the financial benefits of this transition" [MAF, 2020]? Well, let us think about appropriate business models that support waste prevention. What should they look like? Difficult to say. The EU Waste Directive[4] provides a list of possible measures: measures that can affect framework conditions related to the generation of waste, measures that can affect the design and production and distribution phase, and measures that can affect the consumption and use phase.

However, beyond a DfE there seem to be no business models that are viable without external regulation and the EU has not yet been very successful in preventing (or reducing) packaging waste [*Tencati et al.,* 2016]. But DfEs will be voluntarily adopted only if this makes sense from a business perspective.

[3] https://www.umweltbundesamt.de/en/press/pressinformation/level-of-packaging-consumption-in-germany-remains

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN

Increasing the resource efficiency is certainly one of the measures, one of the DfEs, which are continuously and voluntarily used to reduce production costs. In doing so, it supports the objectives of a circular economy, although the primary business goal is to reduce costs in order to become more competitive and attract more customers. In this sense, this measure has to be linked to rebound effects – the increased resource efficiency reduces production costs and increases demand for the products and, thus, also for resources [*Wiesmeth,* 2020, Ch. 12]. The Ellen Mac Arthur Foundation, promoting a variety of business models, also points to the rebound effects, which reduce the waste prevention effects of this kind of DfEs [MAF, 2020]. Again, focusing on the drivers of a market economy, in this case the generation of profits, can threaten the circular economy goals.

The extent to which the digital transformation can and will change the picture remains to be seen. So far it seems to be big businesses with astonishing growth rates for the "digital economy" that can be expected in the coming years. It is clear that implementing a circular economy depends upon the further development of digital technologies. Robot technologies, for example, could be used in waste management "to make treatment of waste more efficient" [*Sarc et al.,* 2019]. However, is not clear whether a more efficient treatment of waste with digital technologies, as nice as it is, helps to prevent waste.

Thus, the results of the digital transformation are mixed regarding the transition to a circular economy. The lockdown during the COVID-19 coronavirus crisis has shown that online shopping, which contributes significantly to an increase in packaging consumption, will not replace regular shopping activities, as one wants and needs the personal contact with others. There is therefore the possibility that the digital transformation, if any, will only marginally reduce transport activities to compensate for other less environmentally friendly activities that come with it.

These considerations imply that existing and future business models will not always effectively support the transition to a circular economy. The requirement to generate profits leads either to the neglect of certain environmentally sound DfEs or to rebound effects with higher consumption and similarly increasing resource use. In any case, waste prevention is not the primary objective of business activities.

To sum up, why should waste prevention then be taken care of in the first place? Recycling waste also reduces environmental damage, and there are enough technologies and constant flows of innovations. Although, as has already been mentioned, this seems to be the predominant position in many countries, including Russia, there are clear reasons not to forget about preventing waste:

a) The more waste we generate, the more will stay in the environment. In view of the Second Law of Thermodynamics, it will become extremely costly, to collect all pieces of waste, plastic waste, for example.

b) Only by preventing waste will it be possible to seriously save resources. It has to be kept in mind that recycling often means downcycling, leading to materials of lower quality.

But the market system, which is part of our society and culture, does not really support waste prevention measures, as the above discussion has shown.

Reusing Commodities in a Circular Economy

Reusing old commodities and thereby extending their lifespan also helps to save resources and prevent waste. However, is the extension of the lifespan of commodities always in the interest of producers and consumers, despite all the second-hand shops we have both offline and online? This subsection explores some aspects of "reuse" in the context of doing business in a circular economy.

There are, of course, many good examples of reuse and sharing. Second-hand clothing and evening attire to rent, used cars and car sharing initiatives, online platforms for the purchase and sale of used commodities and so on are viable and established business models. Some of them are only possible in the digital context, but most of them gain visibility through the digital transformation.

So, is everything on the right track regarding the transition to a circular economy? Let us take a closer look at some of these business models, again with a focus on the role of societal path dependencies.

An initial observation refers to the decentralized, individual decision-making in a market economy. This characteristic feature of a market system is essential for the efficiency of the price mechanism, but it also triggers mechanisms such as the Tragedy of the Commons and the Prisoners' Dilemma, once the framework of a market system is left, by introducing environmental commodities, for example. For a consumer, even with a high level of environmental awareness, it thus becomes "permissible" to buy the latest models of electronic equipment, the latest cars, and the latest fashion. "Fast fashion" describes this observation with respect to the strongly increasing consumption of textiles, fueled by lower prices and lifestyle changes.[5]

Of course, industries tend to be supportive of this consumer behavior. Not to be misunderstood, this is their legitimate business. But these industrial sectors use especially large quantities of natural resources for their production activities and finally create equally large quantities of used and waste commodities. What does this imply for reusing electronic equipment, second-hand cars, and second-hand textiles? Do existing business models always meet the goals of a circular economy? In the context of reuse, can business models generally achieve the goals of a circular economy and promote the systemic change?

Reusing Electronic Equipment

As far as electronic equipment is concerned, a significant proportion of the old electronic devices that have been declared reusable are in developing countries. Due to the

[5] https://www.eea.europa.eu/themes/waste/resource-efficiency/textiles-in-europe-s-circular-economy

large quantities and the imprecise concept of "reusability", a large share of this equipment is "recycled" in these countries in a way that harms both human health and the environment [*Sovacool,* 2019]. In addition, these exported commodities need not be recycled "at home" – perhaps at the cost of the producers. This keeps the cost of recycling low and reduces incentives for a DfE, one of the important tools to prevent waste.

Current business models for electronic equipment therefore present some challenges for the transition to a circular economy. The export of old equipment for reuse to developing countries need not be in accordance with the goals of a circular economy. If these old smartphones, for example, are bought by people, who would otherwise not be able to afford a new one, then this version of "reuse" does not prevent or delay the production of a new smartphone and thus does not really contribute to saving resources and preventing waste [*Zink, Geyer,* 2017]. But what is a legitimate reason to deny these people access to these technologies?

To sum up, we are seeing a kind of mainly reusable devices on the markets for electronic equipment, driven by demand for the latest models and fueled by a steady stream of technological innovation. This situation does not allow for "reuse" in full compliance with a circular economy.

Second-Hand Cars

There is a similar situation regarding second-hand cars: markets for used cars have been around for a long time and are generally important for the car business, as they help with the design and construction of new models. Here too, however, the reuse of old cars is fully in line with the principles of a circular economy only when these cars are used by people who would otherwise have bought a new car. In all other cases, there is only an incomplete replacement of new cars, which does not contribute much to saving resources and preventing waste [*Zink, Geyer,* 2017].

This refers in particular to exports of used cars to developing countries. The recycling of scrap cars in these countries usually leads to further pollution. Moreover, the cars, which need not be recycled at the expense of the car manufacturers, do not increase the total recycling costs for the producers, thereby reducing incentives for a DfE. But, again, who can deny people in these countries access to cars?

To sum up, there also seems to be an oversupply of used cars due to the demand for new models and technologies. This situation is likely to be exacerbated by the current attempts by car manufacturers to increase their sales through public subsidies for new cars in the context of the COVID-19 coronavirus crisis.

Reusing Textiles

According to the European Environment Agency (EEA)[6], of the 5.6 million tons of textile waste generated in the EU in 2013, only 20% was collected for reuse or recycling, with the rest being lost, with 1.5 million tons of waste exported outside the EU. On the other hand, there have long been second-hand shops for clothing, which mainly support young families with cheaper clothes for their children. There are also international markets for used textiles. However, in view of the "fast fashion trend", it could also be that developing countries are flooded with old garments, which could then lead to further environmental problems, similar to old electronic devices.

Again, this kind of reusing textiles need not be beneficial with respect to the environment since the production of new textiles can only be partially avoided by these reuse activities. In addition, the transport of these used commodities can also contribute to increasing pollution [*Sandin, Peters,* 2018]. Figure 3 shows a classification of ways of reusing and recycling textiles, which are not yet being used significantly in the EU, given the current situation.

In summary, the markets for used textiles are also increasingly characterized by oversupply due to societal phenomena such as fast fashion, but also due to the increasing role textiles, in particular technical textiles, are playing in our economies.

The Role of Societal Path Dependencies for Reusing Old Commodities

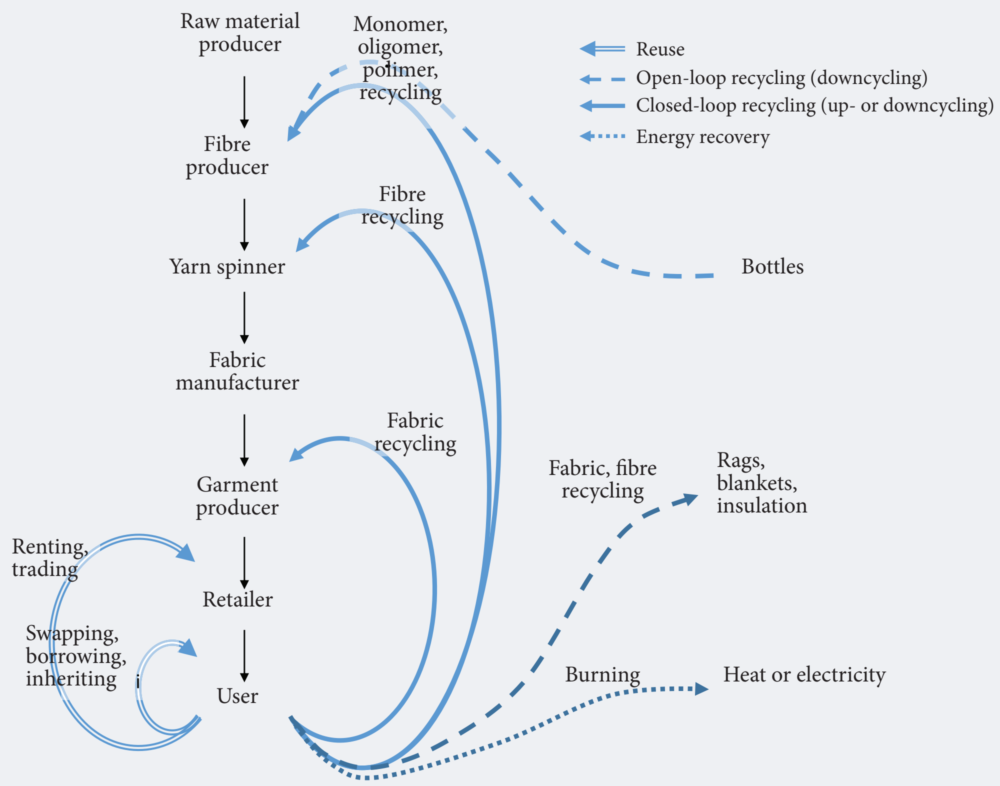
After this investigation of various industrial areas, which is of great relevance for a circular economy, there remains a question regarding the role of societal path dependencies. It is, first and foremost, the decentralized structure of the economic systems, which must be mentioned here. Both consumers and producers make use of their individual preferences, their individual income, and their own knowledge for economic decision-making. Mechanisms, such as the Tragedy of the Commons, keep consumers from taking environmental issues too much into account. Moreover, the growth of the economies in recent decades continues to fuel demand for all kinds of commodities. Therefore, many consumers will look for the latest models, thereby leaving environmental concerns to others. Similarly, producers are "forced" by the Prisoners' Dilemma to restrict their environmental efforts and focus on the economic context of their activities.

In all these cases and in many more, the reuse of old commodities often means selling the used commodities to buyers, who did not want or could not afford new commodities. Reuse in this sense helps to increase sales of the new commodities. This is good for the economy, of course, but it need not represent the "reuse" of commodities as specified in the waste hierarchy.

This observation is reinforced by international trade in used commodities. International trade is often based on the principle of comparative advantage, so that both the exporting and the importing country can gain from trade.

[6] https://www.eea.europa.eu/media/infographics/textile-waste/view

Figure 3. **A Classification of Textile Reuse and Recycling Routes**



Source: [*Sandin, Peters,* 2018, Fig. 1]. Available at: https://ars.els-cdn.com/content/image/1-s2.0-S0959652618305985-gr1.jpg, accessed 16.06.2020.

This principle also applies to environmental contexts with an additional twist: a country with less environmental awareness, presumably the poorer developing countries, could be willing to import commodities that can pollute the environment in one way or another, in view of a comparative advantage. Old electronic equipment, old cars, and old textiles are examples. However, as the foregoing considerations have shown, this way of doing business can, in general, not be in the interest of a circular economy and does not promote the necessary systemic change.

Thus, societal path dependencies create difficulties. It will be a challenge to overcome these dependencies, at least for the context of relevance for the transition to a circular economy. The "sharing economy" will likely also grow due to the digital transformation. However, it remains to be seen whether the associated business models, which are based on decentralized decisions of consumers and producers, meet or can meet the objectives of a circular economy. In addition, international trade is regulated by international agreements, by the World Trade Organization (WTO), with respect to environmental issues. Any attempts to make significant changes will be opposed by appropriate coalitions of developed and developing countries.

Recycling Commodities in a Circular Economy

While the prevention of waste and reuse of old commodities do not yet play a decisive role in the implementation of a circular economy, recycling has become increasingly popular. In many countries, the recycling industry has been developed into a large industry that provides jobs and employment and seems to pave the way for a circular economy. Recycling is often a profitable business and, more importantly, is meant to be a profitable business. As far as waste management is concerned, the regulations usually refer to the waste hierarchy with waste prevention leading, and reuse and then recycling following in the hierarchy. Practice, however, shows that environmental standards are only defined for the collection and recycling of the different kind of waste, so waste prevention is usually forgotten. This holds, for example, also true for the Russian federal project "Formation of an Integrated MSW Management System".[7]

This situation is again the consequence of societal path dependencies. Recycling waste is easy to measure, it guarantees jobs and is open to technological and scientific innovation. Moreover, the possible economic profit-

[7] https://bit.ly/30dJuRG

ability offers business models that can be beneficial for the transition to a circular economy.

There is, however, a problem which is linked to these societal path dependencies: if recycling of certain waste streams is profitable, either directly or indirectly through subsidies, then it should remain profitable and should even grow economically. Any other development would be considered problematic in most societies. Hence, this "path" requires more waste to be recycled, not less, and this likely requires less waste prevented, not more. This result does not meet the goals of the waste hierarchy, and therefore not the goals of a circular economy and again does not correspond with the required systemic change.

One of the consequences of these path dependencies is the observation that some companies, producers, and distributors of drinks, for example, are expanding their share of drinks in one-way packaging with explicit reference to the excellent ways of recycling the empty cans and bottles (see, e.g., the "World Without Waste" initiative of the Coca Cola Company[8]). These strategies result from societal path dependencies in both the consumption and the production sectors of the economies: decentralized, individually optimal decisions that are affected by the Tragedy of the Commons (consumers) and the Prisoners' Dilemma (producers).

Another aspect refers to a change in the focus regarding a DfE. The shift from waste prevention to waste recycling is accompanied by a shift from "Design for Environment" (DfE) to a "Design for Recycling" (DfR). Waste management companies, such as the Green Dot[9] in Germany, promote the DfR, thereby pointing to sustainable packages assured by a recycling-friendly design.

This seems to be a small deviation from the original goal of a DfE. But regarding the principles of a circular economy, it is again less about waste prevention and more about recycling. Of course, the context is clear: societal path dependencies "force" waste management companies to steer their business in this direction – with consequences for many other companies and their production activities and the objectives of a circular economy.

Conclusion

These considerations show that doing business in a circular economy is not always easy while paying attention to the requirements of a circular economy. Of course, there are many examples of viable business models for a circular economy, but these are mainly examples, not more. It was pointed out earlier that it is typically the task of companies to come up with fresh ideas and new models.

The fact that the transformation of the economy, the systemic change, obviously requires support from the outside probably points to societal path dependencies, which need to be redirected. But the above discussion shows that this redirection cannot be achieved with business models in a market economy based on decentralized decisions that are closely linked to these societal path dependencies. The shift towards a digital economy, towards a sharing economy can certainly help in this regard, but it will not be sufficient to get rid of the dependencies discussed above.

It will therefore remain challenging to do business in a circular economy with the waste hierarchy and waste prevention as its priority goal on the one hand, and the business interests on the other. Unfortunately, this is not enough to take into account and resolve only the technological issues relating to all aspects of waste management and sustainability. There is always the human factor, which needs to be taken into account – including the rebound effects and all kinds of technological and societal path dependencies.

The answer to this dilemma cannot be, of course, to replace decentralized decision-making by some other allocation mechanism, such as technological leadership, as sometimes proposed by industrial ecologists [*Lifset, Graedel,* 2002]. In view of the foregoing considerations, this would not help to solve the main problem and it would mean forgetting to use the knowledge that individual consumers and producers possess.

To sum up, these reflections reveal the main features of the systemic change that is required for a successful transition to a circular economy. The core issue seems to be decentralized decision-making, which triggers the Tragedy of the Commons and the Prisoners' Dilemma once business activities are related to environmental commodities.

One possibility is to make use of these societal path dependencies through appropriate environmental regulations such as "Integrated Environmental Policies" [*Wiesmeth,* 2020, Part V]. As a substitute for the market mechanism, these policies can influence decentralized decisions to support the goals of a transition to a circular economy. However, these policies have to be designed very carefully in order to rule out vested interests and less environmentally friendly possibilities for circumventing these regulations – also a challenging task as many practical examples show [*Wiesmeth,* 2020, Ch. 5]. Therefore, these policies can help in the short term, but in the long term the societal path dependencies must be adapted, adequate social norms must be created in order to achieve the necessary systemic change.

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006.

[8] https://www.coca-colacompany.com/faqs/what-is-world-without-waste

[9] https://www.gruener-punkt.de/en/sustainable-packaging/about-design4recycling.html

References

Albino V., Berardi U., Dangelico R.M. (2015) Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology*, *vol. 22*, no 1, pp. 3–21. Available at: https://doi.org/10.1080/10630732.2014.942092, accessed 05.09.2020.

Bidmon C.M., Knab S.F. (2018) The three roles of business models in societal transitions: New linkages between business model and transition research. *Journal of Cleaner Production,* vol. 178, pp. 903–916. Available at: https://doi.org/10.1016/j.jclepro.2017.12.198, accessed 05.09.2020.

BMU (2018) *Waste Management in Germany 2018*, Berlin: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Available at: https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/abfallwirtschaft_2018_en_bf.pdf, accessed 26.06.2020.

Corvellec H. (2016) A performative definition of waste prevention. *Waste Management*, vol. 52, pp. 3–13. Available at: https://doi.org/10.1016/j.wasman.2016.03.051, accessed 05.09.2020.

Engel J., Szech N. (2017) *Little Good is Good Enough: Ethical Consumption, Cheap Excuses, and Moral Self-Licensing* (GEABA Discussion Paper 17-28), Frankfurt*: German Economic Association of Business Administration.* Available at: http://www.geaba.de/wp-contect/uploads/2017/07/DP_17-28.pdf, accessed 05.09.2020.

European Commission (2020) *Circular Economy Action Plan: For a cleaner and more competitive Europe*, Brussels: European Commission. Available at: https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf, accessed 26.06.2020.

Fontagné L., von Kirchbach F., Mimouni M. (2001) *A First Assessment of Environment-Related Trade Barriers* (CEPII Working Papers 2001-10), Paris: CEPII. Available at: https://ideas.repec.org/p/cii/cepidt/2001-10.html#download, accessed 26.06.2020.

Frost & Sullivan (2019) *Smart cities. Frost & Sullivan Value Proposition*, Mountain View, CA: Frost & Sullivan. Available at: https://ww2.frost.com/wp-content/uploads/2019/01/SmartCities.pdf, accessed 26.06.2020.

GTAI (2019) *German Trade and Invest. Environmental technologies in Germany. Fact sheet issue 2019/2020*, Berlin: Federal Ministry for Economic Affairs and Energy. Available at: https://www.gtai.de/resource/blob/64490/603917f069008c31cbf0e732983b0427/fact-sheet-environmental-technologies-en-data.pdf, accessed 26.06.2020.

Gupt Y., Sahay S. (2015) Review of extended producer responsibility: A case study approach. *Waste Management and Research*, vol. 33, no 7, pp. 595–611. Available at: https://doi.org/10.1177/0734242X15592275, accessed 26.06.2020.

Heymann E. (2020) *E-mobility: Remaining a niche phenomenon for now – at least without subsidies,* Frankfurt: Deutsche Bank. Available at: https://www.dbresearch.com/PROD/RPS_EN-PROD/PROD0000000000503906.pdf, accessed 26.06.2020.

ITA (2017) *U.S. Department of Commerce – International Trade Administration. ITA environmental technologies top markets report,* Washington, D.C.: International Trade Administration. Available at: https://legacy.trade.gov/topmarkets/pdf/Environmental_Technologies_Top_Markets_Report2017.pdf, accessed 26.06.2020.

Kirchherr J., Reike D., Hekkert M. (2017) Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, vol. 127, pp. 221–232. Available at: https://doi.org/10.1016/j.resconrec.2017.09.005, accessed 26.06.2020.

Lewandowski M. (2016) Designing the Business Models for Circular Economy – Towards the Conceptual Framework. *Sustainability*, vol. 8, art. 43. Available at: https://doi.org/10.3390/su8010043, accessed 26.06.2020.

Lifset R., Graedel T.E. (2002*)* Industrial Ecology: Goals and Definitions. *A Handbook of Industrial Ecology* (eds. R.U. Ayres, L.W. Ayres), Cheltenham: Edward Elgar Publishing. Available at: https://doi.org/10.4337/9781843765479.0000, accessed 26.06.2020.

MAF (2013) *Towards the Circular Economy,* Cowes (UK): Ellen MacArthur Foundation. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf, accessed 26.06.2020.

MAF (2020) What is Circular Economy. Available at: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy, accessed 26.06.2020.

Meadows D.H., Meadows D.L., Randers J., Behrens III W. (1972) *The Limits to Growth*, New York: Universe Books.

Pearce D.W., Turner R.K. (1989) *Economics of natural resources and the environment*, Baltimore, MD Johns Hopkins University Press.

Plastinina I., Teslyuk L., Dukmasova N., Pikalova E. (2019) Implementation of Circular Economy Principles in Regional Solid Municipal Waste Management: The Case of Sverdlovskaya Oblast (Russian Federation). *Resources,* vol. 8, art. 90. Available at: https://doi.org/10.3390/resources8020090, accessed 26.06.2020.

Preston F., Lehne J., Wellesley L. (2019) *An Inclusive Circular Economy: Priorities for Developing Countries,* London: Chatham House. Available at: https://www.chathamhouse.org/sites/default/files/publications/research/2019-05-22-Circular%20Economy.pdf, accessed 26.06.2020.

Sandin G., Peters G.M. (2018) Environmental impact of textile reuse and recycling – A review. *Journal of Cleaner Production*, vol. 184, pp. 353–365. Available at: https://doi.org/10.1016/j.jclepro.2018.02.266, accessed 26.06.2020.

Sarc R., Curtis A., Kandlbauer L., Khodier K., Lorber K.E., Pomberger R. (2019) Digitalisation and intelligent robotics in value chain of circular economy-oriented waste management – A review. *Waste Management*, vol. 95, pp. 476–492. Available at: https://doi.org/10.1016/j.wasman.2019.06.035, accessed 26.06.2020.

Sovacool B.K. (2019) Toxic transitions in the lifecycle externalities of a digital society: The complex afterlives of electronic waste in Ghana. *Resources Policy*, vol. 64, art. 101459. Available at: https://doi.org/10.1016/j.resourpol.2019.101459, accessed 26.06.2020.

Stack M., Gartland M.P. (2003) Path Creation, Path Dependency, and Alternative Theories of the Firm. *Journal of Economic Issues*, vol. 37, no 2, pp. 487–494. Available at: http://www.jstor.org/stable/4227913, accessed 26.06.2020.

Tencati A., Pogutz S., Moda B., Brambilla M., Cacia C. (2016) Prevention policies addressing packaging and packaging waste: Some emerging trends. *Waste Management*, vol. 56, pp. 35–45. Available at: https://doi.org/10.1016/j.wasman.2016.06.025, accessed 26.06.2020.

UN (2020) *Green Economy,* Geneva: United Nations. Available at: https://www.unenvironment.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-economy, accessed 26.06.2020.

Van Ewijk S., Stegemann J.A. (2016) Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Absolute Reductions in Material Throughput, Energy Use and Emissions*, vol. 132, pp. 122–128. Available at: https://doi.org/10.1016/j.jclepro.2014.11.051, accessed 26.06.2020.

Wiesmeth H. (2020) *Implementing the Circular Economy for Sustainable Development,* Amsterdam: Elsevier. Available at: https://www.elsevier.com/books/implementing-the-circular-economy-for-sustainable-development/wiesmeth/978-0-12-821798-6, accessed 26.06.2020.

Wilts H. (2012) National waste prevention programs: indicators on progress and barriers. *Waste Management and Research*, vol. 30, pp. 29–35. Available at: https://doi.org/10.1177/0734242X12453612, accessed 26.06.2020.

Wilts H. (2016) *Germany on the Road to a Circular Economy?,* Bonn: Friedrich-Ebert-Stiftung. Available at: https://library.fes.de/pdf-files/wiso/12622.pdf, accessed 26.06.2020.

Yuan Z., Bi J., Moriguichi Y. (2006) The Circular Economy: A New Development Strategy in China. *Journal of Industrial Ecology*, vol.10, no 1–2, pp. 4–8. Available at: https://doi.org/10.1162/108819806775545321, accessed 26.06.2020.

Zhu D. (1998) The circular economy and Shanghai's countermeasures. *Social Sciences*, vol. 10, pp. 13–17. Available at: https://ci.nii.ac.jp/naid/10019327337/en/, accessed 26.06.2020.

Zink T., Geyer R. (2017) Circular Economy Rebound. *Journal of Industrial Ecology*, vol. 21, no 3, pp. 593–602. Available at: https://doi.org/10.1111/jiec.12545, accessed 26.06.2020.

Adoption of Industry 4.0 Technologies and Company Competitiveness: Case Studies from a Post-Transition Economy

Marta Götz

Associate Professor, Department of Business and International Relations, m.gotz@vistula.edu.pl
Vistula University, ul. Stokłosy 3, 02-787 Warszawa, Poland

Barbara Jankowska

Associate Professor at the Department of International Competitiveness, barbara.jankowska@ue.poznan.pl
Poznań University of Economics and Business; al. Niepodległości 10, 61-875 Poznań, Poland

Abstract

Manufacturers face increased cost pressures and market volatility. Product life cycles are getting shorter. Production has to be faster and increasingly local. The acceleration of «time-to-market» could happen thanks to the solutions of Industry 4.0 (I4.0), with supply chains morphing into highly adaptive networks with integrated entities. In this paper, we seek to explore the potential impact of I4.0's adoption upon the competitiveness of the firms (foreign subsidiaries among others) and ask about the nature of modernization as part of the global value chain in which the enterprise operates. Our research based on four case studies reveals that the competitive advantage of a firm could be modified in the era of Industry 4.0 as a result of a sector's transformation and changing relationships with partners. These findings correspond with the literature stressing the uncertainty and complexity of the digital economy in general, as well as difficulties with the precise measurement of the expected benefits. The fourth industrial revolution emphasizes «the race to the top», giving priority to quality rather than to cost reduction as a method of improving competitiveness and, since it implies the emergence of connected companies, truly linked to one another, the disappearance of clear boundaries between them.

eywords: Industry 4.0; digital technologies; post-transition economy; manufacturing; case study; competitiveness; product life cycle

Citation: Götz ., Jankowska B. (2020) Adoption of Industry 4.0 Technologies and Company Competitiveness: Case Studies from a Post-Transition Economy. *Foresight and STI Governance*, vol. 14, no 4, pp. 61–78.
DOI: 10.17323/2500-2597.2020.4.61.78

Manufacturers face increased cost pressure and market volatility. Product life cycles are getting shorter. Production must be faster and increasingly local. New business models based on manufacturing as a service (MaaS) have emerged [*Aquilante et al.,* 2016]. The acceleration of "time-to-market" could happen thanks to the solutions of Industry 4.0 (I4.0), with supply chains morphing into highly adaptive networks with integrated entities. What is different about the current revolution from previous ones is that it has been initiated in society and has influenced industry rather than other way round – "its main drivers are the invention of social networks and smart devices (…) this development of interconnectivity pushes into the industrial sector today" [*Schuh et al.*, 2014]. The results obtained by *Edquist et al.* [*Edquist et al.,* 2019] demonstrate that a 10-percentage-point increase in the growth of Internet of Things (IoT) connections (regarded as one of the major I4.0 technologies) per inhabitant is associated with a 0.23-percentage-point increase in TFP growth. Additionally, drawing on a growth-accounting framework, these authors showed that the potential global annual average contribution to growth by the IoT of 0.99% per annum between 2018 and 2030.

In this paper, we seek to identify how much I4.0 has been adopted by the companies in the study, how much they understand the concept of I4.0, and thus, we aim to demonstrate the potential impact of I4.0's adoption upon the competitiveness of the firms. We also attempt to ask about the nature of modernization as part of the global value chain in which the enterprise operates.

Premises of Industry 4.0

Industry 4.0 represents a smart manufacturing networking concept that "marries physical production and operations with smart digital technology, machine learning, and big data to create a more holistic and better-connected ecosystem for companies that focus on manufacturing and supply chain management."[1] The term I4.0 emerged in Germany during the Hannover Fair (originally – Industrie 4.0). However, other countries adopted slightly different terminology – "Industrial Internet" in the United States and "Internet +" in the People's Republic of China [*Wang et al.*, 2016]. I4.0 is founded upon four key sub-concepts: Cyber-Physical Systems (CPS), the Internet of Things, the Internet of Services, and Smart Factories [*Hermann et al.,* 2015]. Since from a technical point of view much of I4.0 is about digitization and automation, the transformation of contemporary business models is to be expected. Such a transformation has already begun and is reflected in the development of digital value chains [*Lasi et al.*, 2014]. This has all happened since companies began exploiting the nine technology advances which are the backbone of I4.0: Big Data and Analytics; Autonomous Robots; Simulation; Horizontal and Vertical System Integration; The Industrial Internet of Things; Cybersecurity, the Cloud; Additive 3D Manufacturing; and Augmented Reality [*Rüßmann et al.*, 2015]. Smart technologies used in the manufacturing processes are translated into holistic digitalized models of products and factories (digital factory) [*Lasi et al.*, 2014; *Lucke et al.*, 2008] (see examples at Table 1).

Various studies confirm that companies face significant challenges in managing their digital transformation. Based on a survey of nearly 200 large and medium-sized Slovenian companies, Štemberger et al. [*Štemberger et al.,* 2019] showed that there are six different successful organizational patterns. The most successful turned out to be the business–IT partnership, where the CEO and the IT department are jointly responsible for the digital transformation. The results obtained also demonstrate the need for orchestrating the activities and actors of digital transformations.

I4.0 stands for a multidimensional system of value creation covering numerous terms in the management of organizational as well as technological and manufacturing-related variables that can be classified and where several interdependencies between them may be identified [*Nosalska et al.,* 2019]. This transforms current business models since, as noted by [*Kagermann et al.*, 2013], it requires companies to reorganize the context of their operations and their own strategic capabilities. Thus, actions in both directions– externally and internally oriented efforts – are needed.

The complexity of I4.0 comes in many forms and shapes. The current understanding of the nature of Industry 4.0 is still blurred with various uncertainties arising, which leads to different scenarios seeming equally possible today [*Culot et al.,* 2020]. It can be depicted by the holistic digitalized models – business models which use VR, AR, or digital twins but at the same time incorporate digital change into HR or broader management processes, not merely in production. I.40 more than ever before highlights the importance of interdependencies between the structure of the industry and the performance of companies. Mutual interlocking relations between processes going on within the sectors and those occurring at the firm level turned out to be critical for the successful implementation of digital technologies due the integrative nature of I4.0 solutions [*Kagermann et al.,* 2013; *Rüßmann et al.,* 2015]. The ability to control digital structures, information availability, and information access would also influence firm boundaries or even constitute new forms of firm boundaries [*Leih et al.,* 2015]. Assets (information) and control (through digital structures) might not any longer lie within company's boundaries but result from some forms of integration. Thus, new concepts of firm boundaries may be required, such as the "open business model" [*Chesbrough,* 2006]. Moreover, adjacent concepts such as networks or platforms have already commanded increasing importance [*Zott et al.*, 2011].

The new industrial revolution shifts our attention from studying simple classical supply buyer-seller relations to seeing them as a whole system and network of value creation and value capturing among co-opetitive players. Hence, the complexity of production networks depicts the number of relations, the non-linearity of such relations, the rapidly changing positions within networks, and hence the necessity of agile approaches and lean management.

I4.0 also implies that competitiveness and competitive advantages arise not simply from owned assets as merely seen in the approach of 'firm as a bundle of resources' but derives from seeing it as part of digital ecosystem. At the same time, I4.0 can stimulate both, the efficiency-driven advantages and innovation-driven advantages. Whereas the first are built upon providing goods and services more efficiently – faster, cheaper, or more flexibly the latter are created by offering new improved products with novel functionalities.

Firm Competitiveness from Different Perspectives

As argued by WEF experts [WEF, 2019], those company leaders called Lighthouses, who move to implement I4.0 technologies very early, will realize the greatest benefit. The competitive advantage of front-runners will by far outweigh the higher transition costs and capital expenditures related to the early adoption of I4.0 solutions. Bearing in mind the nature, key features, and trends characteristic of the fourth industrial revolution, we refer to the industrial organization (I/O), resource-based view (RBV), and Global Value Chain (GVC) perspectives to study the sources of competitive advantage.

Industrial Organization Perspective

The I/O model shows that a firm's performance is greatly determined by the industry or business sector it is in and the factors that define the intensity of rivalry within the industrial operations corresponding to S-C-P (structure-conduct-performance). This paradigm, formulated by [*Bain,* 1956; *Mason,* 1939], demonstrates the interdependencies between the structure of the industry and the performance of companies [*Bain,* 1956]. It was supplemented by the initial conditions that reflected the circumstances in the demand and supply side of the market [*Stead et al.*, 1997, p. 4]. The initial circumstances embrace technological factors among others. Thus, the aspects of I4.0 according to this old paradigm will greatly determine the structural characteristics of the industry as well as the behavior and performance of firms. To identify the impact of I4.0 upon the structural characteristics of an industry, firms can use the analytical model of the five competitive forces and the value chain concept developed by M.E. Porter [*Porter,* 1979]. The five competitive forces model indirectly affects the challenges and opportunities of integration that are typical for the fourth industrial revolution. The integration that is possible thanks to automation may facilitate the performance by firms of more complex and advanced yet agile roles. Related to this, the value chain concept recognizes a company as a chain of interdependent processes – primary and supportive activities – as well as sees the whole industry as a value network that is dedicated to the creation of margin for companies thanks to providing broadly understood value for customers. Both these spheres are nowadays permeated by digitalization.

Resource-Based View (RBV) Perspective

The second perspective that is useful when looking for a conceptual framework to explain the mechanism for the impact of I4.0 upon firms' competitiveness is the resource-based view (RBV) of companies (e.g., [*Barney,* 1991; *Barney, Arikan,* 2005; *Wernerfelt,* 2013]). The foundation of the RBV is the theory, perceiving a firm as a bundle of resources that are heterogeneous [*Penrose,* 1959; *Teece,* 2017]. The RBV postulates the necessity of resource ownership (e.g., [*West et al.*, 2014]) to gain an advantage over competitors. To achieve and keep any competitive advantage, firms have to possess heterogenous, unique, difficult to imitate, and immobile resources which is reflected in the VIRO concept (Valuable, Inimitable, Rare and Organized). Amit & Schoemaker [*Amit, Schoemaker,* 1993] pointed to the fact that industries differ in their characteristics which is why the bundle of resource creating superior performance will differ between industries, too.

Global Value Chain (GVC) Perspective

The concept of GVCs incorporates processes of fragmentation among a growing number of countries and production networks, the development of global buyers and global suppliers [*Lee, Gereffi*, 2015] and also contributes to our understanding of the impact of the digital revolution upon the interactions and relations between companies, in particular cooperating partners. One of the important aspects emerging from relations between entities in a GVC is the compatibility of partners and the ability to keep up with the pace of transformation. The classic five competitive forces model [*Porter,* 1979] can be used for examining the relations between competing and cooperating entities in the reality of

[1] https://www.epicor.com/en/resource-center/articles/what-is-industry-4-0/, access date 15.10.2020.

Table 1. **Examples of Digitalized Models of Products and Factories**

Models / Tools	Sources
Software for production planning and scheduling (e.g., ERP); systems for the automation and management of internal logistics (e.g., RFID)	[*Lasi et al.*, 2014]
New systems in the development of products and services	[*Lucke et al.*, 2008]
Product Lifecycle Management Systems (PLM)	[*Tchoffa et al.*, 2016]
Mobile/wireless devices for programming and the operation of equipment and machinery	[*Drath, Horch*, 2014]
Digital solutions in production (e.g., tablets, smartphones)	[*Drath, Horch*, 2014].
Source: authors› own elaboration.	

the fourth industrial revolution. The literature covering the GVC concept is steadily growing. A study by Éltető, Magasházi & Szalavetz focuses on the topic of upgrading within GVCs [*Éltető et al.*, 2015] which is associated with a move from a lower value-added activity towards a higher value-added one. Humphrey & Schmitz [*Humphrey, Schmitz,* 2002] distinguished four main types of upgrading: product, process, functional, and inter-sectoral upgrading. The types of upgrading are often interlinked; sometimes they overlap or are derived from each other. Another factor that can increase profits in value chains is economies of scale. It is possible that aggregating orders and increasing the volume of sales leads to product 'downgrading', which means that larger amounts of products may generate lower value products.

Firm Competitive Advantage and the New Context of Industry 4.0

The development of I4.0 technologies is supposed to increase industrial productivity and further generally improve company performance. Firms have to think how the new technologies will impact their bargaining position within their industries and how they will reorganize their strategic capabilities. In 1985, Porter & Millar argued that the information revolution modifies the structure of business sectors, greatly impacting the bargaining power of incumbents, their suppliers, customers, substitute providers, and potential new entrants [*Porter, Millar,* 1985]. It also creates new ways to outperform rivals. Thirdly, it restructures internal processes within the value chain and firm's resources and competences. The key manifestations regarding the impact of the information revolution upon firms as listed by Porter and Millar 35 years ago are still visible today. The key manifestations regarding the impact of the information revolution upon firms as listed by Porter and Millar 35 years ago are still visible today [*Porter, Heppelmann,* 2015].

I4.0 technologies will on one hand put pressure on companiI4.0 technologies will on one hand put pressure on companies to upgrade their strategic capabilities, and on the other, they will simultaneously contribute to that upgrading. Simulation is characteristic of I4.0 and supports virtual world testing so as to predict and evaluate the performance of systems that are analytically intractable, underlining the efficiency gains for firms thanks to the integration of sensing, computing, and control. Companies are better able to track customers' needs and procurement orders in real time. Companies are better able to track customers' needs and procurement orders in real time. I4.0 impacts the receiving and storing of components and moving them to production, along with the distribution of the products. RFID technology and intelligent applications based on user community information rather than on GPS data help to save time and avoid bottlenecks. Thus, intra- and inter-firm logistics is an area where companies may achieve substantial gains [*Skapinyecz et al.*, 2018]. The whole value chain can operate more efficiently thanks to digitalization that modifies the intra- and inter-firm logistics, along with production processes that exploit the raw materials and sub-assemblies previously ordered. These modifications respond to the expectations that firms learn about from customers thanks to the Internet of Things and their use of social media. The Internet facilitates the emergence of a digital ecosystem embracing suppliers, manufacturers, and customers. This ecosystem is associated with the notion of a smart factory and optimized real-time new value creation networks. Factories that merit the smart concept are able to adjust their operations to constantly changing circumstances. They are no longer single production units but operate like fully automated, optimized, high-efficiency integrated units which is very much possible thanks to cloud computing. Thus, I4.0 results in the emergence of virtual, horizontally integrated Value Networks.

Big Data and Analytics Implementation can contribute to the reorganization of the sales and marketing operations of a firm and facilitate an even earlier impact upon the focus, scope, and direction of R&D operations within a firm. PwC [PwC, 2016] conducted a study confirming that 72% of the respondents to their survey use data analysis to improve their relationships with customers. The development of new products driven by the customers' preferences and feedback reflected in the huge pool of data gathered by companies may be reinforced by additive 3D manufacturing that enable companies to produce prototypes and individual components that support 3D printing. Thanks to this, firms can moderate their costs by reducing the stock which impacts their procurement operations, manufacturing processes, and internal logistics. These operations within the value chain can become more efficient, which is crucial from the perspective of the margin for a company and to further its competitiveness. Augmented Reality (AR) that combines physical real-world information with virtual information generated by computers [*Craig,* 2013; *Schmalstieg, Hollerer,* 2016] helps firms in decision making since it provides instructions on how to carry out different tasks related to warehousing and maintenance for example, thus visibly impacting the efficiency of value chain operations. Big data analytics enables businesses to discover customers' requirements, conduct market research, and support the simulation and testing of new products with 3D printing supporting prototyping that contributes to the shortening of the product development lifecycle [*Qin et al.,* 2016]. Companies able to develop new products faster and launch them earlier than their competitors gain an advantage [*Rubera et al.*, 2016]. Qin, Liu & Grosvenor [*Qin et al.,* 2016] describe how I4.0 solutions very much develop flexible prototyping capabilities thanks to 3D printing combined with cad-cam designing and flexible machining capabilities.

The competitiveness of firms may be related to efficiency-driven advantages or innovation-driven advantages. In the fourth industrial revolution the efficiency-driven advantages are the threshold advantages that may create competitive gaps between aggressively competing firms. But the gaps can disappear relatively quickly which means the advantages are temporary. A sustainable advantage is founded on knowledge and innovation. The companies need to recognize the need to reorganize their cooperation with suppliers and customers. The new I4.0 solutions enable firms to constantly communicate with their suppliers and customers; however, new collaboration models with business partners need to be developed. To fully exploit the whole set of I4.0 technologies, firms need to take care of their relationships with business partners at each stage in value creation – from research and development, procurement, and production up to sales, marketing and after-sales services. This is related to the implementation of integrated information systems, and the key resources are human resources with new qualifications to drive, produce, and maintain I4.0 systems. All qualified human resources need to be equipped with a knowledge of the IoT, robotics, blockchains, as well as manufacturing.

I4.0 solutions contribute to the integration of the various operations in a company to increase the flow of information within a firm. They also contribute to the integration with suppliers, customers, and other partners in the value chain. These systems support better information sharing within a company – between departments – which is crucial for the integration of data, processes, and technology in real-time that allows for the standardization of various procedures and practices [*Gërvalla, Ternai,* 2019]. Internal integration – vertical in nature since it means the integration of resources – is based on the connection of production management, manufacturing, and low-level PLC (Programmable Logic Controller) systems like machine controllers, sensors, and so on. The aspect of integration may be associated with organized resources that are highlighted in the RBV. The stronger vertical integration of resources increases the exclusivity of the resources, which further adds to the competitive advantage of the firm. Also, the horizontal integration that is reflected in such integration, first in operations within the firm's value chain and second with external partners, makes the position of a particular firm within its industry stronger and therefore contributes to its competitive advantage. A firm is no longer a standalone unit, but a unit integrated with other entities; and so, relationships with external partners when exploiting IT solutions adds to the flexibility and agility of each of the entities involved in the value creation process. Thus, this translates into the competitiveness of firms.

A prerequisite for competitive gains is the regulation and possible neutralization of cybersecurity threats. The I4.0 technologies involve machine controllers, sensors, manufacturing lines, and other devices that are interconnected and based on the same standards and communication protocols. This interconnectedness not only provides gains, but also new challenges and threats as well. The managers of the GVC may reorganize and diversify or develop certain parts. Innovation is not an extraordinary activity anymore but a continuous process which is crucial from the perspective of company survival. Upgrading is initiated by affiliates and reflects a bottom-up process, while governance is a top-down process triggered by the leading firm [*Lee, Gereffi,* 2015]. But from a different perspective, governance may be the domain of the producer or the buyer [*Gereffi, Korzeniewicz,* 1994]. The simple and dual typology became unsatisfactory for many GVCs since production networks are more complex. To face the complexity of production networks, Gereffi *et al.* [*Gereffi et al.,* 2005] defined five types of governance: market, modular, relational, captive, and hierarchical. The first type of governance depends upon transactions where the main governing mechanism is price. Participants are not involved in any formal cooperation [*Gereffi et al.,* 2005]. Modular governance means that suppliers follow the customers' specifications when providing products or services. The product is more sophisticated but still sufficiently modular in design. Suppliers are fully responsible for production and produce independently. However, they may further outsource production. Complex interactions between the supplier and the lead-firm are characteristic of relational governance. Thanks to these interactions, firms exchange tacit knowledge and knowledge spill-overs occur. The lead firm controls the highest valued activity in the chain and defines the specifications of products [*Cattaneo et al.*, 2013]. In the case of captive governance, the lead firm is much involved in the control and monitoring of suppliers. A single lead-firm within a network creates rather unstable circumstances for small firms and these entities may sometimes feel "locked-in". Lead-firms are eager to increase the efficiency of their supply chains. Thus, they assist suppliers in upgrading. Vertical integration and managerial control among firms is then a distinguishing feature of hierarchical governance. This is necessary when products are complex, when it is difficult to codify product specifications and to find competent suppliers [*Cattaneo et al.*, 2013].

A study by Szalavetz [*Szalavetz,* 2017a] investigated the impact of I4.0 – new disruptive technologies – on the current geographical configuration of GVCs from the perspective of FDI-hosting intermediate-level 'factory economies'. A crucial challenge lies in how GVC headquarters realign their strategic location choices with the emergence of the new manufacturing technologies: whether they keep their existing manufacturing facilities and upgrade them through installing I4.0 technologies (retention); consolidate and concentrate manufacturing activities in specific locations (selection); or refresh part of their activities and at the same time establish new facilities and/or outsource certain tasks (reconfiguration). Based on the interviews with Hungarian firms, the author concluded that, in the short term, retention mechanisms seem to prevail over harmful scenarios such as specific location selection or a reconfiguration. It remains open, however, whether or not this will be replaced by medium- and longer-term reconfigurations of GVC architectures. This calls for necessary reforms of the education systems in factory economies. Failure to provide adequately skilled workers and aligning training with skill demands may eventually hinder the adoption of I4.0 resulting in the relocation of activities. As summarized by [*Szalavetz,* 2017b], it is not I4.0 technological progress per se that may hit factory economies hard: the lack of human capital coupled with a rigid education system would make them losers in the digital transformation of manufacturing.

Methodology of Our Study

Although research on I4.0 is gaining an increasing amount of attention and studies in this area have been proliferating recently, to the best of our knowledge they still do not explicitly or fully cover the impact of the digital transformation upon the competitiveness of firms in an international cooperation context. Although exploring various aspects of I4.0, the available reports and impressive databases gathered by consultancies and private firms such as Siemens, BCG [*Lorenz et al.,* 2015], McKinsey [*Breunig et al.,* 2016], Polish ASTOR [*Zieliński*, 2016] and the initiative Przemysl-4.0.pl do not seem to focus on the questions and problems raised in our research.

The goal of our exploratory empirical study is to explore the potential impact of I4.0's adoption upon the competitiveness of firms. This research also asks about the nature of modernization as part of the global value chain in which enterprises operate. Thus, we want to take into account the likely drivers of I4.0 implementation at companies and diagnose the pervasiveness of this ongoing revolution.

The methods and techniques used in this study were determined by the research questions formulated in [*Collis, Hussey,* 2014]. We base our research on the case study research method into four companies. The case study method allows the results of previous research to be combined with new empirical insights [*Andriopoulos, Slater,* 2013]. Mowday & Sutton [Mowday, Sutton, 1993] point out that the context of a case study functions as a unit of analysis over and above the phenomena under study; and as Cappelli & Shere [*Cappelli, Shere,* 1991] indicate, this often explains some hidden non-obvious and salient aspects of the phenomena. Thus, the whole case study predisposes the researcher to study the phenomenon in its natural circumstances and further allows them to formulate new practically and empirically valid insights [*Miles, Huberman,* 1994].

Blumberg et al. [*Blumberg et al.,* 2011] highlight the key features of a properly classified academic study as exploratory, descriptive, and analytical/predictive of the phenomenon it is focused on studying. In our study we focus on four cases – Viacon Polska, Amica, Kompania Piwowarska (KP), and Unilever – and this type of approach is the proper one bearing in mind the interdisciplinary character of the fourth industrial revolution. We refer to some extent to the quantitative approach using a structured questionnaire where we ask the interviewees to respond and explain particular phenomena using a five-point Likert scale. We use narrative descriptions with elements of comparison and exploit the multiple case study approach. We perceive our research as exploratory since it is to investigate the context in which the process of the implementation of the I4.0 solutions occurs. The selected cases are to help us understand the phenomenon under study [*Siggelkow,* 2007]. To better characterize the context for each case study, we refer to secondary data on

[2] https://przemysl-40.pl/, access date 29.10.2020.

the impact of I4.0 on companies in the new industrial reality. We rely on officially available information provided mainly on company websites and to a greater extent on the primary data and information acquired from them during direct interviews with their representatives. The selection of cases for our study was determined by the goal of the study. Purposive sampling was necessary since the adoption of I4.0 technologies and solutions differs among companies representing different business sectors as well as being more or less linked to foreign capital. The origin of the capital, and thus the location of headquarters in countries that differ in terms of their readiness for the fourth industrial revolution, seems to be an important factor explaining the greater or lesser involvement of a company in the fourth industrial revolution.

Our interviews were designed to speak for the uncertainty and complexity of the fourth industrial revolution. The aspects covered reflect namely the multifaceted and multidimensional nature of I4.0. The implementation of I4.0 is a multi-scalar phenomenon with various players involved along the GVC and different technologies used. The obtained results show that surveyed firms may indeed face the challenges that such uncertainty and complexity bring along. They seem for instance only a little familiar with I4.0-related behavior of their partners – cooperating and competing entities. Yet, they also acknowledge the existence of other framework conditions necessary for the successful implementation of digital technologies – as I4.0 comes with strings attached.

Case Analysis: Industry 4.0 Adoption from the Perspective of the Studied Companies[2]

Table 2 represents a general description of Industry 4.0-induced changes across different dimensions among the studied firms, while Tables 3-6 accompanying each of the below represented cases summarize their specific features in the context of the relevant firm.

ViaCon

ViaCon[3] in Poland consists of three companies: ViaCon Sp. z o.o., ViaCon Polska Sp. z o.o., and ViaCon Construction sp. z o.o. All these companies are members of the ViaCon Group, established in Sweden and Norway in 1986. ViaCon specializes in manufacturing steel and plastic pipes, galvanized plate structures for bridges and tunnels, geotextiles, geogrids, and geocomposites among other things for soil drainage and filtration, as well as grids to reinforce bituminous and asphalt pavements. All these products are manufactured in accordance with international standards – ISO 9001:2008, ISO 14001:2004, and OHSAS 18001 – and some products have the CE mark. ViaCon can be classified as an OEM with majority foreign capital and the company is listed on the stock exchange. It exports and cooperates with foreign markets by setting up wholly owned foreign subsidiaries. The company itself is a subsidiary of a multinational enterprise.

ViaCon is actively implementing a digital transformation – its employees, as in the rest studied firms, actively use digital equipment. Besides, the company uses such technologies as Big Data, Cloud Computing, Mobile Technologies, and Social Media. Systems such as customer support systems (CRM) and enterprise resource planning (ERP) are considered those most affected by the technological progress and Industry 4.0. (ViaCon exploits only some of the nine solutions that characterize Industry 4.0 – Big Data and Analytics, Cybersecurity, Cloud, abstaining currently from Autonomous Robots, Simulation (virtual mirror), Horizontal and Vertical System Integration, Industrial Internet of Things, Additive Manufacturing 3D, or Augmented Reality). ViaCon (based on agree/strongly agree) plans to restructure employment because of Industry 4.0 and it admits facing the challenge of cybersecurity and know-how protection. ViaCon reaps advantages from cost reduction resulting from Industry 4.0, from the improvement of efficiency as well as the reduction of the time necessary to perform particular processes. The company seeks to network its value chain and admits to feeling pressure on cost reduction and recognizes legal barriers originating in Industry 4.0, which protects the company. Besides, it does expect to get some support from the government to face the threats of Industry 4.0. ViaCon dedicates particular human resources to monitoring and coping with the challenges of Industry 4.0 and has designed strategic responses to the challenges of Industry 4.0. It organizes special training sessions for improving the automation of manufacturing processes and tries to optimize the administrative processes (i.e., the flow of documents). It admits to dealing with a shortage in personnel able to cope with Industry 4.0 and the need to invest money in research and development under the new pressures presented by this paradigm. ViaCon needs to increase investment expenditures (i.e., new machines, tools, equipment).

In ViaCon's opinion, their suppliers have problems related to the reorganization of manufacturing processes or being an outsider with regard to the GVC, yet they can also see the opportunity for becoming a GVC insider thanks to the Industry 4.0 and may feel the pressure to shorten the value chain. Cer-

[3] The presented findings derive from the results of our survey but they should be regarded as the authors' interpretation based on the interviewers' answers, not necessarily reflecting the firms' official stance.

[4] http://viacon.pl/en, access date 29.10.2020.

Table 2. **Industry 4.0-Induced Changes across Different Dimensions among the Studied Firms**	
Aspect	**Description**
I4.0 implementation level (RBV)	New technologies adopted (tendency of patchy implementation, gradual, fragmented, though, it is similar across firms) possibly reshape the firms› resources (as used by staff and impacting adopted managerial systems) and hence affect their competitive advantage.
Effects/benefits expected (RBV)	New products/new improved processes – efficiency gains enabling new/improved competitive advantages (resources better allocated, more effectively used).
Risks & challenges (RBV)	I4.0 implies active management in order to improve the competitive advantage of available resources (capital investments and labor training are necessary).
Industry reshuffling landscape (I/O)	Ambiguity regarding the position of partners in industry due to I4.0, both chances and challenges are acknowledged; unclear approach to the necessity of mimicking reaction due to I4.0 transformation.
Industry partners relations (I/O)	Ambiguity as to the governmental support, widespread pressure from partners to climb the value chain and better network with each other.
Value chain repositioning and I4.0 induced chances for international expansion (GVC + RBV + IO)	Diverse opinions on actors' role in initiating the digital transformation changes; I4.0 potential for streamlining international business acknowledged.
Source: authors› own elaboration.	

tainly, in the opinion of ViaCon, the buyers feel pressed to look for new distribution channels and the uncertainty because of the possible reduction of economic advantages. Yet thanks to I4.0, they can also enjoy the opportunity to increase sales and improve competitiveness. As seen by ViaCon, the producers of substitutes reorganize their manufacturing processes and their business models. Further they also expect to improve their innovative performance. Last but not least, ViaCon improves its products and processes (i.e., a new technology allows the firm to increase efficiency). The pressure of business partners seems to make the firm move toward more knowledge-intensive functions. It performs more diverse functions and tries to go global while also moving into new business sectors.

ViaCon perceives all these changes as mainly the initiative of the firm itself. It admits also that changes are initiated by the key manufacturer in the value chain who owns the knowledge and expertise, nevertheless changes are also initiated by the buyer who controls the distribution channels and very much influences the marketing functions. The relationships of the firm with business partners are modular – the firm supplies products according to the specifications of the subcontractor. ViaCon strongly disagrees with the statement that the relationships of the firm with business partners are based on hierarchy – there are no external suppliers and cooperation takes place within the internal network of the firm. The company agrees that autonomous robots allow one to repatriate the manufacturing processes, Big data allows for better market research and making more effective investment decisions, whereas additive manufacturing allows one to shorten the value chain. Summing up, interestingly, the company does not seem to care much about the I4.0-related behavior of other firms. The lack of funds for the necessary training of employees does not seem to be a concern for the firm. The situation of firm's buyers, which seem to be very much affected by I4.0, is well-known. Relatively less clear or less known is the situation concerning the company's suppliers. Producers of substitutes, in the opinion of the firm, do not recognize digitalization as a threat for their present business models. The situation of substitute manufacturers seems to be less known for the firm. Adopting I4.0 will allow the company to develop and modernize in many diversified ways.

Amica S.A.

Amica S.A. was founded in 1945 in a small town near Poznań. Nowadays it is the largest Polish manufacturer of household appliances and one of the most recognized companies listed on the Warsaw Stock Exchange.[4] Amica belongs to those OEM and end-user companies with a majority of home market (Polish) capital. It belongs to the group of large private firms with more than 250 employees listed on the Warsaw Stock Exchange. Almost 70% of its sales are generated on export markets, while 30% are sold on the domestic market. Amica sells its products under different brand names, depending on the region. Its strategy is based upon building strong regional brands that are recognizable in the given country. Amica aims to become one of the top three cooking appliance producers in Europe with a planned sales revenue of EUR 1.2 billion by 2023. Amica uses all four major technologies, that is, Big Data, Cloud Computing, Mobile Technologies, and Social Media. Four different systems applied by the firm are all affected by I4.0 progress, i.e., customer support systems (CRM), enterprise resource planning (ERP), manufacturing execution systems (MESs), and energy management systems (EMS).

[5] https://www.amica.pl/en/page/15-Company, access date 29.10.2020.

Table 3. **Summary of Industry 4.0-Induced Changes: ViaCon**

Aspect	***Content***
I4.0 implementation level (RBV)	Customer support systems (CRM) and enterprise resource planning (ERP) are the ones most affected by I4.0. Some of the nine I4.0 solutions were adopted- Big Data and Analytics, Cybersecurity, Cloud; abstaining from Autonomous Robots, Simulation (virtual mirror), Horizontal and Vertical System Integration, Industrial Internet of Things, Additive Manufacturing 3D or Augmented Reality.
Effects/benefits expected (RBV)	Improving products and processes (i.e., new technology allows one to increase efficiency); cost reduction resulting from I4.0, improvement of efficiency as well as time reduction.
Risks & challenges (RBV)	Plans to restructure employment due to I4.0 Challenges of cybersecurity and know-how protection admitted/acknowledged Particular human resources dedicated to monitoring and coping with I4.0 challenges. Strategy to face the challenges of Industry 4.0 defined. Special training to improve automation provided. Actions aiming at optimizing administrative processes. Identified and acknowledged lack of professional workforce able to cope with Industry 4.0 and the need for R&D investments and expenditures on new machines, tools, and equipment amid I4.0 pressure.
Industry reshuffling landscape (I/O)	Suppliers suffering problems related to the reorganization of manufacturing processes or being an outsider of a GVC, yet with new opportunities to become an insider of the GVC thanks to the I4.0 and pressure to shorten the value chain. The buyers under pressure to look for new distribution channels due to the Industry 4.0 and facing uncertainty because of the possible reduction of economic advantages. Thanks to I.40, there is a possibility of enjoying the increase of sales and improvement of competitiveness. Producers of substitutes reorganizing their manufacturing processes and their business models may also improve their innovation performance.
Industry partners relations (I/O)	Seeking to network one's own value chain, pressure on cost reduction admitted. Legal barriers originating from Industry 4.0 which protect company recognized, expectations of some support from the government to face the threats of Industry 4.0. The pressure of business partners causing the firm to shift to more knowledge-intensive functions; performing more diverse functions and going global as well as moving into new business sectors.
Value chain repositioning and I4.0 induced chances for international expansion (GVC + RBV + IO)	All these changes perceived as mainly the initiative of the firm itself. Changes are initiated by the key manufacturer in the value chain who owns the knowledge and expertise, nevertheless, changes are also initiated by the buyer who controls distribution channels and influences the marketing functions. Modular relationships with business partners – the firm supplies products according to the specification of the subcontractor. Strong disagreement with the claim that the relationships of the firm with business partners are based on a hierarchy – there are no external suppliers and cooperation takes place within the internal network of the firm. Full agreement with the statement that autonomous robots allow one to repatriate manufacturing processes; big data allows one to better research the market and make more effective investment decisions, whereas additive manufacturing allows the firm to shorten the value chain.

Source: authors' own elaboration

Out of the nine solutions typical for I4.0, six have been used at Amica: Big Data and Analytics, Autonomous Robots, Horizontal and Vertical System Integration, Industrial Internet of Things, Cybersecurity, and Cloud Computing. Amica confirms monitoring competitors' approach to Industry 4.0, operating in industries with short product life cycles, and is planning to restructure employment because of Industry 4.0. It also seeks to face the challenge of cybersecurity and know-how protection while simultaneously trying to take advantage of the reduction of costs resulting from I4.0 from the improvement of efficiency or from the reduction of the time necessary to perform particular processes. It undertakes actions to better network its value chain and admits to feeling the pressure of cost reduction. It is, however, not convinced about the need for governmental support in order to cope with the possible threats of Industry 4.0 and does seem to face the lack of funding for I4.0 training for employees. In fact, the company dedicates particular human resources to monitoring and coping with I4.0 challenges, has a defined strategy for facing these challenges, and organizes special training to improve the automation of manufacturing processes. Furthermore, Amica seeks to optimize its administrative processes (i.e., the flow of documents). It admits to facing a lack of professional workforce able to cope with Industry 4.0 and hence is investing money in research and development. Not much is known about Amica's suppliers (a number of answers indicate "neither agree nor disagree") besides the fact that they do not seem – in Amica's eyes – to feel problems related to reorganization of manufacturing processes, the lack of proper infrastructure, and pressure to make longer value chains, if then to shorten them. Concerning the firm's buyers, the Amica representative agreed that they might experience pressure to look for new distribution channels because of Industry 4.0. In addition, the company

Table 4. **Summary of Industry 4.0-Induced Changes: Amica**

Aspect	Content
I4.0 implementation level (RBV)	All four major technologies, i.e., Big Data, Cloud Computing, Mobile Technologies, and Social Media adopted. Four different systems applied affected by I4.0, i.e., customer support systems (CRM), enterprise resource planning (ERP), manufacturing execution systems (MESs), and energy management systems (EMS). Out of nine solutions typical for I4.0, six have been used: Big Data and Analytics, Autonomous Robots, Horizontal and Vertical System Integration, Industrial Internet of Things, Cybersecurity, and Cloud Computing.
Effects/benefits expected (RBV)	Cost reductions resulting from I4.0, improvement of efficiency due to I4.0, and reduction in time necessary to perform particular processes. Expectations regarding improvements of products offered and processes performed.
Risks & challenges (RBV)	Plans to restructure employment because of Industry 4.0. Seeking to face the challenge of cybersecurity and know-how protection. Committing human resources to handle I4.0 challenges. Strategy to face the challenges of Industry 4.0 in place. Organization of special training to improve the automation of manufacturing processes as well. Seeking to optimize the administrative processes. Problem of lack of professional workforce able to cope with Industry 4.0 admitted. Investing money in research and development. The lack of funding for training on Industry 4.0 for employees was not an issue.
Industry reshuffling landscape (I/O)	Confirmed monitoring of competitors' approach to I4.0. Operating in industries with short product life cycles. Not much known about suppliers (number of answers indicate "neither agree nor disagree"), most likely not affected by problems related to the reorganization of the manufacturing processes. Expectation as to shortening of value chains. Buyers experiencing pressure to look for new distribution channels due to I4.0. Acknowledged uncertainty due to likely reduction of existing economic advantages. Opportunity to improve the competitiveness thanks to I4.0 acknowledged. Producers of substitutes reorganizing their manufacturing processes, seeing digitalization as a threat for their present business models, and looking into the need to invest in innovation. Expected improvements of innovation performance thanks to I4.0.
Industry partners relations (I/O)	Actions undertaken to better network firm's own value chain. Pressure on cost reduction admitted. Not convinced about the necessity of some governmental support in order to cope with the possible threats of Industry 4.0. Pressure from business partners forcing the firm to move to more knowledge –intensive functions and as a consequence also to perform more functions, often more diverse functions, often globally or in new business sectors.
Value chain repositioning and I4.0 induced chances for international expansion (GVC + RBV + IO)	Disagreement with the statement that changes are initiated by the key manufacturer in the value chain who owns the knowledge and expertise and that the relationships of the firm with business partners are simple market relations created because of convenient price conditions. It, however, supports the view that the changes are made due to the initiative of the firm itself and the buyer who controls the distribution channels and greatly influences the marketing functions. Modular relationships with business partners– the firm supplies products according to the specifications of the subcontractor. Autonomous robots seen as allowing for repatriation of the manufacturing processes and big data allowing for better market research and making more effective investment decisions while the Internet of Things allows for improving the efficiency of manufacturing processes and thus diminishes the pressure on outward foreign direct investment.

Source: authors' own elaboration.

faces uncertainty because of the possible reduction of economic advantages, though, it also has opportunities to improve competitiveness. Amica agrees that concerning the producers of their substitutes, they in general reorganize their manufacturing processes and business models; they recognize digitalization as a threat for their present business models and the need to invest capital in innovation. Besides, they seem to expect improvements in their innovative performance thanks to Industry 4.0. Amica further expects to improve its products and its processes (i.e., new technology allows the firm to increase efficiency). The company feels the pressure of business partners forcing it to move toward more knowledge–intensive functions and as a consequence, also to perform more functions, often more diverse functions, often globally or in new business sectors. Interestingly, Amica does not agree with the statement that the changes have been initiated by the key manufacturer in the value chain who owns the knowledge and expertise and that relationships of the firm with business partners are simple market relations created because of convenient price conditions. It, however, supports the view that the changes are at the initiative of the firm itself and the buyer that controls distribution channels and greatly influences the marketing functions. The relationships of the firm with business partners are modular – the firm supplies products according to the specifications of the subcontractor. Amica sees autonomous robots as allowing it to repatriate the manufacturing processes and it agrees that big data allows it to better research the market and make more effective investment decisions, whereas the Internet of Things allows it to improve the efficiency of manufacturing processes and thus diminishes the pressure of finding outward foreign direct investment.

Kompania Piwowarska (KP)

KP[5] was established on May 4, 1999 as a result of the merger between Tyskie Browary Książęce and Lech Browary Wielkopolski, which led to its establishment as one of the most technologically advanced brewing companies in Poland. KP now operates three breweries with a rich heritage: Tyskie Browary Książęce (established in 1629), the Dojlidy Brewery in Bialystok (1768), and Lech Browary Wielkopolski in Poznan (1895). Thanks to traditionally proven recipes, the usage of only natural ingredients, production in superbly clean breweries, and, last but not least, a skilled workforce, the firm can brew beers that are highly valued in Poland and abroad. In 2009, 100% of KP's shares were acquired by SABMiller. The next ownership change followed eight years later and KP is currently part of Japan's Asahi Group. KP is an OEM with a majority of foreign capital. With more than 250 employees it belongs to the group of large firms which are listed on the stock exchange (as part of the Asahi Group – Tokyo SE). The firm exports (intercompany export) and operates on foreign markets (Asahi Group owned subsidiaries dedicated to serving foreign markets); among others in the UK, USA, Germany, Canada, and by licensing in France and the Netherlands. KP is a subsidiary of a multinational enterprise.

With respect to I4.0, Kompania Piwowarska harnesses four out of nine identified technologies: Big Data, Cloud Computing, Mobile Technologies, and Social Media. According to KP, the systems which are the most affected by technological progress and Industry 4.0 are: customer support systems (CRM), enterprise resource planning (ERP), manufacturing execution systems (MESs), and energy management systems (EMS).

New technological solutions adopted by KP encompass: Big Data and Analytics (semi-autonomous – lines, packaging etc), Horizontal and Vertical System Integration, Industrial Internet of Things (to some extent), Cybersecurity, and Cloud Computing. The firm does not plan to restructure employment because of Industry 4.0, however, it is not convinced of the advantages that will allegedly be reaped from subsequent cost reductions. It does not expect to get any support from the government to face the threats of Industry 4.0 and does not invest money in research and development to deal with relevant pressures from the technological shifts. KP does monitor competitors' approaches to Industry 4.0, it confronts the challenge of cybersecurity and know-how protection. It admits that thanks to these changes, it can take advantage of the improvement in efficiency resulting from Industry 4.0 as well as the reduction of the time necessary to perform particular processes. KP tries to network its value chain and confirms feeling the pressure on cost reduction. It also recognizes legal barriers originating from Industry 4.0 which protect the company. KP dedicates particular human resources to monitoring and coping with the challenges posed by Industry 4.0 and organizes special training to improve the automation of manufacturing processes. It tries to optimize the administrative processes (i.e., the flow of documents) and admits to facing a lack of professional workforce able to cope with Industry 4.0 and the lack of funding for relevant training for employees. The firm faces the need to increase investment expenditures (i.e., new machines, tools, and equipment). It feels that its suppliers are experiencing problems related to the lack of proper infrastructure and feels the pressure to become more of an insider of a GVC to shorten the value chain. In the opinion of KP, their buyers may feel the need for new distribution channels because of Industry 4.0. They most likely experience uncertainty because of the possible reduction of economic advantages as well as the opportunity to increase sales and improve competitiveness. Producers of substitutes for KP's offerings seem to have reorganized their manufacturing processes and their business models. They apparently recognized that capital investments in innovation are a big challenge and expect to improve innovation performance. KP improves its products and processes (i.e., new technology allows it to increase efficiency). It admits that due to the pressure of business partners, the firm has moved to more knowledge–intensive functions and has tried to go global. The ongoing I4.0-related changes are at the initiative of the firm and the relationships of the firm with business partners are the result of knowledge flows and expertise among them. Big data allows for better market research and facilitates more effective investment decisions. The Internet of Things allows the firm to improve the efficiency of manufacturing process and thus

[6] http://en.kp.pl, access date 29.10.2020.

Table 5. **Summary of Industry 4.0-Induced Changes: Kompania Piwowarska**

Aspect	Content
I4.0 implementation level (RBV)	The systems most affected by I4.0: customer support systems (CRM), enterprise resource planning (ERP), manufacturing execution systems (MESs), and energy management systems (EMS). New technological solutions adopted encompass: Big Data and Analytics (semi-autonomous – lines, packaging etc), Horizontal and Vertical System Integration, Industrial Internet of Things (to some extent), Cybersecurity, and Cloud Computing.
Effects/benefits expected (RBV)	Improving products and processes as technology enhances efficiency. Not convinced about the advantage from the cost reduction resulting from I4.0. Possibly taking advantage of improved efficiency resulting from I.4.0 as well as from the reduction of the time necessary to perform particular processes.
Risks & challenges (RBV)	No plans to restructure employment as a consequence of I.40. No particular R&D investments due to pressure from Industry 4.0. Challenges of cybersecurity and know-how protection evaluated. Attempts to optimize the administrative processes (i.e., the flow of documents). Facing a lack of professional workforce able to cope with Industry 4.0 and lack of funding for relevant training for employees. The need to increase investment expenditures (i.e., new machines, tools, equipment) identified. Particular human resources dedicated to monitoring and coping with I4.0 challenges. Special training to improve the automation of manufacturing processes offered.
Industry reshuffling landscape (I/O)	Monitoring competitors' approaches to Industry 4.0. Suppliers experiencing problems related to the lack of proper infrastructure and under pressure to become more of an insider of a GVC and to shorten the value chain. Buyers possibly in need of new distribution channels because of I4.0. Most likely experiencing the uncertainty because of the possible economic advantage reduction. Opportunity to increase sales thanks to Industry 4.0 and to improve the competitiveness also recognized. Producers of substitutes reorganizing their manufacturing processes and their business models. Apparently recognizing the need for capital investments in innovation because of Industry 4.0. Expectations of improved innovation performance thanks to I4.0.
Industry partners relations (I/O)	No expectations concerning support from the government to face I.40 challenges. Attempts to network value chain. The pressure on cost reduction confirmed. Recognizing legal barriers originating in Industry 4.0 which protect the company. Recognizing the pressure from business partners moving into more knowledge–intensive functions also on a global scale.
Value chain repositioning and I4.0 induced chances for international expansion (GVC + RBV + IO)	Disagreement with statement that the relationships of the firm with business partners arise from control – captive relationships and that the firm is under the control of a stronger business partner. Further, KP does not agree with the statement that the relationships of the firm with business partners are based on hierarchy – there are no external suppliers and cooperation takes place within the internal network of the firm. Big data enables better market research and more effective investment decisions. The Internet of Things allows for improving the efficiency of the manufacturing process and thus reduces pressure on outward foreign direct investment whereas additive manufacturing allows for shortening the value chain. Autonomous robots are not perceived as allowing for the repatriation of manufacturing processes.

Source: authors' own elaboration

diminishes the pressure on outward foreign direct investment whereas additive manufacturing allows KP to shorten the value chain. It is worth emphasizing that KP disagrees, however, that the relationships of the firm with business partners arise from control – captive relationships. It refutes the assertion that the firm is under the strong control of a stronger business partner, that the relationships of the firm with its business partners are based on hierarchy – there are no external suppliers and cooperation takes place within the internal network of the firm. It also does not see autonomous robots as allowing it to repatriate the manufacturing processes.

Unilever Polska S.A.

UNILEVER[6] is a British-Dutch transnational consumer goods company co-headquartered in London, UK and Rotterdam, Netherlands. Its products include foods and beverages (about 40% of its revenue), cleaning agents, and personal care products. It is Europe's seventh most valuable company. Unilever Polska S.A. has more than 250 employees, operates as a subsidiary of Unilever plc., and is listed on the stock exchange.

Out of the nine technologies regarded as the family of I4.0, Unilever adopts: Mobile Technologies and Social Media. Its systems that are most affected

[7] https://www.unilever.pl, access date 29.10.2020.

by technological progress and Industry 4.0 are the customer support systems (CRM) and enterprise resource planning (ERP).

Solutions harnessed by Unilever encompass Big Data and Analytics, Autonomous Robots, Cybersecurity, and Cloud Computing. Unilever, apparently, does not monitor competitors' approaches to Industry 4.0. It tries, however, to address the challenge of cybersecurity and know-how protection. It feels the pressure on cost reduction and admits to facing a lack of professional workforce able to cope with Industry 4.0. Unilever invests money in research and development under the auspice of I4.0 and confirms the issue of lack of funding for relevant training for employees. In Unilever's opinion, its suppliers face problems related to the lack of proper infrastructure and are under pressure to shorten the value chain. It disagrees, however, with the statement that buyers feel pressure to look for new distribution channels because of Industry 4.0. Producers of substitutes of Unilever products seem to recognize digitalization as a threat for their present business models and consider capital investments in innovation critical. Unilever improves its processes (i.e., new technology allows it to increase efficiency) and admits that it is under the pressure from business partners as the firm moves to more knowledge–intensive functions. The changes are initiated by the key manufacturer in the value chain who owns the knowledge and expertise. The company disagrees with the statement that the relationships of the firm with business partners are simple market relations created because of convenient price conditions and that the firm's relationships are modular meaning that the firm supplies products according to the specifications of the subcontractor. It agrees that Big Data allows for better market research and more effective investment decisions. Striking in the case of this firm is at the level of "neither nor" answers (3).

Discussion of Results

By looking closely at the governance type, we may assert the dominance of responses involving "neither agree nor disagree" indicating a lack of knowledge or neutral opinions, which seem to feature most frequently. Yet we may confirm that firms tend to have relationships with partners that are either purely market-based or modular where the firm supplies products according to the required specifications. However, two other firms disagree as their relationships arise from control which are typical captive relations or are based on a hierarchy taking place within an enterprise. This pattern most likely reflects their position within wider networks as weak with regard to the power and autonomy of surveyed firm. We may speculate that such linkages are chosen intentionally and that they mirror

Table 6. **Summary of Industry 4.0-Induced changes: Unilever**

Aspect	Content
I4.0 implementation level (RBV)	Systems most affected by I4.0: customer support systems (CRM) and enterprise resource planning (ERP). Harnessed solutions encompass Big Data and Analytics, Autonomous Robots, Cybersecurity, and Cloud Computing.
Effects/benefits expected (RBV)	Improvement of the efficiency of conducted processes.
Risks & challenges (RBV)	Attempts to face the challenge of cybersecurity and know-how protection. Pressure on cost reduction recognized and challenge of lack of professional workforce able to cope with I.4.0 admitted. Investing into R&D under pressure of I4.0. Lack of funding for I.40 trainings for employees evaluated.
Industry reshuffling landscape (I/O)	No monitoring of competitors' behavior in terms of I4.0. Suppliers facing problems related to the lack of proper infrastructure and under pressure to shorten value chain. Buyers not affected by the pressure to look for new distribution channels due to I4.0. Producers of substitutes recognize digitalization as a threat for their present business models and are considering capital investments in innovation due to Industry 4.0.
Industry partners relations (I/O)	Under the pressure of the business partners moving to more knowledge-intensive functions.
Value chain repositioning and I4.0 induced chances for international expansion (GVC + RBV + IO)	The changes are initiated by the key manufacturer in the value chain who owns the knowledge and expertise. Disagreement with regard to statement that the relationships of the firm with business partners are simple market relations created because of convenient price conditions and that the relationships of the firm with business partners are modular meaning that the firm supplies products according to the specifications of the subcontractor. Big data allows for better market research and more effective investment decisions.
Source: authors' own elaboration.	

the firm's strategy which is aimed at maximizing the benefits arising from the implementation of I4.0 – whether it is more effective to leave certain processes to the market or internalize them according to strict rules within narrower, controlled group. The obtained results partially reflect the assumptions that a higher level of internalization goes in line with a greater knowledge pool for the company since the most valuable tacit knowledge is organizationally embedded and difficult to transfer. It contributes to the competitive advantage of firms since such knowledge is characterized by imperfect imitability and imperfect mobility [*Lippman, Rumelt*, 1982]. Furthermore, the firms suggest that not just internalization of particular operations provides advantages for companies, but rather smart embedding of the firm in a network – the relational capital can offset transaction costs thanks to the reciprocity and trust [*Holm et al.,* 1999]. The lead firm in a hierarchy could provide cutting-edge technologies when it adopts the strategy of sharing instead of appropriation, though, some recent studies show that discovering new knowledge and creating innovations, also radical ones, requires rather heterarchical relations where power is decentralized and managerial competences and skills are dispersed [*Gancarczyk, Najda-Janoszka,* 2020]. The ambiguity of the link between the governance of the relations and knowledge as a source of competitive advantage manifests once again amid the uncertainty with which companies have to cope.

As far as the competitive advantage of the firms is concerned, we may note that three of the four studied entities revealed pressure concerning cost reduction which reflects the basic character of the efficiency-driven advantages. The challenges in cost management are general and only companies that satisfy these requirements may improve upon their advantages and move towards innovation-driven advantages. The four companies respect these challenges and implement lean management principles. At each of these companies a lean coordinator was appointed. Thus, they exploit the lean philosophy not only in an implicit but also in an explicit way. Being aware of the complexity of production networks, they tried to introduce and cultivate the relevant principles. Their passion for lean management will be further facilitated by their eagerness to implement I4.0 technologies since lean management and digitalization correspond with one another. The companies use IoT technology and Cloud Computing solutions which allow the firms to collect larger amounts of data and make traditional database infrastructure obsolete. IoT allows the firms to gather multi-dimensional data via embedded RFID (Radio Frequency Identification) devices or sensors and to share the data among machines, to analyze them by cloud computing software, which contributes to the creation of complex but at the same time lean production systems without human intervention. Two of the companies – Viacon and Amica – seem to have great potential for getting involved in 3D printing, as it further contributes to the lean management efforts since 3D printing allows one to use materials just-in-time with no waste. This trend will be continued since the technological advancements allow them to reduce costs (efficiency-driven advantages) but at the same time add to the innovation-driven advantages of the companies.

Based on the results of our interviews, we synthetized the main findings obtained by drawing on the introduced conceptual lenses. Though the firms have been adopting new technologies, it seems there is some tendency toward rather fragmented, patchy implementation, which may reflect the evolutionary nature of this fourth industrial revolution. This trend, relatively similar across firms, can possibly reshape the resource allocation and efficiency of staff and consequently, by impacting the adopted managerial systems, affect their competitive advantage. Nevertheless, at each of the studied companies, CRM and ERP systems are exploited and affected by I4.0. These companies try to move towards digital factories and to represent a holistic digitalized model of a company. In the case of Amica, these attempts are reflected within the logistic processes where strong efforts to automate the operations are visible.

Thanks to the technologies implemented and the I4.0 solutions studied, companies are able to offer new products and better shape their business processes. They can thus achieve efficiency gains resulting in new and improved competitive advantages as resources can be better allocated and/or more effectively used. The I4.0 transformation does not happen spontaneously in a vacuum – it requires that firms undertake concrete measures and this implies active management in order to improve the competitive advantage of available resources – so capital investment and labor training are necessary. At the industry level, there is a certain ambiguity regarding the position of partners due to I4.0, both the opportunities and challenges they face are acknowledged. Being aware of the greater or lesser vision of the studied firms on the challenges their suppliers, customers, and substitute providers face with regard to the fourth industrial revolution, we may assume they strive toward the creation of value networks embracing the aforementioned entities. Viacon, Amica, Kompania Piwowarska, and Unilever develop relations with these entities and equip these links with digital solutions to make the creation of value easier and to facilitate the move toward digital ecosystems. It is of course just the start of the journey. Viacon, Amica, and Unilever declared their involvement in modular relations with their clients. Their turn toward modularization means that they are able on the one hand to produce a basic product and then to adjust it according to the expectations of particular customers. Their involvement in modularization allows them to reduce costs (efficiency-driven advantages) and simultaneously respect specific expectations of particular customers that goes in line with innovation-driven advantages. Besides, a rather unclear approach dominates among the studied firms as to the need for mimicking or observing the reaction of other sector actors (suppliers, customers) due to the I4.0 transformation. The lack of unanimity regarding hypothetical governmental support can be diagnosed along with the more widespread and recognized pressures from partners to climb the value chain and network better with one another. Diverse opinions on actors' roles in initiating digital transformation changes can be identified among the studied companies, though the I4.0 potential for streamlining their international business is acknowledged.

Conclusions

Our study explores the reasons for and effects of the adoption of Industry 4.0 and how it influences firm competitiveness in the international context. What can be learned from a pilot study drawing on these cases? As revealed by the answers obtained, the expected impact of I4.0 is supposed to be significant and complex; though, as it seems, based more on guesses and speculation than hard data. Firms are also trying to get ready to face related challenges – cost pressures, cybersecurity. They see many benefits but are fully aware of the risks involved and adopt a sober approach by not exaggerating or unnecessarily inflating their expectations. Their knowledge regarding the situation of major partners (buyers and consumers) differ, as does their familiarity with partners' progress in implementing I4.0 technologies.

The competitive advantage of a firm could be reshaped in the I4.0 era, not solely due to adopting modern solutions and advanced technologies allowing for multiple economic gains which would materialize at the company level. Competitive advantages could also be modified as a result of a sector's transformation and changing relationships with partners. Yet it seems, based on the results obtained, it is much easier for firms to predict the assumed implications in terms of the companies' own levels, whereas much ambiguity and uncertainty surrounds developments in industrial sectors.

These findings seem to correspond with the conclusions in other literature stressing the uncertainty and complexity of the digital economy in general [*Kovacs*, 2018], as well as difficulties with the precise measuring of the expected benefits [*Dalenogare et al.*, 2018]. Based on a literature review (I4.0 tenets and the changing digital macroeconomic landscape; RBV, I/O strategies, and GVC perspective) we can put forward the thesis that the fourth industrial revolution emphasizes "the race to the top", giving priority to quality rather than cost reduction as a method of improving competitiveness. Since it implies the emergence of connected companies, truly linked with each other, it also heralds the disappearance of clear boundaries between them.

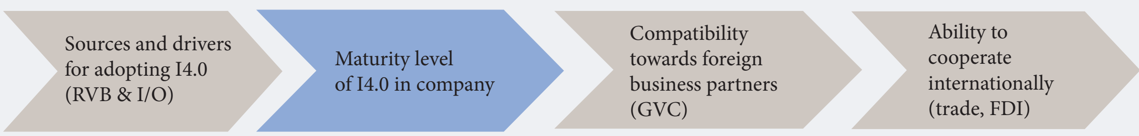
Companies that (try to) escape the trend towards digital networks and the optimization of value-creation chains are in danger of losing competitiveness and market relevance in the near future. Stabilizing or even increasing competitiveness will require even more efficient production procedures. We believe that our study may contribute to the upcoming research stream of Industry 4.0 and can support decision-makers in assessing their need for transformation toward Industry 4.0 practices.

We have tried to show that in the future – in the digital era – company competitiveness will be a function of Industry 4.0 maturity, which itself could be driven by various motives depending upon a firm's resources, sector characteristics, and value chain relationships with partners (whole sequence – Figure 1).

Hence, as compared to other studies which were centered on identifying the readiness and application of certain I4.0 solutions (blue part), the added value of our research can be seen in its focus on a broader perspective including the sources/drivers of this maturity or I4.0 readiness.

Based on the obtained results we posit a wider I4.0 awareness by firms as another approach to measuring Industry 4.0 readiness and maturity. We argue

Figure 1. **Logic of competitiveness and cross-border cooperation in the digital era**



Source: compiled by the authors.

there are alternative ways of approaching the problem of I4.0 maturity. Instead of simply using technology absorption or adaptation level, one may utilize the broader intelligence and awareness concerning the ecosystem as an indicator of I.40 readiness.

I4.0 will impact firms' competitiveness, though, the benefits of such adoption are anything but natural. In fact, they can materialize only under certain circumstances. Surveyed firms are aware of this and point out necessary conditions (complementary recourses, training, and investments) to be fulfilled for successful and beneficial I4.0 implementation.

Industry 4.0 adoption and its impact upon competitiveness derive from cooperation with partners. This is particularly true as digital transformation implies far-reaching interconnectedness and integration along value chains and within networks. Hence, the importance of becoming digitally conscious [*Saarikko et al.,* 2020] and knowing partners better cannot be underestimated. Yet, as our study demonstrates, the knowledge about firms' ecosystems remains rather uncharted territory.

We are fully aware of limitations of our research, in particular the interpretation of the presented case studies and the focus on firms from just one country. We believe that these findings should be regarded as a starting point for more nuanced explorations within the grounded theory method. Such qualitative investigations based on semi-structured and in-depth interviews should verify our presuppositions and research on the impact of I4.0 upon company competitiveness using the lenses of the GVC approach. It also fits into recent calls for a modified research agenda which focuses on various aspects of GVCs in connection with the internationalization theory [*Benito et al.,* 2019].

This paper is a result of the studies within the project of the National Science Centre in Poland. Grant no. 2016/21/B/HS4/03030, title: Innovation performance of a foreign subsidiary and its position in the network of a multinational enterprise – the perspective of foreign subsidiaries established in Poland. The authors are grateful to Prof. Jan Polowczyk from Poznań University of Economics and Business for the support in collecting data on Kompania Piwowarska and Unilever.

References

Amit R., Schoemaker P. (1993) Strategic Assets and Organizational Rent. *Strategic Management Journal,* vol. 14, no 1, pp. 33–46. Available at: https://doi.org/10.1002/smj.4250140105, accessed 16.09.2020.

Andriopoulos C., Slater S. (2013) Exploring the landscape of qualitative research in international marketing: Two decades of IMR. *International Marketing Review*, vol. 30, no 4, pp. 384–412. Available at: https://doi.org/10.1108/IMR-03-2012-0061, accessed 16.09.2020.

Aquilante T., Bustinza O.F., Vendrell-Herrero F. (2016) Services in European manufacturing: Servinomics explained. Available at: http://bruegel.org/2016/03/services-in-european-manufacturing-servinomics-explained/, accessed 16.09.2020.

Bain J.S. (1956) *Barriers to new competition*, Cambridge, MA: Harvard University Press.

Barney J.B., Arikan A.M. (2005) The resource–based view: Origins and implications. *The Blackwell Handbook of Strategic Management* (eds M.A. Hitt, R.E. Freeman, J.S. Harrison), Hoboken, NJ: Wiley-Blackwell, pp. 123–182. Available at: https://doi.org/10.1111/b.9780631218616.2006.00006.x, accessed 16.09.2020.

Benito G.R., Petersen B., Welch L.S. (2019) The global value chain and internalization theory. *Journal of International Business Studies*, vol. 50, no 8, pp. 1414–1423. DOI: 10.1057/s41267-019-00218-8.

Blumberg B., Cooper D., Schindler P. (2011) *Business Research Methods*, New York: McGraw-Hill Education.

Breunig M., Kelly R., Mathis R., Wee D. (2016) *Getting the most out of Industry 4.0 operations*, Chicago: McKinsey & Company. Available at: https://mck.co/3lCclZB, accessed 25.01.2019.

Burmeister Ch., Lüttgens D., Piller F.T. (2016) Business Model Innovation for Industrie 4.0: Why the "Industrial Internet" Mandates a New Perspective on Innovation. *Die Unternehmung*, vol. 2, pp. 124–152. Available at: https://dx.doi.org/10.2139/ssrn.2571033, accessed 15.01.2020.

Cappelli P., Sherer P.D. (1991) The missing role of context in OB: The need for a meso-level approach. *Research in Organizational Behavior*, vol. 13, pp. 55–110.

Cattaneo O., Gereffi G., Miroudot S., Taglioni D. (2013) *Joining, upgrading and being competitive in global value chains: A strategic framework*, Washington, D.C.: The World Bank.

Chesbrough H. (2006) *Open business models: How to thrive in the new innovation landscape*, Boston, MA: Harvard Business School Press.

Collis J., Hussey R. (2009) *A practical guide for undergraduate and postgraduate students*, New York: Palgrave Macmillan.

Craig A. (2013) *Understanding Augmented Reality. Concepts and Applications* (1st ed.), Amsterdam: Elsevier.

Culot G., Orzes G., Sartor M., Nassimbeni G. (2020) The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0. *Technological Forecasting and Social Change*, vol. 157, art. 120092. Available at: https://doi.org/10.1016/j.techfore.2020.120092, accessed 15.08.2020.

Dalenogare L.S., Benitez G.B., Ayala N.F., Frank A.G. (2018) The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, vol. 204, pp. 383–394. DOI: 10.1016/j.ijpe.2018.08.019.

Drath R., Horch A. (2014) Industrie 4.0: Hit or hype? *IEEE Industrial Electronics Magazine*, vol. 8, no 2, pp. 56–58. DOI: 10.1109/MIE.2014.2312079.

Edquist H., Goodridge P., Haskel J. (2019) The Internet of Things and Economic Growth in a Panel of Countries. *Economics of Innovation and New Technology* (in press, first published online 06.12.2019), Available at: https://doi.org/10.1080/10438599.2019.1695941, accessed 15.08.2020.

Éltető A., Magasházi A., Szalavetz A., Túry G. (2015) Global Value Chains and Upgrading: The Experience of Hungarian Firms in the Heavy Engineering and Automotive Industries. *Competitio*, vol. 14, no 1, pp. 5–22. DOI:10.21845/comp/2015/1/1.

Gancarczyk J., Najda-Janoszka M. (2020) Models for Development of an Innovation Network in Clusters. *Problemy Zarządzania / Management Issues*, vol. 18, no 1, pp. 179–192. Available at: https://doi.org/10.7172/1644-9584.87.8, accessed 15.08.2020.

Gereffi G., Korzeniewicz M. (eds.) (1994) *Commodity chains and global capitalism*, London: Praeger.

Gereffi G., Humphrey J., Sturgeon T. (2005) The governance of global value chains. *Review of International Political Economy*, vol. 12, no 1, pp. 78–104. Available at: https://doi.org/10.1080/09692290500049805, accessed 15.08.2020.

Gërvalla M., Ternai K. (2019) The Impact of Industry 4.0 to the ERP Approach. *SEFBIS Journal*, no 13, pp. 56–62.

Hermann M., Pentek T., Otto B. (2015) *Design Principles for Industrie 4.0 Scenarios: A Literature Review* (TU Dortmund Working Paper 01), Dortmund: Technische Universität Dortmund. Available at: http://www.snom.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design-Principles-for-Industrie-4_0-Scenarios.pdf, accessed 18.03.2020.

Holm D., Eriksson K., Johanson J. (1999) Value creation through mutual commitment to business network relationships. *Strategic Management Journal*, vol. 20, no 5, pp. 467–486. Available at: https://doi.org/10.1002/(SICI)1097-0266(199905)20:5%3C467::AID-SMJ38%3E3.0.CO;2-J, accessed 15.08.2020.

Humphrey J., Schmitz H. (2002) How does insertion in global value chains affect upgrading in industrial clusters? *Regional Studies*, vol. 36, no 9, pp. 1017–1027. Available at: https://doi.org/10.1080/0034340022000022198, accessed 18.03.2020.

Kagermann H., Wahlster W., Helbig J. (2013) *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*, Frankfurt/Main: Acatech. Available at: https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf, accessed 18.03.2020.

Kovacs O. (2018) The dark corners of industry 4.0 — Grounding economic governance 2.0. *Technology in Society*, vol. 55, pp. 140–145. Available at: https://doi.org/10.1016/j.techsoc.2018.07.009, accessed 18.03.2020.

Lasi H., Fettke P., Kemper H.G., Feld T., Hoffmann M. (2014) Industry 4.0. *Business and Information Systems Engineering*, vol. 6, no 4, pp. 239–242. Available at: https://doi.org/10.1007/s12599-014-0334-4, accessed 18.03.2020.

Lee J., Gereffi G. (2015) Global value chains, rising power firms and economic and social upgrading. *Critical Perspectives on International Business*, vol. 11, no 3/4, pp. 319–339. Available at: https://doi.org/10.1108/cpoib-03-2014-0018, accessed 18.03.2020.

Leih S., Linden G., Teece D.J. (2015) Business Model Innovation and Organizational Design: A Dynamic Capabilities Perspective. *Business Model Innovation: The Organizational Dimension* (eds. N.J. Foss, T. Saebi), Oxford: Oxford University Press, pp. 24–43. DOI:10.1093/acprof:oso/9780198701873.003.0002.

Lippman S., Rumelt R.P. (1982) Uncertain imitability: An analysis of interfirm differences in efficiency under competition. *Bell Journal of Economics*, vol. 13, no 2, pp. 418–438. DOI: 10.2307/3003464.

Lorenz M., Rüßmann M., Strack R., Lueth K., Bolle M. (2015) *Man and Machine in Industry 4.0. How Will Technology Transform the Industrial Workforce Through 2025?* Available at: https://www.bcg.com/publications/2015/technology-business-transformation-engineered-products-infrastructure-man-machine-industry-4.aspx, accessed 20.03.2020.

Lucke D., Constantinescu C., Westkämper E. (2008) Smart Factory — A Step towards the Next Generation of Manufacturing. *Manufacturing Systems and Technologies for the New Frontier* (eds. M. Mitsuishi, K. Ueda, F. Kimura), Heidelberg, New York, Dordrecht, London: Springer: Springer, pp. 115–118. Available at: https://doi.org/10.1007/978-1-84800-267-8_23, accessed 20.03.2020.

Mason E.S. (1939) Price and production policies of large scale enterprises. *American Economic Review*, vol. 29, pp. 61–74. Available at: https://www.jstor.org/stable/1806955, accessed 20.03.2020.

Miles M.B., Huberman M. (1994) *Qualitative Data Analysis: An Expanded Sourcebook*, London: SAGE.

Mowday R.T., Sutton R.I. (1993) Organizational behavior: Linking individuals and groups to organizational contexts. *Annual Review of Psychology*, vol. 44, pp. 195–229. Available at: https://doi.org/10.1146/annurev.ps.44.020193.001211, accessed 20.03.2020.

Nosalska K., Piątek Z., Mazurek G., Rządca R. (2019) Industry 4.0: coherent definition framework with technological and organizational interdependencies. *Journal of Manufacturing Technology Management* (in press, first published online 27.11.2019). Available at: https://doi.org/10.1108/JMTM-08-2018-0238, accessed 20.03.2020.

Penrose E. (1959) *The theory of the growth of the firm,* Oxford: Blackwell.

Porter M.E., Heppelmann J. (2015) How Smart, Connected Products are Transforming Companies. *Harvard Business Review*, October issue. Available at: https://hbr.org/2015/10/how-smart-connected-products-are-transforming-companies, accessed 20.03.2020.

Porter M.E., Millar V.E. (1985) How information gives you competitive advantage. *Harvard Business Review*, vol. 63, pp. 149–174. Available at: https://hbr.org/1985/07/how-information-gives-you-competitive-advantage, accessed 20.03.2020.

Porter M.E. (1979) The structure within industries and companies' performance. *The Review of Economics and Statistics*, vol. 61, no 2, pp. 214–227. DOI: 10.2307/1924589.

PwC (2016) *Industry 4.0 — Building the Digital Enterprise*, London: PricewaterhouseCoopers LLP. Available at: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf, accessed 20.03.2020.

Qin J., Liu Y., Grosvenor R. (2016) A categorical framework of manufacturing for industry 4.0 and beyond. *Procedia CIRP*, vol. 52, pp. 173–178. Available at: https://doi.org/10.1016/j.procir.2016.08.005, accessed 20.03.2020.

Rubera G., Chandrasekaran D., Ordanini A. (2016) Open innovation, product portfolio innovativeness and firm performance: The dual role of new product development capabilities. *Journal of the Academy of Marketing Science*, vol. 44, no 2, pp. 166–184. DOI: 10.1007/s11747-014-0423-4.

Rüßmann M., Lorenz M., Gerbert P., Waldner M., Justus J., Engel P., Harnisch M. (2015) *Industry 4.0: The Future of Productivity and Growth in Manufacturing*, Boston, MA: Boston Consulting Group. Available at: https://image-src.bcg.com/Images/Industry_40_Future_of_Productivity_April_2015_tcm9-61694.pdf, accessed 24.08.2020.

Saarikko T., Westergren U.H., Blomquist T. (2020) Digital transformation: Five recommendations for the digitally conscious firm. *Business Horizons* (in press, first published online 15.08.2020). Available at: https://doi.org/10.1016/j.bushor.2020.07.005, accessed 24.08.2020.

Schmalstieg D., Hollerer T. (2016) *Augmented Reality: Principles and Practice (Usability)* (1st ed.), Boston, MA: Pearson Education.

Schuh G., Potente T., Wesch-Potente C., Weber A.R., Prote J.P. (2014) Collaboration Mechanisms to increase Productivity in the Context of Industrie 4.0. *Procedia CIRP*, vol. 19, pp. 51–56. Available at: https://doi.org/10.1016/j.procir.2014.05.016, accessed 24.08.2020.

Siggelkow N. (2007) Persuasion with Case Studies. *Academy of Management Journal*, vol. 50, no 1, pp. 20–24.

Skapinyecz R., Illés B., Bányai Á. (2018) Logistic aspects of Industry 4.0. *IOP Conference Series: Materials Science and Engineering*, vol. 448 (Proceedings of the XXIII International Conference on Manufacturing, 7–8 June 2018, Kecskemét, Hungary), Article 012014. DOI:10.1088/1757-899X/448/1/012014. Available at: https://iopscience.iop.org/article/10.1088/1757-899X/448/1/012014/pdf, accessed 24.03.2020.

Stead R., Curwen P., Lawler K. (1997) *Industrial Economics. Theory, Applications and Policy*, London: McGraw-Hill.

Štemberger M.I., Erjavec J., Manfreda A., Jaklič J. (2019) Patterns of approaches to digital transformation: An institutional arrangements perspective. *Economic & Business Review*, vol. 21, no 3, pp. 467–492. DOI: 10.15458/ebr.93.

Szalavetz A. (2017a) Upgrading and value capture in global value chains in Hungary: More complex than what the smile curve suggests. *Foreign Direct Investment in Central and Eastern Europe: Post-Crisis Perspectives* (ed. S. Balázs), London: Palgrave, pp. 127–150. Available at: https://doi.org/10.1007/978-3-319-40496-7_6, accessed 24.03.2020.

Szalavetz A. (2017b) Industry 4.0 in 'factory economies. *Condemned to be left behind? Can Central and Eastern Europe emerge from its low-wage model? (eds. B. Galgóczi and J. Drahokoupil), Brussels: ETUI, pp. 133–152.* Available at: *https://www.etui.org/sites/default/files/Chapter%205_6.pdf*, accessed 24.03.2020.

Tchoffa D., Figay N., Ghodous P., Expósito E., Kermad L., Vosgien T., El Mhamedi A. (2016) Digital factory system for dynamic manufacturing network supporting networked collaborative product development. *Data & Knowledge Engineering*, vol. 105, pp. 130–154. Available at: https://doi.org/10.1016/j.datak.2016.02.004, accessed 24.03.2020.

Teece D.J. (2017) Towards a capability theory of (innovating) firms: Implications for management and policy. *Cambridge Journal of Economics*, vol. 41, no 3, pp. 693–720. Available at: https://doi.org/10.1093/cje/bew063, accessed 24.03.2020.

Wang S., Wan J., Li D., Zhang Ch. (2016) Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*, vol. 12, no 1, art. 3159805. Available at: https://doi.org/10.1155/2016/3159805, accessed 24.03.2020.

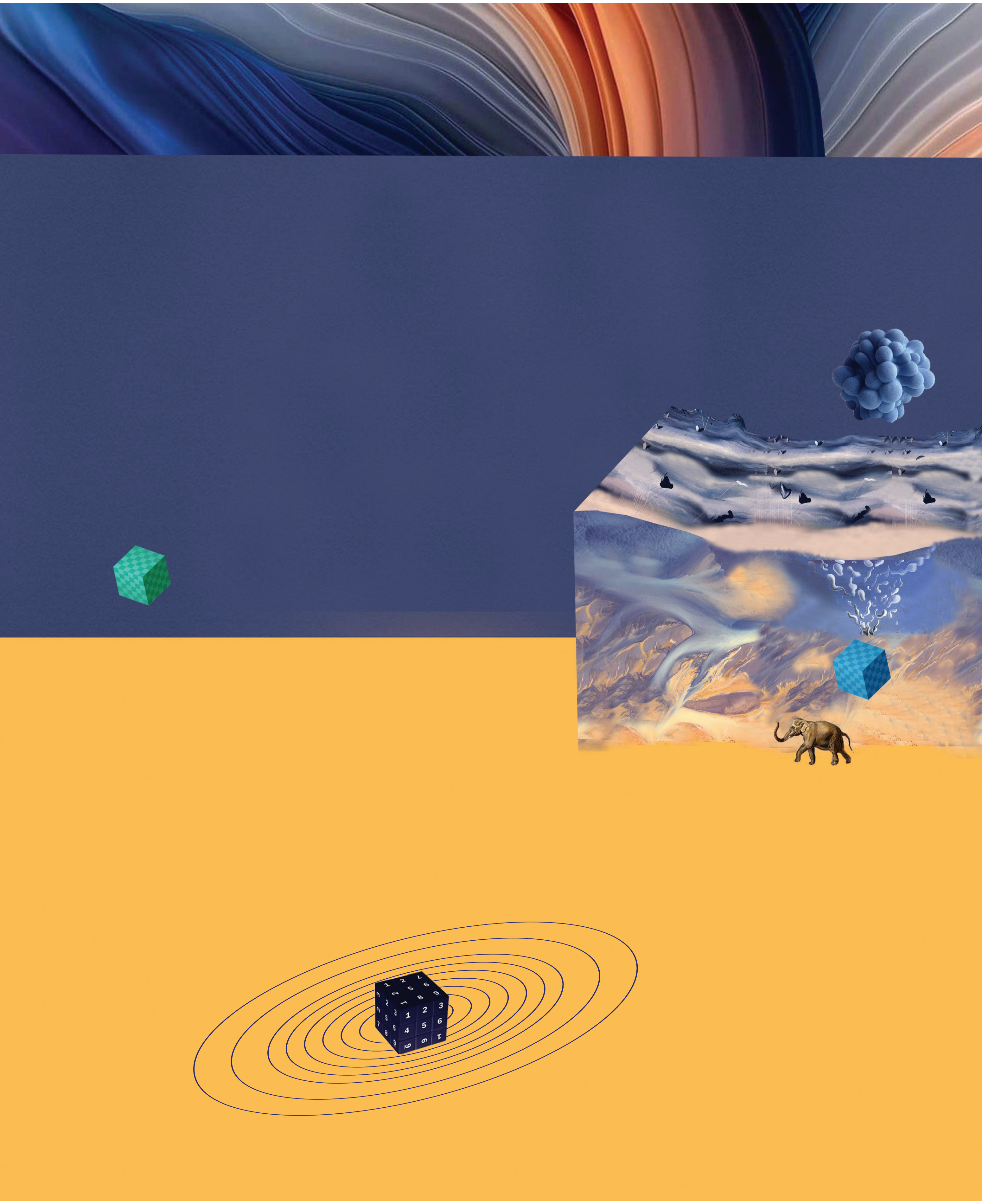
Wernerfelt B. (2013) Small Forces and Large Firms: Foundations of the RBV. *Strategic Management Journal*, vol. 34, no 6, pp. 635–643. Available at: https://doi.org/10.1002/smj.2043, accessed 24.03.2020.

West J., Salter A., Vanhaverbeke W., Chesbrough H. (2014) Open innovation: The next decade. *Research Policy*, vol. 43, no 5, pp. 805–811. Available at: https://doi.org/10.1016/j.respol.2014.03.001, accessed 24.03.2020.

WEF (2019) *White Paper Global Lighthouse Network: Insights from the Forefront of the Fourth Industrial Revolution*, Geneva: World Economic Forum, McKinsey. Available at: http://www3.weforum.org/docs/WEF_Global_Lighthouse_Network.pdf, accessed 20.03.2020.

Zieliński M. (2016) *Przemysł 4.0 w polskich fabrykach* [Industry 4.0 in Polish factories]. Available at: https://www.astor.com.pl/biznes-i-produkcja/raport-przemysl-4-0-polskich-fabrykach/, accessed 20.03.2020 (in Polish).

Zott C., Amit R., Massa L. (2011) The Business Model: Recent Developments and Future Research. *Journal of Management*, vol. 37, no 4, pp. 1019–1042. Available at: https://doi.org/10.1177%2F0149206311406265, accessed 20.03.2020.



Cooperative Strategies in the Age of Open Innovation: Choice of Partners, Geography and Duration

Valeriya Vlasova

Research Fellow, Laboratory for Economics of Innovation at the Institute for Statistical Studies and Economics of Knowledge (ISSEK); and Doctoral Student, ISSEK Department of Educational Programmes

Vitaliy Roud

Deputy Head, ISSEK Laboratory for Economics of Innovation; and Associate Professor, ISSEK Department of Educational Programmes, vroud@hse.ru

National Research University Higher School of Economics, 11, Myasnitskaya str., Moscow, Russian Federation

Abstract

In the era of "open innovation", the choice of a cooperative strategy is one of the most significant factors determining the effectiveness of innovation activities. The authors investigate the typical configurations of cooperative networks in Russian manufacturing, including the choice of partners, the role of spatial distance, and the duration of joint projects. Using the firm-level data (1,324 in 2015 and 545 in 2018) the paper evaluates the role of cooperation in the innovation outcomes in terms of innovation novelty and export capacity.

The most common cooperative strategy is vertical cooperation, which is the involvement of clients and suppliers in the process of innovative development. The geography of cooperation rarely extends beyond a region's borders and is mostly of an irregular (short-term) nature. A small number of enterprises that engage in international cooperation tend to rely upon long-term linkages with academia, which is a distinctive feature of the most innovative Russian companies, including those involved in the creation and distribution of intellectual property.

Keywords: open innovation; innovation activity; innovation cooperation; networks; geography; duration; industry-science cooperation; manufacturing

Citation: Vlasova V., Roud V. (2020) Cooperative Strategies in the Age of Open Innovation: Choice of Partners, Geography and Duration. *Foresight and STI Governance*, vol. 14, no 4, pp. 80–94. DOI: 10.17323/2500-2597.2020.4.80.94

The generation of knowledge and ideas, and their practical implementation in innovations is a network phenomenon that involves the results from the organized interaction of many participants. While an individual invention can be made in isolation, the regular and systematic development of innovations is impossible without cooperation. Cooperative interaction between various actors is at the core of the contemporary companies' innovation models. It serves as the basis for a systemic approach to innovative development on a national scale. Such models are typical for the most advanced innovation-oriented players who control global value chains.

In contrast to an ideal situation where all actors implement the best possible strategies, in reality, a high degree of interconnectedness between the firms' innovations as well as a broad scope of cooperation networks remain rather the exception. This study illustrates this phenomenon using the empirical evidence obtained by surveying Russian companies. Key structural characteristics of network innovation partnerships, geographical and temporal aspects of cooperation in the development and implementation of innovations in Russia have been studied. A popular, but not indisputably confirmed hypothesis about the relationship between the "openness" of a strategy and the innovation productivity was tested. The network factor's impact upon the differences in companies' innovation capabilities, their ability to create innovations new to the market, and to participate in global value chains were assessed. Configurations of cooperation networks' innovative businesses were also examined.

Cooperation has been a central topic to all actual models of innovation processes. The very emergence of the innovation concept, in addition to the traditional "linear model" describing the impact of technological progress on economic development was largely due to the need to take into account the diverse knowledge channels and flows required to apply innovations (such as technology borrowing, third-party development, etc.).[1] In the late 1990s-early 2000s, a wealth of empirical evidence was accumulated, confirming the importance of external information sources for corporate innovation. The proactive position taken by the most productive industry players, in particular multinational corporations, contributed to the development of the "open innovation" model which recognizes the key role of all kinds of knowledge and technology flows in innovation [*Chesbrough*, 2003; *Carlsson et al.*, 2011].

A systemic approach to analyzing countries' innovation capabilities, which is reflected in the framework "national innovation systems" concept [*Freeman,* 1987; *Lundvall,* 1992; *Nelson,* 1993], is also focused on cooperation issues. The strength of connections between innovation systems' specific components and actors is a decisive factor in the innovative productivity in the national, regional, and sectoral contexts [*Edquist,* 2011; *Fagerberg et al.,* 2005]. If such links are not sufficiently strong, it becomes a limitation and encourages making compensatory efforts and developing special support measures in the framework of national innovation policy.

Studying cooperation networks' configuration is closely related to other research areas related to development, catching up, and technological upgrading. The diversity and roles of companies' external information sources are studied by researchers of sectoral technological regimes [*Breschi et al.,* 2000], competitive advantages, and windows of opportunity in order to close the productivity gap with the world's leading economies and the technological development of national industries [*Humphrey, Schmitz,* 2002; *Lee,* 2020]. The length of cooperation is determined by the level of trust, the depth of actors' interaction, and their "institutional closeness" [*Boschma,* 2005; *Plewa et al.,* 2013]. This affects firms' absorption capacity, which is needed to promote the dissemination of advanced technologies and organizational practices at the national level. Geographic localization of knowledge chains is crucial in substantiating cluster policy and smart specialization strategies [*Balland et al.,* 2019].

The idea of making innovation process as open as possible was suggested on the basis of the experience of the most advanced global companies. However, not all innovation players use the available information dissemination channels, are integrated into mutual exchange networks, or share openness values. Surveys of enterprise innovation activities based on the framework approaches described in the Oslo Manual [OECD, Eurostat, 2018] – the international standard for measuring and interpreting innovative behavior indicators in the business sector – are the most important source of relevant empirical data. Methodological principles, a conceptual apparatus, a detailed system of definitions, and algorithms for framing questions and interpreting answers allow one to obtain internationally harmonized data on a wide range of characteristics of companies' innovation activities, suitable for comparative analysis.

Surveys carried out in line with the Oslo Manual have shown that openness is a multidimensional and complex phenomenon. The significant amount of accumulated empirical data indicates that enterprises are involved in cooperation to a different extent [*Dahlander, Gann,* 2010], while factors that determine the choice of partners and the formats of their interaction are heterogenous [*Belderbos et al.,* 2004b].

[1] About the non-linear innovation model see: [*Kline, Rosenberg*, 1986; *Godin*, 2008].

Researchers note the coexistence of both predominantly open and autonomous innovation strategies. Similar conclusions were made on the basis of Russian material. The relatively low level of companies' cooperation with the key national innovation system actors is reflected in the relevant national statistical indicators [HSE, 2019]. Kratzer et al. [*Kratzer et al.,* 2017] discovered that only about 10% of innovative manufacturing enterprises have both a proactively open culture and a detailed cooperation strategy.

Our research is devoted to the "mechanics" of cooperation links in the Russian context. How does the openness of cooperation networks' configuration affect companies' innovative capabilities? Is it true that the more "open" a company is, the more effectively it creates innovations new to the market? Do such companies have advantages facilitating their integration into global value chains? What is the role of businesses' ties with "institutional" knowledge producers – research and educational organizations compared with numerous other information sources for, and partners in the development of innovations? To answer these questions, the results of two waves of the Higher School of Economics' Monitoring of Enterprises' Innovation Activity survey were used.

Manufacturing enterprises, which are the object of our analysis, have a special place on the modern economic and technological development agenda since they have the highest demand for advanced production technologies. The radical transformation of this sector defines the prospects for a new industrial revolution – significantly increased global productivity and the reconfiguration of value chains [OECD, 2015]. The manufacturing industry also plays an important role in the structural transformation of the Russian economy since it makes a significant contribution to GDP (14.6% in 2019) and employment (14.3% of the national workforce in 2019). According to the innovation activity indicators [HSE, 2019], the highest number of companies successfully implementing technological innovations are concentrated in the manufacturing sector. Making adequate use of "windows of opportunity" to promote the growth of the national economy requires understanding the mechanisms for implementing innovative capabilities in manufacturing. Studying the role of the cooperation component as a factor in the success of innovation is necessary for the effective implementation and scaling of innovation-oriented business models.

Based on the review of theoretical approaches to studying innovative development cooperation, we have analyzed the cooperation network configurations typical for Russian manufacturing enterprises, including the location of partners and length of their interaction. Networking patterns were correlated with the companies' innovation performance. A special role that Russian enterprises' cooperation with R&D and educational organizations plays in the former's innovative capabilities was revealed. Firms' distinctive characteristics are presented as a basis for assessing the factors impacting the complexity and productivity of Russian businesses' cooperation strategies. Conclusions were made regarding the concept of "openness" and the empirical characteristics of cooperation strategies, which could help accomplish the objectives of accelerating technological development, stepping up innovation activity, and increasing enterprises' relevant capabilities.

Cooperation in Modern Innovation Models

Contemporary studies of innovation are based on the idea of nonlinear innovative development, application, and dissemination processes; the use of diverse innovation strategies; different configurations of innovation implementation chains; multiple sources of innovation ideas; and the particular importance of the effective interaction of both internal and external partners [*Leydesdorff et al.,* 2013; *Roud, Fursov,* 2011]. In the last three decades, research on innovation has been developing in line with the "chain" (nonlinear) model proposed in [*Kline, Rosenberg,* 1986]. Its key provisions are based on recognizing the economic role of the full range of possible innovation strategies, from full-scale research and development (R&D) to technology borrowing and the direct purchase of equipment. The departure from the linear model [*Godin,* 2006], understanding that a significant share of important innovations can be developed and implemented without conducting formal R&D on the basis of knowledge gained from experience ("doing, using, interacting") or outside of the enterprise, provided the key to explaining the technology diffusion processes and the catching-up as well as the advanced development of particular countries and industries.

Since the 1980s, researchers have recognized the key role of the cooperation factor in building companies' innovative capabilities in the framework of basic concepts such as the resource-based view of a firm [*Barney,* 2001; *Wernerfelt,* 1984], companies' absorptive capacity [*Cohen, Levinthal,* 1990], and dynamic capabilities [*Teece,* 2007]. This conceptual framework allows one to embed the current economic agenda into innovation management practice. By the late 1990s-early 2000s, systemic observations have revealed the evolution of business strategies towards strengthening companies' network connections [*Rosenbloom, Spencer,* 1996], including in the scope of the "open innovation" concept [*Chesbrough,* 2003]. Open innovations propose new cooperation models typical of the most advanced and proactive companies [*Chesbrough,* 2012], which consider the process of creating and implementing innovations as a combination of inbound and outbound knowledge flows [*Dahlander, Gann,* 2010], and thus use internal and external resources in the most efficient way possible with the help of new communication technologies.

The digital era provides new opportunities for opening the innovation process [*Nambisan et al.*, 2019] by expanding the range of participants, using new formats to share resources and intellectual activity results, and generating knowledge by synthesizing the actions of a wide range of diverse, independent, and uncoordinated actors through use of big data. As a result, cooperation strategies become more complex and heterogeneous.

Cooperation practices command serious attention in the scope of systemic empirical observations of the creation, implementation, and application of innovation. The current Oslo Manual edition [OECD, Eurostat, 2018] recommends one measure resources, innovation results, and the process of implementing new ideas separately, which allows for taking into account the diversity of companies' innovative behavior models and assessing the effectiveness of particular innovation implementation strategies in specific market, industry, and institutional settings.

The Oslo Manual defines innovations as new or improved products (services, business processes) brought to the market, which are significantly different from previously existing ones. All kinds of innovations are seen as economically significant: those new for the enterprise, but not for the market (reflect the process of accumulating competitiveness), new for the market, and new for the world. Innovation comprises the entire set of the firm's relevant activities, in any arrangement or combination: R&D, production design, engineering, acquisition of patent rights or licenses to use intellectual property, patenting (registration) of intellectual activity results, purchases of machinery, equipment and other fixed assets for innovation purposes, the development and acquisition of software and databases, planning, creation and implementation of new methods of doing business, organizing jobs and external relations, the marketing of new products, education and training of personnel, and other costs directly related to innovation [OECD, Eurostat, 2018, Chapter 4].

The above approach allows one to take into account the "openness" of the innovation process to the maximum possible extent. In terms of inbound knowledge flows, any type of innovation activity can be carried out by third-party organizations (through outsourcing, the procurement of relevant services, etc.) on a commercial basis, which is clearly reflected in innovation cost statistics. Companies use a wide range of information channels to develop and implement innovations. These include both internal (the company's own R&D, production, etc. divisions) and external sources. The sources of inbound knowledge flows include affiliated and non-affiliated enterprises (suppliers of equipment, materials and services); public and private R&D and educational organizations; customers, competitors, investors, other businesses, authorities, non-profit organizations, households, and individuals. In certain cases, a wider range of sources is considered, including informal ones (e.g., specialized exhibitions and conferences, etc.). Finally, companies' cooperation is analyzed, that is, the joint activities to develop innovations by counterpart type (in line with the list of external innovation sources).

Surveys based on the Oslo Manual approach are the main source of empirical data for harmonized (and therefore comparable) studies of the role of cooperation in companies' innovation. A quantitative analysis of various aspects of the relationship between cooperation and innovation strategies' productivity is based on the European Community Innovation Survey data. The results of these studies provide a framework for key hypotheses to empirically analyze the patterns common to cooperative innovation development strategies:

- Different forms of cooperation have different, but statistically significant effects upon innovative performance [*Belderbos et al.*, 2004a; *Laursen, Salter,* 2006; *Greco et al.*, 2016; *Wang et al.*, 2015]. In general, large firms have a greater propensity to engage in innovation cooperation [*Fritsch, Lukas,* 2001]. However, the effects vary significantly depending upon the types of innovations [*Aschhoff, Schmidt,* 2008; *Nieto, Santamaría,* 2007; *van Beers, Zand,* 2014].
- The effects vary greatly depending upon the type of economic activity (TEA). Depending on the specifics of the industry markets, certain network configurations are more common [*Arranz, de Arroyabe,* 2008; *Tether,* 2002]. Another source of variability is the differences in institutional conditions and competition regimes [*Kim, Vonortas,* 2014; *Srholec,* 2015].
- Involvement in cooperation networks is more important for innovative development compared to contributions from isolated cooperation partners [*Becker, Dietz,* 2004; *de Faria et al.*, 2010].
- In addition to the "breadth" of coverage (diversity of partners), the "depth" of cooperation, i.e., the intensity and duration of interaction with specific partners, plays a significant role [*Lhuillery, Pfister,* 2009; *Plewa et al.*, 2013]. The effects of such integration may vary depending upon the type of partner (e.g., in the case of industry-science cooperation, long-term research projects may be implemented, while cooperation with clients may involve additional product customization to meet customers' requirements).
- Spatial proximity is important to the extent that it does not depend upon the "cultural" proximity of cooperation partners – a common understanding of the context, the unity of objectives, and the ability to quickly exchange information over the course of a project [*Boschma,* 2005; *Torre,* 2008].
- Industry-science cooperation plays a special role [*Caloghirou et al.*, 2004; *Kaufmann, Tödtling,*

2001; *Perkmann, Walsh,* 2007]. The effectiveness of cooperation with R&D organizations and universities depends upon the overall technological level and innovative development of a country [*Castellacci,* 2008; *Dachs et al.,* 2008; *Hayter et al.,* 2018].

Harmonized international studies allow one to effectively identify specific national features. Cooperation success essentially reflects the quality of the innovation system. Creating conditions for the emergence and scaling of such cooperation is an important political objective associated with increasing the level and productivity of innovation. Network cooperation studies are a valuable source of insights into the current state of the innovation landscape in order to identify inefficiency and windows of opportunity as well as to fine-tune relevant policies.

In the Russian economy, the generally low involvement of enterprises in innovative activities is a key factor in the cooperation intensity. A number of quantitative studies identified the main barriers to scaling up innovation: limited availability of resources for companies, especially financial ones [*Kuznetsova, Roud,* 2013; *Teplykh,* 2015]; an unfavorable institutional environment in terms of the quality of government regulation; the low level of market competition; and the significant role played by the state in the economy [*Gokhberg, Kuznetsova,* 2015; *Yakovlev,* 2014]. The negative impact of these factors is evident both in real sector organizations' demand for innovations and in the productivity of companies already involved in innovative activities. As a result, Russian enterprises rarely implement breakthrough innovation projects leading to the development of high-tech products that are competitive on foreign markets [*Bessonova, Gonchar,* 2019]. "Openness" and network cooperation are practiced only by actively growing companies, for whom these activities make up an important part of their business models.

The quantitative parameters of cooperation processes in Russia are reflected in the official statistics of enterprises' innovation activity, in particular the proportion of organizations involved in joint R&D projects. In 2017 their share was 4.9% of the total number of manufacturing enterprises. The highest level of joint R&D was noted in high-tech sectors (in the production of computers, electronic, and optical products, 16.1% of companies are involved in such projects; in production of medicines and medical materials – 12.1%), and in certain other economic activity types (EATs) (in metallurgical production this figure is 12.1%, in the production of coke and petroleum products – 11.3%). It should be kept in mind that this indicator only reflects joint R&D, i.e., just some of the possible cooperation formats to develop innovations. The assessment of the activities' scale and of third-party organizations' contribution to the development and implementation of innovations by enterprises is based on indicators such as "Share of organizations in total number of those that applied ready-made technological innovations over past three years, mainly developed...by other organizations" (18.2%); "jointly with other organizations" (27.1%); "by changing or modifying products developed by other organizations" (5.8%); "on their own" (51.5%). Thus, the absence of external partners' significant contribution to innovative development was established for more than half of enterprises engaged in technological innovation. For manufacturing enterprises, the most valuable sources of information they need to create technological innovations are the consumers of their products and services (11% of organizations), suppliers of (raw) materials (5.4%), competitors (5%), and legislative and executive authorities (4.6%). R&D and educational organizations play a much less important role for most enterprises: academic R&D organizations account for 0.6%, industrial ones for 2.7%, and universities for 1.2% of the total number of surveyed organizations.

Aggregated official statistical indicators reflect the generally low level of cooperative ties in the Russian national innovation system. Studies that use data on individual enterprises present in-depth analyses of various aspects of cooperation, including quantitative parameters of factors, barriers, and drivers of business-science cooperation [*Roud, Vlasova,* 2020; Dezhina et al., 2018; Simachev et al., 2014]. One of the main conclusions of these studies is that partnership with R&D organizations goes beyond the traditional linear innovation model, since cooperation may not be limited to joint R&D projects and include various types of knowledge-intensive services, human capital development, or strengthening internal competencies. Such cooperation is based on cultural similarity, which allows one to overcome barriers to cooperation associated with different management strategies and the "target functionality" of companies and R&D organizations, which understand project success differently. The stereotype about Russian science's inability to provide high-quality applied results has not actually been confirmed. Rather, we should talk about different strategic goals of business and science due both to institutional and corporate specifics (e.g., short planning horizons) and the R&D sphere's structural features (the prevalence of public funding and the almost complete absence of mechanisms for attracting funds from other sources among R&D organizations' performance indicators).

There is a pronounced lack of studies presenting a micro-level analysis of companies' network innovative development cooperation with a wide range of partners (based on data for individual enterprises). In some cases (e.g., [*Bykova, Molodchik,* 2009]), the authors positively assess the relationship between cooperation and certain aspects of enterprises' performance. However, without the harmonized conceptual apparatus of the Oslo Manual, it is impossible to compare and unambiguously interpret the identified patterns [*Kratzer et al.*, 2017]. Using Russian enterprises' open innovation strategic culture as an example, it can be demonstrated that only 9.3% of innovative manufacturing enterprises have developed an internal culture focused on the efficient absorption of external ideas and knowledge, which, taken together with the available statistical data, calls into question the development prospects for the country's innovation capabilities. Studying the diversity of innovation strategies, the compatibility of various partnership formats, and factors affecting the forms and nature of such cooperation becomes relevant to better understanding the mechanisms of the Russian national innovation system and shaping effective state science and innovation policy.

Methodology and the Basis of this Study

The results of two waves of the Monitoring of Russian Enterprises' Innovation Activity survey (2015 and 2018), conducted by the Institute for Statistical Studies and Economics of Knowledge (ISSEK) of the Higher School of Economics (HSE) since 2009 in the framework of the HSE Basic Research Programme[2] provided the empirical basis for this study. The survey covers manufacturing enterprises in at least 40 Russian regions, in all federal districts, which employ more than 15 workers; its methodology is based on the Oslo Manual [OECD, Eurostat, 2018]. Data was collected through a series of structured interviews with executive managers using a questionnaire. The questionnaire comprised several sections: general characteristics of the enterprise; development and implementation of innovations; innovation development cooperation; public support of innovation; use of advanced technologies; and organization of production.

In 2015, the survey was conducted across all manufacturing industries. The final sample comprised 1,324 enterprises, 805 of which (60.8%) were innovation-active, i.e., they developed and/or introduced at least one technological innovation in 2011-2013. In 2018, the survey covered high-tech and medium tohigh technology manufacturing firms (according to the OECD/Eurostat classification).[3] A total of 545 companies were surveyed; 422 of which (77.4%) were innovation-active. The survey data was weighted by population characteristics (the number of enterprises in each industry sector and size group) derived from the Federal State Statistics Service (Rosstat).

At the first stage, typical configurations of cooperation networks were investigated. To identify them, three aspects of the cooperation strategy were analyzed: the choice of partners, the role of spatial distance, and the duration of cooperation. These models were examined in terms of enterprise size, age, ownership structure, and type of economic activity. Cluster analysis served as the main research method. Differences in variables' average values across clusters were analyzed to assess the "openness" of innovation strategies.[4]

To operationalize the innovative performance, a typology covering two key dimensions was used: the degree of innovation novelty in accordance with Oslo Manual recommendations (new to the firm or new to the market) and enterprises' integration into global value chains through export activities (non-zero volume of products shipped to foreign markets). Four gradations of "advanced" innovators were constructed, within which the role of cooperation was investigated. The impact of cooperation networks' configuration upon enterprises' innovative capabilities was estimated using multivariate logistic regressions.

Particular attention was paid to the role of industry-science cooperation as a driver of technological innovation. A comparative analysis of entrepreneurial strategies, along with intellectual property creation and dissemination practices of enterprises engaged and not engaged in cooperation with R&D and educational organizations was carried out.[5] Taking into account that high- and medium-to-high-tech manufacturing enterprises demonstrate the highest level of innovative activity (the share of enterprises engaged in technological innovation of all enterprises in 2017 is 31.8% and 19.9% of organizations, respectively), the analysis was based on the 2018 survey data.

The Configuration of Cooperation Networks

To identify patterns in innovation partnership network configurations in the Russian manufacturing industry, three aspects of network cooperation were studied: choice of cooperation partners, geographic distance from them, and length of cooperation. The analysis allowed the authors to identify differences in enterprises' innovative behavior depending upon their cooperation strategy.

The results confirm that innovation is a network phenomenon. Cooperation plays an important role in Russian manufacturing enterprises' innovation strategies: the vast majority of respondents in the survey (98.5%) involve external organizations in their innovation projects. Practically all of them cooperate with members of their value chain, first of all, with direct consumers of their products (76.3%) and sup-

[2] For more, see: https://www.hse.ru/monitoring/innproc/, accessed on 20.08.2020.

[3] For more, see: https://ec.europa.eu/eurostat/statistics-explained/pdfscache/6384.pdf, accessed on 20.08.2020.

[4] The statistical significance of the differences in mean values between clusters was tested using the Kruskal-Wallis test.

[5] Fisher's criterion was applied to assess the significance of differences between companies engaged and not engaged in science-industry cooperation.

Table 1. **Cooperation Partners (share of those who chose the appropriate option in the total number of innovative enterprises, by innovation and enterprise type, %)**

Partners	Total	Firms by innovation status and export activity			
		New to firm, Non-exporters	New to firm, Exporters	New to market, Non-exporters	New to market, Exporters
		62.2	17.1	14.0	6.7
Clients	76.3	77.0	71.0	73.5	88.6
Suppliers	73.8	74.1	78.1	64.9	77.9
Providers of services	31.1	31.1	35.7	28.1	25.9
Related value-chain members	29.6	29.1	30.3	25.7	39.7
Competitors	17.1	16.5	18.3	17.5	18.7
R&D organizations	25.0	19.1	39.9	16.9	58.3
Universities	18.5	15.9	25.8	15.3	29.9
Consulting firms	8.9	9.3	10.6	4.8	9.8
Public authorities	22.1	23.9	19.8	14.4	27.7

Question: Please indicate the type of innovation cooperation partner

Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity, 2015

pliers of (raw) materials and components (73.8%) (Table 1).

However, the networking remains underdeveloped. Enterprises with a high innovative capabilities tend to have detailed cooperation strategies. Enterprises integrated into global value chains (23.8%) are more likely to involve R&D organizations and universities in their innovation projects (over 25% in each group) and cooperate with government agencies. More than half of the companies producing highly innovative products competitive on international markets (20.7%) cooperate with R&D organizations.

A cooperation strategy primarily focused on supply chain partners is more typical for small and low-tech enterprises (39.9%) who cooperate only with regional suppliers and consumers, and for large companies interested in exporting newly developed innovative products (42.6%) and integrating into national and global value chains (Table 2).

Less than 20% of the surveyed enterprises had a geographically wide network of partners. Global networking tends to increase with companies' more advanced industrial activities and ambition to compete with foreign manufacturers. A distinctive feature of advanced innovators is cooperating with R&D organizations and universities as well as involving public authorities and consulting firms in their innovation projects.

Due to the complexity and long duration of innovation projects, establishing long-term relationships with partners is a key to successful cooperation. Meanwhile, over 40% of Russian manufacturing enterprises only have irregular one-off contracts with their partners, mainly in the value chain framework (Table 3). About a third of enterprises maintain permanent contacts with customers and suppliers of (raw) materials and components but interact with other partners only occasionally. Enterprises' entry on foreign high-tech product markets and public participation in their ownership facilitates the expansion of their cooperation and the establishment of long-term partnerships, including with R&D organizations.

Classifying cooperation strategies by partners' geographical location and length of cooperation with them revealed that one-time contracts with regional and national suppliers and customers remain the most common cooperation model in the Russian manufacturing industry (Table 4). International network cooperation is extremely rare and only happens in the framework of long-term relationships, including those involving R&D organizations and universities in innovation projects.

Assessing the impact of openness upon the actual productivity of enterprises' innovation activities confirmed the hypothesis of its high importance for broad network cooperation with various partners (Table 5). For example, focusing on the domestic market and the development of incremental innovations require partnerships with the federal authorities, while to successfully export products, enterprises need to integrate into national and global value chains and cooperate with R&D organizations and/or universities. Furthermore, only participation in complex cooperation networks in the framework of long-term relationships with the R&D sector and market participants outside their value chain (i.e., competitors and related companies) and the region increases companies' chances to integrate into global value chains.

Advanced innovators tend to actively cooperate with the R&D sector. Strengthening industry-science cooperation and partnerships with value chain members outside the region play a key role in export-oriented manufacturing enterprises' activities. Establishing long-term relations with R&D organizations

Table 2. **Cooperation Network Configurations Based on the Spatial Proximity to Partners (cluster analysis results)**

A. Cooperation Models: Geographical Aspect

Clusters		Value chain: within region	Value chain: beyond region	Value chain: global, Science: within region	Value chain: global, Science: beyond region	Total
Cluster size		39.9	42.6	12.7	4.9	
Indicators: Innovation cooperation with (% of enterprises)						
Clients	R	73.4	34.1	85.1	30.0	56.1
	N	0.0	52.9	72.2	65.2	34.9
	F	0.0	9.1	27.6	17.4	8.2
Suppliers	R	67.1	17.4	76.1	34.2	45.5
	N	0.4	60.7	88.9	59.5	40.2
	F	1.6	16.5	47.6	38.5	15.6
Providers of services	R	26.6	7.6	84.2	14.6	25.3
	N	0.0	11.9	44.2	31.2	12.2
	F	0.0	1.2	17.7	8.5	3.2
Related value-chain members	R	24.1	4.0	54.5	30.6	19.7
	N	1.7	14.7	42.4	42.8	14.4
	F	0.0	3.1	8.8	6.7	2.8
Competitors	R	11.0	1.6	47.7	2.9	11.2
	N	0.9	4.6	38.5	21.0	8.2
	F	1.1	1.3	9.1	4.4	2.4
R&D organizations	R	11.5	4.1	42.8	55.7	14.5
	N	1.5	17.0	21.5	94.1	15.2
	F	0.0	1.9	0.0	10.1	1.3
Universities	R	9.5	7.2	44.1	51.6	14.9
	N	0.4	1.9	8.5	88.9	6.4
	F	0.0	0.1	0.0	9.3	0.5
Consulting firms	R	6.9	0.0	19.5	17.2	6.1
	N	0.0	1.9	10.1	15.6	2.9
	F	0.0	1.3	0.6	4.3	0.9
Public authorities	R	19.0	5.8	45.6	44.7	18.0
	N	0.4	5.6	12.2	43.3	6.2
	F	0.0	0.2	0.0	1.7	0.2

Partners: R — regional (located at a distance of less than 100 km); N — national (more than 100 km); F — foreign

Models of co-operation: ■ — vertical (actors in supply chains); ■ — horizontal (other market players); ■ — institutional (R&D organizations); ■ — consulting firms; ■ — governmental bodies. The same legend is for Table 3A.

B. Enterprise Characteristics

Clusters	Value chain: within region	Value chain: beyond region	Value chain: global, Science: within region	Value chain: global, Science: beyond region	Total
Size:					
small (< 100 employees)	42.5	26.9	11.7	11.1	30.4
medium (100–500)	43.5	53.4	67.3	38.9	50.5
large (> 500)	14.0	19.7	20.9	50.0	19.1
Newly established (less than 5 years)	7.8	5.7	4.5	1.9	6.2
State ownership	13.7	5.9	7.2	29.0	10.3
Sector:					
low-tech	62.1	41.1	32.7	13.0	47.0
medium low-tech	20.2	20.9	24.8	18.5	21.0
medium high-tech	11.5	28.9	32.4	38.4	22.9
high-tech	6.2	9.1	10.1	30.1	9.1
Types of enterprises-technological innovators:					
new to firm, non-exporters	73.3	55.7	59.5	35.6	62.2
new to firm, exporters	8.9	22.5	20.5	28.4	17.1
new to market, non-exporters	16.7	12.5	12.8	8.5	14.0
new to market, exporters	1.1	9.4	7.2	27.6	6.7

Note: Black font highlights values that are beyong average (the last column), gray highlights values that are lower. Differences between clusters are statistically significant. The authors can provide group comparison results based on the Kruskal-Wallis test upon request. The same is applicable to the Table 3.

Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity, 2015

Table 3. Cooperation Network Configurations Based on the Duration of Cooperation (cluster analysis results)

A. Cooperation Models: Temporal Aspect

Clusters		Value chain: one-time	Value chain: regular	Science: long-term	Networking: long-term	Total
Cluster size		43.8	35.4	15.4	5.4	
Indicators: Innovation cooperation with (% of enterprises)						
Clients	S	20.4	0.7	13.9	14.8	12.1
	M	13.0	15.7	17.0	10.9	14.5
	L	15.5	83.5	56.0	56.5	48.0
Suppliers	S	20.7	3.0	15.7	0.0	12.5
	M	15.2	20.2	14.8	32.2	17.8
	L	11.8	73.4	51.1	60.2	42.3
Providers of services	S	9.1	4.1	5.1	0.7	6.3
	M	4.0	10.7	5.9	15.5	7.3
	L	4.3	28.5	12.0	57.2	16.9
Related value-chain members	S	6.9	2.2	6.2	0.7	4.8
	M	7.4	4.0	9.8	15.9	7.0
	L	7.7	23.0	22.8	40.3	17.2
Competitors	S	2.0	3.3	0.3	14.8	2.9
	M	2.1	5.8	3.5	8.4	3.9
	L	0.9	17.9	9.0	34.9	10.0
R&D organizations	S	7.4	5.1	4.1	15.4	6.5
	M	0.9	3.2	25.9	13.4	6.3
	L	0.4	1.5	55.6	54.5	12.2
Universities	S	1.4	3.5	4.1	0.7	2.5
	M	1.9	3.1	14.3	36.2	6.1
	L	0.3	1.8	43.6	39.0	9.6
Consulting firms	S	2.8	2.3	3.3	14.8	3.4
	M	0.8	1.1	0.0	33.9	2.6
	L	0.0	0.0	0.0	51.4	2.8
Public authorities	S	4.0	2.0	4.9	0.7	3.2
	M	1.9	4.8	6.1	11.2	4.1
	L	7.0	14.4	22.5	55.9	14.7

Links: S — short-term (one-time and/or <1 year); M — medium-term (1-5 years), L — long-term (>5 years and/or regular)

B. Enterprise Characteristics

Clusters	Value chain: one-time	Value chain: regular	Science: long-term	Networking: long-term	Total
Size:					
small (< 100 employees)	32.9	35.1	12.6	30.2	30.4
medium (100–500)	49.9	50.8	55.1	40.4	50.5
large (> 500)	17.2	14.1	32.3	29.5	19.1
Newly established (less than 5 years)	8.4	6.3	2.2	0.0	6.2
State ownership	6.3	9.8	16.3	29.3	10.3
Sector:					
low-tech	53.0	51.9	16.1	55.4	47.0
medium low-tech	22.2	21.1	21.9	8.4	21.0
medium high-tech	19.7	18.1	43.3	21.5	22.9
high-tech	5.1	8.9	18.7	14.7	9.1
Types of enterprises-technological innovators:					
new to firm, non-exporters	63.8	69.2	40.5	65.0	62.2
new to firm, exporters	17.9	12.3	25.9	17.0	17.1
new to market, non-exporters	15.7	14.2	11.8	5.7	14.0
new to market, exporters	2.6	4.3	21.8	12.3	6.7

Note: Differences between clusters are statistically significant. The authors can provide group comparison results based on the Kruskal-Wallis test upon request.

Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity, 2015

Table 4. **Cooperation Network Configurations (share of those who chose the appropriate model in the total number of innovative enterprises, %)**

Geographic scope	Duration				Total
	Value chain: one-time	Value chain: regular	Science: long-term	Networking: long-term	
Value chain: within region	21.5	14.2	2.9	1.3	39.9
Value chain: beyond region	20.9	13.8	7.0	0.8	42.6
Value chain: global, Science: within region	1.1	7.2	2.5	2.0	12.7
Value chain: global, Science: beyond region	0.3	0.3	3.0	1.3	4.9
Total	43.8	35.4	15.4	5.4	100.0

Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity, 2015

and universities strengthens companies' innovation capabilities and increases their export opportunities.

Cooperation with Science as a Driver of Innovation

An analysis of cooperation networks' configurations showed that collaborating with the R&D sector is the most important strategic vector and attribute of innovative international-level companies. Let us see what the differences are between innovatively active enterprises cooperating with R&D organizations and/or universities and those who neglect it.

According to the survey results, R&D sector players are an important source of information for enterprises that rely on innovation as their main competitive advantage (Table 6). Over the course of innovative development, companies that introduce new (69.1%) and improve existing products (48.2%) most actively

Table 5. **Components of Cooperation Networks that Determine the Types of Enterprises – Technological Innovators in Russian Manufacturing**

Partners	Components of cooperation networks	Firms by innovation status and export activity			
		New to firm. Non–exporters	New to firm. Exporters	New to market. Non–exporters	New to market. Exporters
Value–chain members	Cooperation=Yes	0.035	0.025	–0.027	–0.033
		(0.071)	(0.049)	(0.054)	(0.037)
	Geography: out of region	**–0.141*** **	**0.131*** **	–0.006	0.016
		(0.039)	(0.028)	(0.029)	(0.018)
	Duration: more than 1 year	0.081	0.012	–0.056	–0.037
		(0.051)	(0.036)	(0.040)	(0.029)
R&D organizations and/or universities	Cooperation=Yes	**–0.108** **	**0.085** **	0.004	0.019
		(0.043)	(0.034)	(0.031)	(0.018)
	Geography: out of region	**–0.171*** **	**0.071* **	0.062	0.038
		(0.054)	(0.040)	(0.043)	(0.024)
	Duration: more than 1 year	**–0.153*** **	**0.107*** **	0.009	**0.038* **
		(0.046)	(0.037)	(0.033)	(0.021)
Other market actors	Cooperation=Yes	–0.003	**–0.0465* **	0.024	0.026
		(0.037)	(0.027)	(0.026)	(0.016)
	Geography: out of region	–0.026	–0.037	0.024	**0.039* **
		(0.043)	(0.028)	(0.032)	(0.021)
	Duration: more than 1 year	–(0.028)	**–0.0505* **	(0.047)	**0.031* **
		(0.039)	(0.028)	(0.029)	(0.018)
Public authorities	Cooperation=Yes	0.024	–0.020	–0.039	0.035
		(0.046)	(0.032)	(0.031)	(0.022)
	Geography: out of region	**0.125** **	–0.037	**–0.0994*** **	0.011
		(0.061)	(0.041)	(0.032)	(0.026)
	Duration: more than 1 year	0.049	–0.042	–0.028	0.021
		(0.049)	(0.033)	(0.034)	(0.022)

Note: The results of three multinomial logit-models estimation by cooperation components (marginal effects). Additional control variables: size, age, state ownership, and sector. Statistically significant coefficients are presented in bold characters; *. ** and *** denote significance at 10%. 5% and 1%. respectively.

Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity. 2015

Table 6. **Strategic Priorities of High and Medium-High Technology Manufacturing Enterprises (share of those who chose the appropriate option in the total number of innovative enterprises, %)**

Percentage of enterprises strategically focused on:	Cooperation with universities or R&D organizations in innovation		Total
	Yes	No	
Improving existing goods and services	48.2	45.4	46.8
Introducing new goods or services	69.1	60.9	64.8
Providing low-prices (price leadership)	16.4	34.7	25.9
Providing high-quality (quality leadership)	75.3	84.6	80.1
Guaranteeing adherence to delivery times	45.5	47.4	46.5
Providing product-related services	18.5	18.4	18.5
Satisfying established customer groups	12.4	18.1	15.3
Reaching out to new customer groups	35.3	27.0	31.0
Manufacturing one or a small number of key goods or services	13.1	11.5	12.2
Manufacturing a broad range of goods or services	17.8	21.8	19.9
Offering standardized goods or services	4.4	11.0	7.8
Offering customer-specific solutions	18.6	25.5	22.1
Compliance with international standards	15.7	25.4	20.8
Sustainable and responsible production (eco-friendly, ethical, etc.)	9.4	16.2	12.9

Question: Which of the following strategies is more important to the economic performance of your enterprise? Choose no more than four answers.

Note: Black font highlights values that are beyong average (the last column), gray highlights values that are lower. The authors can provide the results of checking the differences between enterprise groups using the Fisher test upon request.

Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity, 2018.

cooperate with research organizations and universities to achieve commercial success. In contrast to those not involved in industry-science cooperation, they are more often focused on the strategic search for new customer groups (35.3%) and expanding their product line (13.1%).

Companies interacting with the R&D sector proactively generate, disseminate, and commercially apply new knowledge. They are the key technology market operators and the cornerstones of the innovation system. This is evidenced by their demand for the official protection of created intangible assets and involvement in intellectual property transfers, which are higher than the average for high- and medium-high technology manufacturing enterprises (Table 7). More than 40% of innovative enterprises cooperating with R&D organizations and universities have applied for a patent at least once over the past three years. Trademarks (26.1%), utility models (21.9%), and know-how (18.5%) were used less frequently. A much smaller share of enterprises (less than 6%) is involved in the transfer of intellectual property. The main dissemination channels are agreements on using know-how, licensing, and exchanging intellectual activity results.

The conducted empirical analysis provided a comprehensive picture of Russian manufacturing enterprises' cooperation strategies. It demonstrated that enterprises' ability to develop network cooperation determines the level of their innovative efforts (the capabilities to develop innovations that are new for the market) and their access to global value chains. A distinctive feature of the most innovative enterprises is the ability to establish close cooperation with R&D organizations and maintain long-term relationships.

Conclusion

This study intended to deliver empirical evidence from the Russian context on the variety of cooperative strategies and their impact upon innovative performance. A positive relationship has been demonstrated between the openness of innovation strategies and enterprises' innovation productivity expressed as the ability to produce products that are new for the market and are integrated into global value chains.

The survey results emphasize that in the Russian manufacturing industry, almost all innovation-active enterprises cooperate with external partners in developing innovations. However, only a few companies have an extensive partner network. Classifying cooperation strategies by partners' geographical location and length of cooperation revealed that the absolute majority of companies prefer one-time contracts with participants in regional and national value chains (direct consumers of their products and suppliers of (raw) materials and services), while international and long-term network cooperation remains underdeveloped.

Table 7. **Creation and Dissemination of Intellectual Property (share of those who chose the appropriate option in the total number of innovative enterprises, %)**

Question: During the period between 2016 and 2018, did your enterprise perform the following actions with IPRs? Please choose all the appropriate responses.	Cooperation with universities or R&D organisations in innovation		Total
	Yes	No	
Creation:			
Applying for a patent in Russia	43.1	25.8	34.2
Registering a trandmark	26.1	22.2	24.1
Applying for a utility model	21.9	14.5	18.1
Creating know-how	18.5	2.3	12.7
Claiming a copyright	9.1	6.7	7.9
Applying for a patent abroad	5.4	4.1	4.8
Registering an industrial design right	4.0	1.5	2.7
Dissemination:			
Contracting for know-how	6.0	3.9	4.9
License out its own intellectual property rights (IPRs) to others	5.2	2.3	3.7
Selling IPRs	3.1	4.7	4.0
Exchanging IPRs	2.2	1.1	1.6
Establishing franchise relations	0.4	2.1	1.3

Note: Black font highlights values that are beyong average (the last column), gray highlights values that are lower.
Source: authors' estimates based on data from the HSE Monitoring of Enterprises' Innovation Activity, 2018.

This research supports the statement that it is the integration into complex partnership networks and the joint implementation of innovation projects with counterparts from different sectors of the economy that contribute to strengthening enterprises' innovative capabilities. Integration into global value chains is facilitated by abandoning the rigid vertical cooperation model (limited by the value chain framework) and strengthening cooperation with R&D organizations. Increasing the level of business innovation (i.e., the ability to create solutions not available on the market) is directly related to establishing stable, long-term network connections, cooperating with Russian science (universities, academic organizations) and with market participants outside the value chain (competitors and related enterprises).

Therefore, enterprises with the highest innovative capabilities tend to cooperate with R&D and educational organizations. Active cooperation with universities and research organizations determines companies' ability to create highly innovative products that are competitive on foreign markets. Innovation (making new and improving existing products) is a key element of business models and a decisive factor in the commercial success of such companies, as opposed to those not involved in industry-science cooperation. Such enterprises can turn into "facilitators of technological dissemination" in the Russian innovation system and act as proactive technology market operators relatively more often by becoming involved in the creation and dissemination of intangible assets.

Company size has traditionally played a critical role in scaling network connections and developing innovation partnerships. In the Russian manufacturing industry, large high and medium-high technology enterprises are more likely to have detailed cooperation strategies. The variables associated with government participation in enterprise management are statistically significant. Such companies have a pronounced tendency to establish links with other institutional partners. However, the available data does not yet allow one to assess the effectiveness of these contacts.

Thus, a study based on Russian material has demonstrated that having an extensive partner network is a clear indicator that the enterprise has high innovative capabilities. Against this background, the weak development of innovation partnership networks in the Russian manufacturing industry and the low intensity of ties between the participants in innovative activities become a "bottleneck" of the national innovation system. Understanding enterprises' actual innovative behavior strategies and their possible development paths provides an empirical basis for developing support measures in the field of innovation. The key to strengthening innovation in the real sector and accelerating technological development is in promoting and scaling network collaboration and industry-science cooperation.

The paper was prepared as a result of research carried out in the framework of the National Research University Higher School of Economics Basic Research Programme.

References

Arranz N., de Arroyabe J.C.F. (2008) The choice of partners in R&D cooperation: An empirical analysis of Spanish firms. *Technovation,* vol. 28, no 1–2, pp. 88–100. DOI: 10.1016/j.technovation.2007.07.006.

Aschhoff B., Schmidt T. (2008) Empirical evidence on the success of R&D cooperation — happy together? *Review of Industrial Organization,* vol. 33, no 1, pp. 41–62. DOI: 10.1007/s11151-008-9179-7.

Balland P.A., Boschma R., Crespo J., Rigby D.L. (2019) Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. *Regional Studies,* vol. 53, no 9, pp. 1252–1268. DOI: 10.1080/00343404.2018.1437900.

Barney J.B. (2001) Resource-based theories of competitive advantage: A ten-year retrospective on the resource-based view. Journal of Management, vol. 27, no 6, pp. 643–650. DOI: 10.1177/014920630102700602.

Becker W., Dietz J. (2004) R&D cooperation and innovation activities of firms — evidence for the German manufacturing industry. *Research Policy,* vol. 33, no 2, pp. 209–223. DOI: 10.1016/j.respol.2003.07.003.

Belderbos R., Carree M., Diederen B., Lokshin B., Veugelers R. (2004) Heterogeneity in R&D cooperation strategies. *International Journal of Industrial Organization,* vol. 22, no 8–9, pp. 1237–1263. DOI:10.1016/j.ijindorg.2004.08.001.

Belderbos R., Carree M., Lokshin B. (2004) Cooperative R&D and firm performance. *Research olicy,* vol. 33, no 10, pp. 1477–1492. DOI: 10.26481/umamet.2004020.

Bessonova E., Gonchar K. (2019) How the innovation-competition link is shaped by technology distance in a high-barrier catch-up economy. *Technovation,* vol. 86, pp. 15–32. DOI: 10.1016/j.technovation.2019.01.002.

Boschma R. (2005) Proximity and innovation: A critical assessment. *Regional Studies,* vol. 39, no 1, pp. 61–74. DOI: 10.1080/0034340052000320887.

Breschi S., Malerba F., Orsenigo L. (2000) Technological regimes and Schumpeterian patterns of innovation. *Economic Journal,* vol. 110, no 463, pp. 388–410. DOI: 10.1111/1468-0297.00530.

Bykova A., Molodchik M. (2009) Praktiki «otkrytykh innovatsii» v Rossii: empiricheskoe issledovanie innovatsionnogo povedeniia predpriiatii Permskogo kraia [Open innovation practices: empirical research of firm's innovation activity in Perm Region]. *Korporativnye finansy / Journal of Corporate Finance Research*, vol. 3, no 3, pp. 77–93. DOI: 10.17323/j.jcfr.2073-0438.3.3.2009.77-93 (in Russian).

Caloghirou Y., Kastelli I., Tsakanikas A. (2004) Internal capabilities and external knowledge sources: complements or substitutes for innovative performance? *Technovation,* vol. 24, no 1, pp. 29–39. DOI: 10.1007/s12130-005-1005-z.

Carlsson S., Corvello V., Schroll A., Mild A. (2011) Open innovation modes and the role of internal R&D. *European Journal of Innovation Management,* vol. 14, no 4, pp. 475–495. DOI: 10.1108/14601061111174925.

Castellacci F. (2008) Technological paradigms, regimes and trajectories: Manufacturing and service industries in a new taxonomy of sectoral patterns of innovation. *Research Policy,* vol. 37, no 6–7, pp. 978–994. DOI: 10.1016/j.respol.2008.03.011.

Chesbrough H. (2012) Open innovation: Where we've been and where we're going. *Research-Technology Management,* vol. 55, no 4, pp. 20–27. DOI: 10.5437/08956308x5504085.

Chesbrough H.W. (2003) *Open innovation: The new imperative for creating and profiting from technology*, Boston, MA: Harvard Business Press.

Cohen W.M., Levinthal D.A. (1990) Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly,* vol. 35, no 1, pp. 128–152. DOI: 10.2307/2393553.

Dachs B., Ebersberger B., Pyka A. (2008) Why do firms cooperate for innovation? A comparison of Austrian and Finnish CIS3 results. *International Journal of Foresight and Innovation Policy,* vol. 4, no 3–4, pp. 200–229. DOI: 10.1504/ijfip.2008.017577.

Dahlander L., Gann D.M. (2010) How open is innovation? *Research Policy*, vol. 39, no 6, pp. 699–709. DOI: 10.1016/j.respol.2010.01.013.

De Faria P., Lima F., Santos R. (2010) Cooperation in innovation activities: The importance of partners. *Research Policy,* vol. 39, no 8, pp. 1082–1092. DOI: 10.1016/j.respol.2010.05.003.

Dezhina I.G., Medovnikov D.S., Rozmirovich S.D. (2018) Otsenki sprosa rossiiskogo srednego tekhnologicheskogo biznesa na sotrudnichestvo s vuzami [Evaluating the demand of Russian medium-size technological companies in cooperation with higher educational institutes]. *Zhurnal Novoj ehkonomicheskoj associacii / Journal of the New Economic Association*, vol. 36, no 4, pp. 81–105. DOI: 10.31737/2221-2264-2017-36-4-4 (in Russian).

Edquist C. (2011) Design of innovation policy through diagnostic analysis: Identification of systemic problems (or failures). *Industrial and Corporate Change,* vol. 20, no 6, pp. 1725–1753. DOI: 10.1093/icc/dtr060.

Fagerberg J., Mowery D.C., Nelson R.R. (eds.) (2005) *The Oxford Handbook of Innovation,* Oxford (UK): Oxford University Press. DOI: 10.1093/oxfordhb/9780199286805.001.0001.

Freeman C. (1987) *Technology policy and economic performance: Lessons from Japan,* London: Pinter.

Fritsch M., Lukas R. (2001) Who cooperates on R&D? *Research Policy,* vol. 30, no 2, pp. 297–312. DOI: 10.1016/s0048-7333(99)00115-8.

Godin B. (2006) The linear model of innovation: The historical construction of an analytical framework. *Science, Technology and Human Values,* vol. 31, no 6, pp. 639–667. DOI: 10.1177/0162243906291865.

Godin B. (2008) *Innovation: The history of a category* (Project on the Intellectual History of Innovation Working Paper no 1), Québec: Institut national de la recherche scientifique.

Gokhberg L., Kuznetsova T. (2015) Russian Federation. *UNESCO Science Report: Towards 2030* (ed. S. Schneegans), Paris: UNESCO, pp. 343–363.

Greco M., Grimaldi M., Cricelli L. (2016) An analysis of the open innovation effect on firm performance. *European Management Journal,* vol. 34, no 5, pp. 501–516. DOI: 10.1016/j.emj.2016.02.008.

Hayter C.S., Nelson A.J., Zayed S., O'Connor A.C. (2018) Conceptualizing academic entrepreneurship ecosystems: A review, analysis and extension of the literature. *Journal of Technology Transfer*, vol. 43, no 4, pp. 1039–1082. DOI: 10.2139/ssrn.3137406.

HSE (2019) *Indikatory innovatsionnoi deyatel'nosti: statisticheskii sbornik* [Indicators of Innovation: Yearbook], oscow: HSE (in Russian).

Humphrey J., Schmitz H. (2002) How does insertion in global value chains affect upgrading in industrial clusters? *Regional Studies,* vol. 36, no 9, pp. 1017–1027. DOI: 10.1080/0034340022000022198.

Kaufmann A., Tödtling F. (2001) Science–industry interaction in the process of innovation: The importance of boundary-crossing between systems. *Research Policy,* vol. 30, no 5, pp. 791–804. DOI: 10.1016/s0048-7333(00)00118-9.

Kim Y., Vonortas N.S. (2014) Cooperation in the formative years: Evidence from small enterprises in Europe. *European Management Journal,* vol. 32, no 5, pp. 795–805. DOI: 10.1016/j.emj.2014.02.003.

Kline S., Rosenberg N. (1986) *The positive sum strategy: Harnessing technology for economic growth*, Washington, DC: National Academy Press. DOI: 10.17226/612.

Kratzer J., Meissner D., Roud, V. (2017) Open innovation and company culture: Internal openness makes the difference. *Technological Forecasting and Social Change,* vol. 119, pp. 128–138. DOI: 10.1016/j.techfore.2017.03.022.

Kuznetsova T., Roud V. (2013) Konkurenciya, innovacii i strategii razvitiya rossijskih predpriyatij (rezul'taty empiricheskih issledovanij [Competition, innovation and strategy: Empirical evidence from Russian enterprises]. *Voprosy Ekonomiki,* no 12, pp. 86–108. DOI: 10.32609/0042-8736-2013-12-86-108 (in Russian).

Laursen K., Salter A. (2006) Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal,* vol. 27, no 2, pp. 131–150. DOI: 10.1002/smj.507.

Lee K. (2020) Openness and innovation in online higher education: A historical review of the two discourses. *Open Learning: The Journal of Open, Distance and e-Learning,* pp. 1–21. DOI: 10.1080/02680513.2020.1713737.

Leydesdorff L., Rotolo D., de Nooy W. (2013) Innovation as a nonlinear process, the scientometric perspective, and the specification of an 'innovation opportunities explorer. *Technology Analysis and Strategic Management*, vol. 25, no 6, pp. 641–653. DOI: 10.1080/09537325.2013.801948.

Lhuillery S., Pfister E. (2009) R&D cooperation and failures in innovation projects: Empirical evidence from French CIS data. *Research Policy,* vol. 38, no 1, pp. 45–57. DOI: 10.1016/j.respol.2008.09.002.

Lundvall B.Å. (1992) *National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning*, London: Pinter.

Nambisan S., Wright M., Feldman M. (2019) The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes. *Research Policy,* vol. 48, no 8, pp. 1–9. DOI: 10.1016/j.respol.2019.03.018.

Nelson R. (ed.) (1993) *National Innovation Systems,* New York: Oxford University Press.

Nieto M.J., Santamaría L. (2007) The importance of diverse collaborative networks for the novelty of product innovation. *Technovation,* vol. 27, no 6–7, pp. 367–377. DOI: 10.1016/j.technovation.2006.10.001.

OECD (2015) *The future of productivity. Joint Economics Department and the Directorate for Science, Technology and Innovation Policy Note,* Paris: OECD. DOI: 10.1787/9789264248533-en.

OECD, Eurostat (2018) *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation* (4th ed.), Paris: OECD. DOI: 10.1787/24132764.

Perkmann M., Walsh K. (2007) University–industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews,* vol. 9, no 4, pp. 259–280. DOI: 10.1111/j.1468-2370.2007.00225.x.

Plewa C., Korff N., Baaken T., Macpherson G. (2013) University–industry linkage evolution: An empirical investigation of relational success factors. *R&D Management,* vol. 43, no 4, pp. 365–380. DOI: 10.1111/radm.12021.

Rosenbloom R.S., Spencer W.J. (1996) The transformation of industrial research. *Issues in Science and Technology,* vol. 12, no 3, pp. 68–74.

Roud V., Fursov K. (2011) Rol' statistiki v diskussii o nauchno-tekhnologicheskom i innovatsionnom razvitii [The role of statistics in the debate on science, technology, and innovation]. *Voprosy Ekonomiki*, no 1, pp. 138–150. DOI: 10.32609/0042-8736-2011-1-138-150 (in Russian).

Roud V., Vlasova V. (2020) Strategies of industry-science cooperation in the Russian manufacturing sector. *Journal of Technology Transfer,* vol. 45, no 3, pp. 870–907. DOI: 10.1007/s10961-018-9703-3.

Simachev Y., Kuzyk M., Feygina V. (2014) Vzaimodejstvie rossijskih kompanij i issledovatel'skih organizacij v provedenii NIOKR: tretij ne lishnij? [R&D cooperation between Russian firms and research organizations: Is there a need for state assistance?]. *Voprosy Ekonomiki*, no 7, pp. 4–34. DOI: 10.32609/0042-8736-2014-7-4-34 (in Russian).

Srholec M. (2015) Understanding the diversity of cooperation on innovation across countries: Multi-level evidence from Europe. *Economics of Innovation and New Technology,* vol. 24, no 1–2, pp. 159–182. DOI: 10.1080/10438599.2014.897864.

Teece D.J. (2007) Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal,* vol. 28, no 13, pp. 1319–1350. DOI: 10.1002/smj.640.

Teplykh G. (2015) Draivery innovatsionnoi aktivnosti promyshlennykh kompanii v Rossii [Drivers of innovation activity of manufacturing enterprises in Russia]. *Prikladnaya ekonometrika / Applied Econometrics,* no 2 (38), pp. 83–110 (in Russian).

Tether B.S. (2002) Who co-operates for innovation, and why: An empirical analysis. *Research Policy,* vol. 31, no 6, pp. 947–967. DOI: 0.1016/S0048-7333(01)00172-X.

Torre A. (2008) On the role played by temporary geographical proximity in knowledge transmission. *Regional Studies,* vol. 42, no 6, pp. 869–889. DOI: 10.1080/00343400801922814.

Van Beers C., Zand F. (2014) R&D cooperation, partner diversity, and innovation performance: An empirical analysis. *Journal of Product Innovation Management,* vol. 31, no 2, pp. 292–312. DOI: 10.1111/jpim.12096.

Wang C.H., Chang C.H., Shen G.C. (2015) The effect of inbound open innovation on firm performance: Evidence from high-tech industry. *Technological Forecasting and Social Change,* vol. 99, pp. 222–230. DOI: 10.1016/j.techfore.2015.07.006.

Wernerfelt B. (1984) A resource–based view of the firm. *Strategic Management Journal,* vol. 5, no 2, pp. 171–180. DOI: 10.1002/smj.4250050207.

Yakovlev A. (2014) Russian modernization: Between the need for new players and the fear of losing control of rent sources. *Journal of Eurasian Studies,* vol. 5, no 1, pp. 10–20. DOI: 10.1016/j.euras.2013.09.004.

Opening Science and Innovation: Opportunities for Emerging Economies

Selma Leticia Capinzaiki Ottonicar
Ph.D. Candidate, selma.leticia@hotmail.com

Paloma Marín Arraiza
Ph.D. Candidate, pmarrai11@googlemail.com

Sao Paulo State University UNESP, Câmpus de Marília Av. Hygino Muzzi Filho, 737 — Mirante — Marília/SP, Sao Paulo, Brazil

Fabiano Armellini
Assistant Professor, Department of Mathematics and Industrial Engineering, fabiano.armellini@polymtl.ca

Polytechnique Montréal, 2500 Chemin de Polytechnique, Montréal, QC H3T 1J4, Canada

Abstract

Open innovation allows for partnerships between businesses through knowledge sharing. The mission of open science is to encourage information sharing about academic research. The purpose of this paper is to demonstrate the relevance of open science to open innovation and vice versa, especially in the context of emerging economies. Furthermore, it aims to show the results of the intersection between university and innovative companies. The methodology was based upon a systematic literature review to understand how researchers have been studying the subject. It also focuses on the relevance of open innovation and open science for business management and information science fields. Therefore, the connection between open science and open innovation is fundamental to encouraging the partnership between businesses and universities. This kind of partnership contributes to the economy of developing countries, so business can become more competitive.

eywords: open science; open innovation; emerging economies; systematic literature review; innovation; developing countries; business partnership; university and company; business management; information science

Citation: Ottonicar S.L.C., Arraiza P., Armellini F. (2020) Opening Science and Innovation: Opportunities for Emerging Economies. *Foresight and STI Governance*, vol. 14, no 4, pp. 95–111. DOI: 10.17323/2500-2597.2020.4.95.111

Information and communication technology is evolving rapidly and it has become essential in an increasing number of sectors. Both innovation and science have experienced a change in their communication workflows, in their production processes, and, in a more general way, in their modus operandi. Therefore, the world today faces a paradigm shift in scientific and innovation practices.

In the scientific context, the concept of open science is becoming popular. This approach to the scientific process consists of disseminating knowledge and results from the early stages of the process. It also aims at reducing barriers to access to results while open innovation focuses on opening the innovation process to experts in other fields, unlike traditional practice, which focused only on the company's internal human capital [*Chesbrough,* 2003].

Given the fact that Small and Medium Enterprises (SMEs) constitute the most significant number of companies within an economy [*Friesike et al.,* 2015], it is essential to find ways to approximate open business models and the open innovation culture for this type of company. Defining a path toward innovation is particularly necessary for environments such as emerging economies, where the companies do not have enough resources to face such a change as, for instance, the partnerships created between universities and enterprises through collaborative tools to achieve innovative goals. These innovations contribute to information and knowledge sharing which influence competitiveness.

According to [*Chesbrough,* 2003], open innovation fosters the internal and external information flux internally and externally through different tools and allows for the incorporation of new perspectives in all stages of the value chain. The implementation of partnerships focused upon open innovation is fundamental to enterprise adaptation toward new business models and the implementation of best practices.

Germany has some initiatives concerning open science and open innovation because they encourage innovation and knowledge development. German researchers developed a framework of open science and innovation to lead the way toward strategic openness. Open innovation research is more popular than open science, so most studies do not connect the topics [*Blümel et al.,* 2018].

Another example is Sweden, which developed an international partnership with Brazil. This partnership occurs through the Swedish-Brazilian Research and Innovation Centre (CISB) which encourages international collaboration between these two countries. The organization focuses on the partnership between government, academia, and industry to promote open innovation and open science.[1]

These partnerships are particularly important in emerging economies because they provide a solid foundation for the further development of these economies. The term "emerging economies" refers to the rapidly growing, but also volatile, economies of some Asian, African, and Latin American countries. They are also characterized by intermediate incomes and institutional transformations that lead to an economic opening [*Vercueil,* 2012].

Therefore, the purpose of this paper to delve into the intersection between open science and open innovation and demonstrate how SMEs can benefit from this connection and apply it in further product developments. Based on a Systematic Literature Review performed over four different scientific databases with international coverage, this article aims to answer the following research questions.

RQ1: What are the central topics in the literature about open science and open innovation?

RQ2: What are the differences and complementary elements between open science and open innovation?

Open Science to Open Innovation

Open Science is commonly defined as an umbrella term that embraces all the transformations occurring in scientific knowledge creation and dissemination, including open access, open data, open reproducible research, open science evaluation, open science policies, and open science tools. In the literature, OS is understood as knowledge, transparent knowledge, accessible knowledge, shared knowledge, and collaboratively developed knowledge [*Vicente-Saez, Martinez-Fuentes,* 2018]. The OS movement aims to apply the openness principles to all stages of the scientific process, from the hypothesis to data reuse. The opening process "drives collaboration and innovation and maximizes the potential to solve global challenges" [*Ayris et al.,* 2018] and leads to a "new *modus operandi* for science" [European Commission, 2016]. It has been also pointed out that OS practices should always be adopted by scientists [*Watson,* 2015].

With the development of new working models, scientific practices should attract new industrial stakeholders leading to a potent combination of academic and industrial science. However, OS does not directly translate into innovations [*Chesbrough,* 2015]. One aspect is the clear difference in goals: scientific practice aims to generate foundation knowledge and prototype technologies, whereas enterprises are focused on product development. Innovation can be a secondary effect of science; however, there has to be a clear understanding of the OS movement and its implications among the scientific community, industry, and enterprises [*Vicente-Saez, Martinez-Fuentes,* 2018]. This understanding begins by elaborating upon the meaning of "open" in each of the movements. For OS, "open" refers to free access, without cost barriers or with as few barriers as possible. However, "open" in the context of OI means beyond barriers, that is, to be able to attract external

[1] For more details see: http://www.cisb.org.br/, access date 07.11.2020.

talent that complements the internal enterprise development through projects and strategic partnerships.

Considering the different stakeholders of the OS movement, there are four clear perspectives [*Friesike et al.,* 2015]. The *philanthropic* perspective advocates for the democratization of science and focuses on open access to scientific content. The *reflationary* perspective emphasizes the importance of knowledge sharing at the beginning of the research process as a way to promote ideas within the scientific community. The *constructivist* perspective highlights that new knowledge also brings new opportunities for user models and business, for instance, the crowdsourcing model. Finally, the *exploitative* perspective points out how scientific knowledge sharing will lead to a smaller gap between university research and application-oriented knowledge. Following the latter, there is an ever-increasing interest within the scientific community to apply science to business problems [*Chesbrough,* 2015]. Consequently, universities around the world are now actively participating in enterprise incubator centers and public makerspaces and they have established Technology Transfer Offices (TTO) to manage and maximize the use of its intellectual property. All this is in line with the "entrepreneurial university" phenomenon [*Etzkowitz et al.,* 2000] in order to connect university knowledge and practical knowledge, which is created by business processes.

Nonetheless, universities might need to adopt an enabling role in the process of opening innovation and also act as a main stakeholder. According to [*García-Peñalvo et al.,* 2010, p. 530], there are necessary actions for universities to take in order to enable the process: (1) promote an attitude of entrepreneurship, (2) adapt and evolve the educational model continuously in the country or region, using all possible opportunities, (3) combine entrepreneurship and education with a lifelong learning system, (4) support critical and free-thinking, (5) maintain a structure within organizations to promote innovation, and (6) favor open innovation.

It is essential to add the use and promotion of open licenses to these requirements. As indicated in the project FOSTER Open Science, open licenses, such as Creative Commons (CC), "amplify the affordances of digital technology and provide an enhanced means for social production in the networked economy" [European Comission, 2016]. The benefits of the acquisition of this type of license in business might have a direct impact upon cost reduction, the reduction of legal uncertainty, and the promotion of sustainability among SMEs.[2]

The implementation of open licenses also leads to a redefinition of intellectual property (IP), as indicated in the project FOSTER Open Science. IP should no longer be a defensive tool to protect knowledge but instead facilitates knowledge transfers between academia and industry and fosters transparency across the research and development (R&D) system.

Both the OS movement and the OI movement imply a new mindset in how research and R&D activities are developed. The OI movement established a contrast with the traditional vertical integration model where R&D activities, product development, and product distribution occurred exclusively inside and by the firm [*West, Gallaguer,* 2006]. On the other hand, the OS movement leads to the non-restricted distribution of research results and processes, coining terms such as open access, open data, open-source software, open collaboration, or open knowledge.

Even though both movements are separated currents, following the perspectives listed by Friesike et al. (2015), it is possible to distinguish some points of convergence between them. The *philanthropic* perspective brings science and research closer to society. This does not translate into OI; however, it can serve as a basis for developing OI projects if the right open business models are applied to foster benefits from the openness. For instance, makerspaces in academic libraries can be considered such a business model. The *reflationary* perspective fosters discussions from the very early stage of the research process. In the case of OI, this might be understood as an idea management process or even a design thinking process. However, with this process, OS aims to generate knowledge, whereas OI focuses on innovation and product development. The *constructivist* perspective places OS and OI one step closer by thinking of bringing new knowledge into new user models and new business. Virtual rooms and crowdsourcing models apply to both OS and OI, to enable knowledge fusion and the generation of innovative solutions. Research centers here acquire the role of knowledge intermediaries. This role is reflected in the *exploitative* perspective that leads to the concretization of openness effects. The application-oriented knowledge can be understood as a point of convergence between OS and OI.

Methods

Usually, these approaches do not reach the main scientific publication current and remain hidden. The purpose here is to provide an overview of open innovation and open science worldwide. This article presents an exploratory and quanti-qualitative investigation based on a Systematic Literature Review (SLR) [*Tranfield et al.,* 2003; *Cook,* 1997]. The searching protocol described in Table 1 makes the research process more transparent and allows for its reproduction [*Tranfield et al.,* 2003].

The selected databases were Web of Science, Scopus, Scientific Electronic Library Online (SciELO) and Brazilian database of Information Science periodical articles (BRAPCI). The first two databases facilitate the

[2] See description of Creative Commons licenses and tools for businesses: https://docs.google.com/document/d/1rDLqZ95fatIAz-17efwJL7oXz9Y48peExZ-F4y4EQNks/edit, access date 07.11.2020.

retrieval of transdisciplinary studies from global high-impact journals, whereas the third and the fourth enable the analysis of Latin American approaches to the topic, where the predominant languages are Spanish and Portuguese, respectively. The BRAPCI was chosen as a database because it provides papers in the Portuguese language, especially in the Information Science field. We did not limit the SLR by timeframes because the topic of this paper is innovative. Our goal was to retrieve as much as possible. A more exploratory research approach allowed us to look at the phenomena in a broader way.

The keywords used were open science and open innovation without quotes. The papers collected demonstrate how international academia has studied Open Science and Open Innovation together, whereas emerging economies still face challenges to establishing a relationship between business and academia. In fact, no article available at BRAPCI or SciELO combines both keywords either in its title or in its abstract or keywords of the study. Furthermore, Figure 1 shows the number of collected and selected articles.

The SLR enabled the recovery of 211 published articles on innovation and open science. A filtering process based on a review of the titles and keywords was performed, resulting in the selection of 88 articles (see Figure 2). A complete reading of the 88 articles was carried out in order to understand the approaches of the different topics across the literature in the area of Information Science. Other areas of knowledge, such as business management, public, or production engineering are also publishing about open innovation and open science. This fact demonstrates that there is a multidisciplinary interest in the subject, and therefore, there is the production of knowledge from various perspectives.

The retrieval was based on Boolean searches, using the operator 'AND' for the intersection of the terms 'open science' and 'open innovation' in order to find papers approaching OS and OI as compatible terms or those applying OS practices to innovation processes. If no result was found with this intersection in one specific database, as it was the case for BRAPCI and SciELO, the terms were searched for separately. The approaches presented in the retrieved papers were contrasted to find possible overlapping. Conference abstracts retrieved in Web of Science and Scopus were excluded from the final evaluation due to full-text unavailability. Because of being international databases, the content available in Web of Science and Scopus usually overlap. Consequently, eight of the ten articles selected from Web of Science were already in Scopus. Therefore, to avoid duplication, just two articles from Scopus were analyzed.

After that, the concepts of open science and open innovation were connected in a theoretical matrix. Table 1 presents the matrix with the central topics found in the articles and the number of articles following that perspective. This matrix shows how OS and OI can be connected, but also their divergences. The points of convergence of OS and OI, as well as the relevant aspects of each movement resulting from the SLR, are discussed in detail in Section 4.

The analysis of the papers allowed for the construction of Table 3. The 74 papers were analyzed based on text marking tags. Table 3 shows the intersection between open science and open innovation identified in the papers. In addition to these papers, we incorporated other RSL about open science and open innovation which were published separately. There are eight RSL about open innovation and three about open science. Because of that, this paper focuses on the connection between these two concepts. Both lead to a different mindset in the way research and enterprise activities are conducted. However, even having overlapping topics, OS and OI develop separately.

Results and Discussion

Two different approaches to open innovation were identified in the papers. The first approach is related to the inter-organizational process, so the ideas are shared internally to create value. The second approach explains the connections between the organization and its external context, which is known as the ecosystem perspective. Both of them have something in common: the knowledge sharing with individuals and the creativity encouragement through learning.

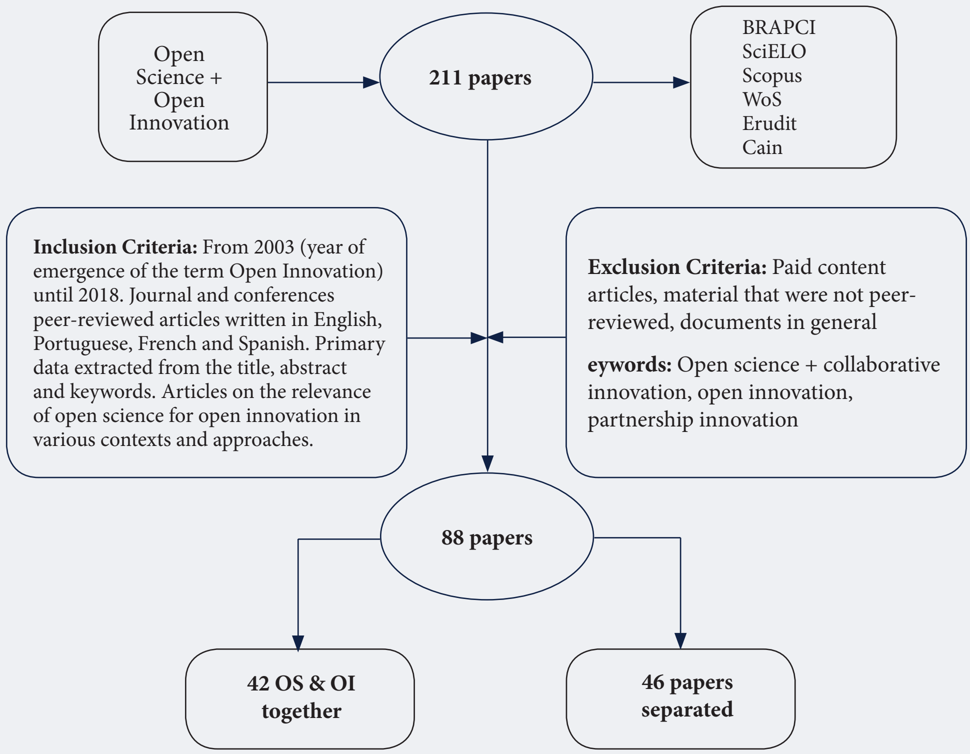
According to Table 3, most of the papers explain the creation and dissemination of knowledge, stakeholders' partnerships, and knowledge use as a strategic tool. Therefore, there is a gap in the literature related to the application of open access in public management, culture, information management, and in the development of individual skills. These gaps are opportunities for the development of new scientific investigation.

Open Innovation

Most of the companies in emerging economies are categorized as small or medium enterprises. These businesses offer job opportunities and economic growth for the country [*Carvalho, Sugano,* 2016]. The SLR demonstrated only 28 papers that study open science and open innovation in the context of SMEs. Therefore, there is scope for further research on the opening of innovation and research projects.

There is a relationship between open innovation and the development of SMEs since knowledge allows one to find new markets and influence finances positively. Open innovation reduces innovation costs and helps knowledge management create new ideas [*Henttonen, Lehtimaki,* 2017; *Akinwale*, 2018; *Bravo-Ibarra et al.*, 2014]. In fact, SMEs could develop more innovative products and ideas by avoiding working in an isolated way [*Friesike et al.,* 2015]. Group business disseminates information to improve their research activities.

Figure 1. **Protocol of SLR**



Source: elaborated by the authors.

Every organization needs to adopt a specific strategy to use open innovation such as Citizen Science [*Gura,* 2013], Open Access, and Open Data [*Bernius,* 2010; *Sa, Grieco,* 2016; *Piedra, Suárez*, 2018; *Arza et al.*, 2017; *Cardoso et al.*, 2009]. The selection of the tool depends upon the business goals, resources, and the time of innovation.

Beyond formal partnerships, businesses can use open-source software solutions and web-based tools, such as cloud computing, to apply open innovation strategies and collaboration [*Roman et al.*, 2018; *Schlagwein et al.*, 2017; *Viseur,* 2015; *Bianchi et al.*, 2015; *García-Peñalvo et al.,* 2010]. "Strategic partnerships can be important strategies to be adopted in the context of disruptive innovations, such as cloud computing" [*Cândido, Sousa,* 2017]. The connected technology produces data and information which are shared in information systems of the business. The government actions can also encourage the network between business and university such as the aerospace industry in Brazil. This business agglomeration is important for the economy of Brazil since companies share information and sell products to Embraer. Embraer is a Brazilian company which produces airplanes internationally [*Armellini et al.*, 2014].

Partnerships between universities and business complement the skills needed to improve the performance of the businesses [*Azmi, Alavi,* 2013; *Dewes et al.*, 2010; *Becker, Eube,* 2018; *Lucia et al.,* 2012]. Doing so, they will encourage open innovation and collaboration between businesses and universities.

There is an explanation of knowledge dissemination between partners: "entrepreneurial ecosystems may be superior to entrepreneurship alone" [*Cooke,* 2017]. These partnerships may reduce the research costs, create knowledge, encourage innovation, and share knowledge from educational organizations [*Gold,* 2016]. There is evidence of the advantages of Neuro Open Science created in Montreal demonstrated by [*Gold,* 2016], which is considered crucial to the growth of Neurosciences.

The growth of the collaboration between businesses and universities guides new insights that influence innovation. Open innovation allows this relationship to become a competitive advantage for both partners. "Given the different motivational backgrounds between private and public institutions, a symbiotic relationship becomes evident, where research institutions enable research capabilities, and private companies contribute commercialization know-how" [*Friesike et al.,* 2015].

Open science brings with it the possibility of shared co-construction and the generation of open innovation to contribute to the public sphere as well as pri-

Table 1. **Classification of the Articles by Number and Topic**

Central Topics	OS Only	OI Only	Both
Collaborative ecosystems and new tools for collaboration	-	-	17
Knowledge dissemination	-	-	15
Open Source software	-	-	4
Intellectual property and licenses	-	-	4
Human capacities in strategy	-	-	3
Change in institutional culture	-	-	3
Development for micro- and small enterprises	-	5	-
Emerging technologies in technology driven enterprises	-	4	-
Open Innovation as key for product development	-	4	-
Information management as tool for innovation	-	4	-
Open Innovation focused on strategy	-	4	-
Open Innovation in public management	-	3	-
Public policy development	4	-	-
TOTAL	10	64	74

Source: elaborated by the authors.

vate contexts. Although the contributions have been provided in the last decades, there is still much to be done in the practices of open science and the challenges to overcome in order to keep expanding upon the subject of open science [*Ramírez-Montoya, García-Peñalvo,* 2018]. The decision to participate in OS is not only an internal decision of the firm but is also dependent upon interactions with academic partners [*Simeth, Raffo,* 2013].

Open innovation neither refers to knowledge and technology access nor to knowledge dissemination, but to forms of decentralized information which are shared [*Dillaerts,* 2017; *Guichard, Tran,* 2006]. The authors use the decentralized expression for such information to explain the lack of hierarchy, so information and knowledge can be disseminated at every level. This sharing may occur in a virtual environment to create new data, information, and knowledge [*Roman et al.,* 2018]. A similar idea is emphasized in [*Schlagwein et al.,* 2017]: "Openness is an important and powerful concept, especially in combination with IT. Key "open" aspects – such as resources access and process participation – can be increased or enacted in entirely new ways through IT."

Open innovation is a useful tool since it can be considered the systematic integration of collaborative, sourcing, and revealing practices into a firm's business strategy [*Armellini et al.*, 2014; *Harison, Koski,* 2010]. Therefore, businesses can use many methods and tools to enable partnerships.

Chesbrough [*Chesbrough,* 2006] highlights the characteristics of open innovation that guide the partnerships such as context perception, knowledge creation, the importance of knowledge sources to organizational culture, the role of business models in R&D, acquisition availability, partnerships of co-development, identification of project failure, the relevance of knowledge flow, intellectual property management, the relevance of intermediaries in the innovation chain, the intensity of ICT use, and the evaluation of R&D performance. These characteristics are also present when addressing collaboration for product development [*Katsikis et al.*, 2016; *Bueno, Balestrin*, 2012; *Griffin et al.*, 2014; *Rubera et al.*, 2016] and knowledge management [*Wu, Hu,* 2018; *Grimsdottir, Edvardsson,* 2018; *Celadon,* 2014].

The elements exposed by [*Chesbrough,* 2006] are crucial to open organization since they contribute to developing quality innovation. Furthermore, they help to evaluate the projects and to face the challenges of open innovation.

Apart from these challenges, another aspect to be taken into consideration is the institutional and cultural factors when implementing open innovation practices. For instance, the open business model studies are almost exclusively American and European, leaving African countries and other emerging economies out of the analysis [*Khumalo, van der Lingen,* 2017].

The type of SME plays a determinant role. Whereas technology-driven enterprises [*Rodrigues et al.*, 2010; *Henttonen, Lehtimaki,* 2017], biotech companies, and construction companies [*Vlaisavljevic et al.,* 2020; *Jamett et al.*, 2017] might have a stronger connection with innovation, other industries such as tourism [*Iglesias-Sánchez et al.*, 2019] still must define a strategy and systemized open innovation to explore its potential.

Open Science

For universities and public research institutions, OS means being able to share research results in an unrestricted and free of charge manner. This action aims to achieve a fair way of conducting research, as well as to create a supportive environment for the rapid and more accurate development of science. A well-configured OS strategy opens the door for open innovation and contributes to both the public and the private sphere [*Ramírez-Montoya, García-Peñalvo,* 2018]. Collaborative practices enlarge the number of stakeholders in the research ecosystem, who "will benefit from Open Science, although it will change work habits and business models" [*Crouzier,* 2015].

The concept of the ecosystem is recent in the academic context. For several authors, a cluster is also an extension of the value chain. This concept was created due to the complexity of the current context of clusters that demand new relationships with the external environment. Ecosystems are structured in an open innovation model and combine their ability to generate technolo-

Table 2. **A Comparison between Open Science and Open Innovation**

Distinctive Attributes of OI	Perspectives in OS	Convergence of Perspectives	Sources
New perception of the external knowledge generation scenario	Philanthropic perspective – approaches of science and research to society	Externally produced knowledge is considered necessary. Enterprises use competitive technological intelligence and science integrates citizen science. Appropriate open business models are required.	[*Ramírez-Montoya, García-Peñalvo,* 2018; *Smith, Seward,* 2017; *Cooke,* 2017; *Gold,* 2016; *Viseur,* 2015; *Freitas, Dacorso,* 2014; *Sánchez-González, Herrera,* 2014; *Azmi, Alavi,* 2013; *Simeth, Raffo,* 2013; *Stodden,* 2010]
Importance of external and internal knowledge sources in organizational culture and throughout the process	Reflationary perspective – knowledge sharing in early stages and the promotion of new scientific ideas	External and internal knowledge sources have a distinctive role. Enterprises and science open their knowledge generation cycles to networks and allow for the contributions from the first stages of innovation or research processes.	[*Roman et al.,* 2018; *Schlagwein et al.,* 2017; *Dillaerts,* 2017; *Arza et al.,* 2017; *Fressoli, Arza,* 2017; *Friesike et al.,* 2015; *Simeth, Raffo,* 2013; *Touati, Denis,* 2013; *Cardoso et al.,* 2009]
Central role of the business model in R&D management	Constructivist perspective – collaborative forms of knowledge creation and new user models	Technology and scientific results enlarge the number of available assets (open technology, open software, open data, etc.). There is a focus on the added value.	[*Khumalo, van der Lingen,* 2017; *Ngongoni et al.,* 2017; *Álvarez-Aros, Bernal-Torres,* 2017; *Katsikis et al.,* 2016; *Carvalho, Sugano,* 2016; *Bravo-Ibarra et al.,* 2014; *Bueno, Balestrin,* 2012; *Saebi, Foss,* 2015; *Feller et al.,* 2011; *Berglund, Sandström,* 2013; *Yun et al.,* 2016]
Acquisition readiness	Constructivist perspective – development and use of virtual exchange platforms	Enterprises focus their acquisition efforts on innovative and technology-based companies to improve and accelerate the technical infrastructure. Scientific practices use appropriate infrastructure for data-driven research with distributed computing as a base.	[*Ramírez-Montoya, García-Peñalvo,* 2018; *Rodrigues et al.,* 2010; *García-Peñalvo et al.,* 2010]
Use of co-development partnerships	Reflationary perspective – feedback from colleagues and joint collaborative knowledge creation	Innovation and research processes benefit from the collaboration with external partners, leading to enhanced results.	[*Akinwale,* 2018; *Lopes et al.,* 2017; *Merino et al.,* 2015; *Schuster, Brem,* 2015; *Scuotto et al.,* 2020]
Mitigation of R&D project failures	Reflationary perspective – avoidance of local research bias and fast error identification	New business and science evaluation models characterized by open practices allow for rapid error identification and enable process improvement.	[*Jamett et al.,* 2017; *De Pablos-Heredero et al.,* 2013; *Dewes et al.,* 2010; *Gerhart et al.,* 2000; *Strasak et al.,* 2007; *Lee et al.,* 2012]
Importance of the flow of knowledge outputs	Constructivist perspective – availability of open platforms and interdisciplinary integration	Knowledge outputs openly available, even when not directly connected with the main aim of the innovation or research process, can generate new perspectives for the development of infrastructure or enterprises (such as start-ups).	[*Armellini et al.,* 2014; *Celadon,* 2014; *Remneland-Wikhamn,* 2013; *Calderón-Martínez,* 2009, 2010]
Intellectual property management model	Exploitative perspective – generation of scientific findings with real-life applications	IP management is based on free licenses, for instance CC licenses in science and enterprises. These licenses amplify the affordability of digital technology and provide an enhanced means for social production in the networked economy.	[*Roman et al.,* 2018]
Importance of new intermediaries in the innovation chain	Reflationary perspective – introduction of groupthink and idea sharing within the community	New external intermediaries take over actions that were previously internal. This is likely to happen at all stages of the research or innovation process, through openly sharing of activities and accepting external participation (e.g., Citizen Science).	[*Callon,* 2012; *Schenk, Guittard,* 2012]
Intensity in the use of ICT	Exploitative perspective – shared construction of ICT artifacts	The technical infrastructure enables activity management in both the innovation and the research process. Therefore, ICT is considered essential.	[*Bianchi et al.,* 2015; *Lakeman-Fraser et al.,* 2016; *Abbate et al.,* 2019]
Metrics for the measurement of R&D performance	Exploitative perspective – measurement of research application in academia and beyond.	Opening processes involve a renewal of the metrics used to measure R&D performance and research article impact.	[*Ajzen et al.,* 2016; *Neely et al.,* 2005; *Gulbrandsen, Smeby,* 2005; *Breunig et al.,* 2014; *Chen et al.,* 2015]

Source: elaborated by the authors.

gies with external partnerships. Innovation ecosystem theory is broader than the concept of systems of innovation, as it goes beyond the regional economy context and it is normally company- or technology-centered [*Faissal-Bassis, Armelini,* 2018].

There is a de facto convergence of academic and industrial science, especially for application-oriented purposes, which increases the importance of cooperation and understanding OS practices [*Friesike et al.,* 2015]. Establishing cooperation models is necessary for strategic and tactical processes [*Martínez-Noya, Narula,* 2018]. The decision to participate in these cooperation models and the consequent development of an appropriate open business model depends upon the internal decisions of the firm and the interactions with academic partners [*Simeth, Raffo,* 2013]. In some cases, these interactions are not only limited to academic and industrial partners, but they progressively include other ways of collaboration, for example, with the general public [*Fressoli, Arza*, 2017]. In some cases, external and intermediary actors are essential to generating new technology, so they need to align their strategies and interests. Besides, the relevance of the knowledge and competence of the actors must not be forgotten [*Federer et al.,* 2020].

Information technologies (IT) offer several tools in order to guarantee interactions among the research ecosystem, inside and outside academia, for instance to access resources and guarantee process participation [*Schlagwein et al.,* 2017]. These tools can vary from online writing tools or academic social networks [*Viseur,* 2015] to virtual research environments (VREs). In fact, it is suggested that VREs "foster the transfer of research data from university to industry and its exploitation to generate new data sets, information and knowledge" [*Roman et al.,* 2018].

Apart from that, IT solutions expand the scope and openness of academic research [*Abbate et al.,* 2019; *Arza et al*., 2017]. Up to now, scientific public goods were limited to textual publications, however, nowadays, open data and open infrastructure are also part of these goods. Consequently, the use of new forms of evaluation of scientific production that include these research assets is required. Examples are usage metrics (measuring downloads and savings), alternative metrics (measuring research impact in Wikipedia, blogs, news, bookmark tools, and social media), or data citation.

If a well-configured OS strategy is combined with a well-configured OI strategy, enterprises will be more open to joining the research ecosystems that benefit their activities.

Intersection between Open Science and Open Innovation

There are distinguishing features between the attributes of OI in contrast with closed innovation [*Chesbrough,* 2006]. In order to see the intersection between OS and OI, we contrasted these attributes with the perspectives in OS described by [*Friesike et al.,* 2015] and introduced above.

The following table (Table 2) presents a comparison between the attributes of OI and the perspectives in OS. The aim is to identify a convergence of the perspectives and distinguish possible areas for joint action.

In the process of open innovation, the involved individuals develop the perception of the scenario and the relevance of knowledge generation. At the same time, open innovation aims to provide information and knowledge through quality sources [*Ramírez-Montoya, García-Peñalvo,* 2018; *Smith, Seward,* 2017; *Cooke,* 2017; *Gold,* 2016; *Viseur,* 2015; *Sánchez-González, Herrera,* 2014; *Freitas, Dacorso,* 2014; *Azmi, Alavi,* 2013; *Simeth, Raffo,* 2013; *Stodden,* 2010]. Thus, it manages the results of production through collaborative networks and, eventually, through social networks for users [*Vrgovic et al.,* 2012; *Liu et al.,* 2017]. Therefore, learning about academic information enables the understanding of the context and creates strategies to overcome the challenges.

The relative importance of knowledge [*Secundo et al.,* 2019; *Akinwale*, 2018] sources should be emphasized in a company's culture, as managers and employees start to value the sources of quality information. The opening of the innovation processes is marked by the massive production of data and information [*Schwab,* 2016], so they must know how to deal with false information. In the academic field, open science seeks to provide information and knowledge through quality sources. That is why it is considered necessary to publish partial results and research data from the early stages of the process. On the other hand, a way to review these early-stage results is required to guarantee content quality. In this sense, some platforms are developed for the evaluation of results by the scientific community, for example RIO (for grant proposal), Hypothesis.is (for commenting openly), or Protocols.io (for protocols and workflows).

The management of the development of new products and services is necessary as there is a progressive increase in information [*Nambisan et al.,* 2017]. Such an increase also occurs in universities. Therefore, editors must manage scientific articles, authors, and reviewers for the organization of the process. In this sense, new evaluation possibilities and methodologies are also valued, for example, collective evaluation on open platforms, especially when dealing with large data sets and not with a single textual publication, as explained in the project FOSTER Open Science.

Time becomes a great challenge because the academic knowledge focused on business competitiveness must obey the deadlines, be developed with quality, and done so more rapidly in order to accompany the business transformations. To this end, the partnership between enterprises and universities is central for both organizations to benefit from collaborative learning [*Chesbrough,* 2015].

Open innovation partnerships require readiness for technological and human capital acquisitions [*Belenzon, Schankerman,* 2015]. Open science also needs to invite researchers considered relevant to the field. It must have an online domain and be easy to communicate with the user. Besides, both open science and open innovation are looking for innovative methods [*Chesbrough,* 2006] suitable for new intelligent production methods and spaces. Examples of these spaces are virtual research environments or makerspaces.

The use of co-development partnerships occurs through research institutions, universities, industrial clusters, companies, trade and industrial associations, and government agencies [*Roman et al.,* 2018]. In the context of open science, many partnerships are made through virtual collaboration [*Friesike et al.,* 2015; *Simeth, Raffo,* 2013]. In addition, research groups attract international knowledge due to open access to publications. Therefore, the interlocking relationships between innovation and open science can bring together various organizations to share the results of the research and development of practical projects as well as forms of joint project funding with the government.

The mitigation of project failures means analyzing the problems that arose during the collaborative innovation project. This phase makes it possible to improve processes and save time in the future. In open science, results are available from the beginning of the research cycle, which allows peers to identify their failures and evaluate projects that have not worked to improve processes. As many companies are still in transition to open innovation, this process is crucial in order to adapt the organizational routine to achieve the proposed goals.

Open innovation has as its central focus the flow of knowledge outputs. This flow is the product of learning between the companies and organizations involved in the partnership. Open access values the availability of information to generate knowledge [*Bernius,* 2010; *Jamett et al.,* 2017; *Pitassi,* 2012]. Thus, journals value the publication of the numbers and share them with the companies and industrial agglomerations. Thus, it can offer a useful service, disseminating quality knowledge to both researchers and professionals.

New ideas and innovation are transformed into intellectual property by companies. Thus, they apply models of management of this property [*Brem et al.,* 2017]. In this sense, it is convenient to analyze the application of open licenses, both for scientific and business products, to reduce costs and ensure sustainability. Thus, innovation and open science are concerned both with intellectual property and the right to ideas in university-business partnerships [*Roman et al.,* 2018].

The importance of intermediaries in the innovation chain influences the information flows of open innovation since the actors need to share knowledge intelligently. Effective communication between the evaluator and the researcher is a key factor for open science, which is why the open-peer review is introduced. Communication plays a crucial role in the insertion of external actors (e.g., citizen scientists) to have control over data collection and the obtaining of results [*Lewis,* 2020; *Callon,* 2012; *Schenk, Guittard,* 2012]. It is necessary to know the limitations of the research or project, suggest clear improvements, remove doubts from users, and manage exchanges between academics and managers.

The intensity in the use of ICT and measures of performance evaluation of R&D are also part of the concepts of open innovation. Open science uses modern systems and online domains to organize and process information [*Doyle et al.,* 2019; Álvarez-Aros, *Bernal-Torres,* 2017; *Khumalo, van der Lingen,* 2017; *Katsikis et al.,* 2016; *Carvalho, Sugano,* 2016; *Bravo-Ibarra et al.,* 2014; *Bueno, Balestrin,* 2012; *Ngongoni et al.,* 2017]. The focus is on those who respect a sustainable information architecture and ensure that data is findable, accessible, interoperable, and reusable. Open science and open innovation contribute to the dissemination of partnerships between academia and business, stimulating them in emerging economies [*Chaston, Scott,* 2012; *Kafouros, Forsans,* 2012]. Such partnerships provide the opportunity to take advantage of market opportunities in Industry 4.0 [*Carvalho, Sugano,* 2016]. In the context of Industry 4.0, ICTs are considered intelligent because they are connected, produce, and transfer data and information. The framework below illustrates the connection between open science and innovation.

Open Science and Open Innovation in Emerging Economies

Given the inclusion in the SLR of databases such as SciELO, whose scope is mainly Latin America and some African countries (such as South Africa), the SLR also delivered some facts about OS and OI approaches in emerging economies.

As stated by [*Friesike et al.,* 2015], SMEs represent the most significant number of companies within an economy. However, the issue of how SMEs in emerging economies can benefit from open innovation practices has not been explored in depth in the literature [*Khumalo, van der Lingen,* 2017] and there is a need for designing requirements for an open innovation approach in these economies [*Krause, Schutte,* 2015].

In some cases, the need for a basis for technology transfer and knowledge management is pointed out in order to create a solid industrial network [*Lehtimaki et al.,* 2009; *Valencia-Vazquez et al.,* 2014; *Jamett et al.,* 2017; *Pitassi,* 2012]. Such a solid network allows for crossing firm boundaries and implies that both internal and external knowledge can find their way to commercialization for existing or new markets [*Amponsah, Adams,* 2017; *Akinwale*, 2018] and find potential new clients [*Merino et al.,* 2015]. Collaboration with academic partners might also lead to the better development of public policies for idea generation, activity control, and patent registry [*Bianchi et al.,* 2015; *García-Peñalvo et al.,* 2010]. It is worth mentioning that the validation of collaborative practices also involves an in-depth study of IP and IP policies in open innovation strategies [*Hagedoorn, Zobel,* 2015; *Lichtenthaler,* 2010; *Bianchi et al*., 2015; *Bravo-Ibarra et al*., 2014]. The development of these policies turns governments also into important actors in the OS and OI process [*Sa, Grieco,* 2016; *Yoon,* 2017; *Freitas, Dacorso*, 2014].

How OS and OI are addressed in a particular territory has a strong dependence upon culture. More collectivistic societies, such as China, are more likely to favor cooperative initiatives, whereas other societies might follow a more individualistic approach [*Cooke,* 2017].

Cultural aspects also affect the *modus operandi* of a community. In some cases, the adoption of open strategies generates a "culture of the fear". Among the scientific community, it is fear of information misuse or misinterpretation [*Fressoli, Arza,* 2017]. Among enterprises, it is fear of sharing strategic information, even though this sharing might attenuate risks and increase efficiency [*Riley et al.,* 2016; *Cândido, Sousa*, 2017; *De Pablos-Heredero et al.,* 2013]. In fact, this dissemination can occur ethically, for instance, following best practices for knowledge sharing such as the adoption of open licenses in both academia and industry. In this sense, enterprises benefit from ecosystem engagement and value creation when building a culture of collaboration and information-sharing [*Ngongoni et al.,* 2017].

Another aspect highlighted in the literature about emerging economies is the building of new competencies. One of the primary motivations for collaboration between universities and enterprises is the reduction of time for innovation by means of learning [*Morandi,* 2013; *Perkmann, Walsh,* 2007; *Lopes et al*., 2017]. As a result, individuals can acquire and develop new skills during their practices in the process of open innovation. Furthermore, they can learn from the information openly available in a long-life learning process. Therefore, enterprises should focus on the role of human talent as a strategy to boost innovation capacities [*Bartelsman et al.,* 2015; Álvarez-Aros, *Bernal-Torres*, 2017]. On the other hand, universities might adopt an intermediary role offering the knowledge and expertise on new technologies and on information literacy [*Ottonicar et al.,* 2018]. Connected technology, such as cloud computing, produces data and information which are shared in the information systems of the businesses, requiring sustainable infrastructure for data archiving and preservation.

Finally, innovative activities in enterprises should be monitored as a way to evaluate performance. On the other hand, inside academia, the way research performance is evaluated should also consider further parameters due to the fact that research outputs embrace not only articles but also data or infrastructure [*Arza et al.,* 2017].

Open science and open innovation practices can be adopted simultaneously by academics, researchers, managers, and employers in the partnerships. The aim is to share information and knowledge about processes, products, and services which are demanded by consumers in a technology-driven context, which requires immediacy in development. Public policies serve as the first step for university-enterprise engagement in emerging economies. Apart from that, it is necessary to establish workflows that help in the management data, information, and knowledge transfer between all stakeholders. According to [*Serrano-Bedia et al.,* 2018] a variety of sources of knowledge influence innovation. Therefore, stakeholders are relevant sources of knowledge.

This paper proposes the following framework (Figure 2) so that innovation can be achieved by the connection between OS and OI.

Open science is connected to policy makers because scientific knowledge contributes to the development of economic policy [*Sa, Grieco,* 2016; *Arza et al.,* 2017; *Freitas, Dacorso*, 2014]. Open innovation encourages the relationship between business, research institutes, and the government, and it creates an organizational structure to connect business, universities, and policy makers.

Both open innovation and open science generate and use knowledge. Lifelong learning creates knowledge [*Fletcher et al.,* 2010; *Jamett et al.,* 2017; *Pitassi,* 2012]. That learning is based on applied and basic research [*Akinwale,* 2018; Álvarez-Aros, *Bernal-Torres,* 2017]. Therefore, knowledge and infrastructure influence business competitiveness [*Serrano-Bedia et al.,* 2018]. Furthermore, competitiveness needs open science, open innovation, and public policy to encourage knowledge sharing between business and universities [*Bianchi et al.,* 2015; *García-Peñalvo et al.,* 2010].

Economic policy must encourage open innovation to help businesses grow through partnerships [*Schuster, Brem,* 2015; *Freitas, Dacorso*, 2014]. Researchers must study the fact that "the public action towards innovation has changed to foster more collaborative and open innovation" [*Jugend et al.,* 2020]. Therefore, policy makers, open innovation, and open science influence the competitive advantage of countries.

Conclusions

In this paper we performed an SLR to delve into the intersection between open science and open innovation and demonstrate how emerging economies can benefit from this connection and apply it in further product developments. Only 28 papers connected both themes, so we encourage both fields of business management and information science to develop research about the subject.

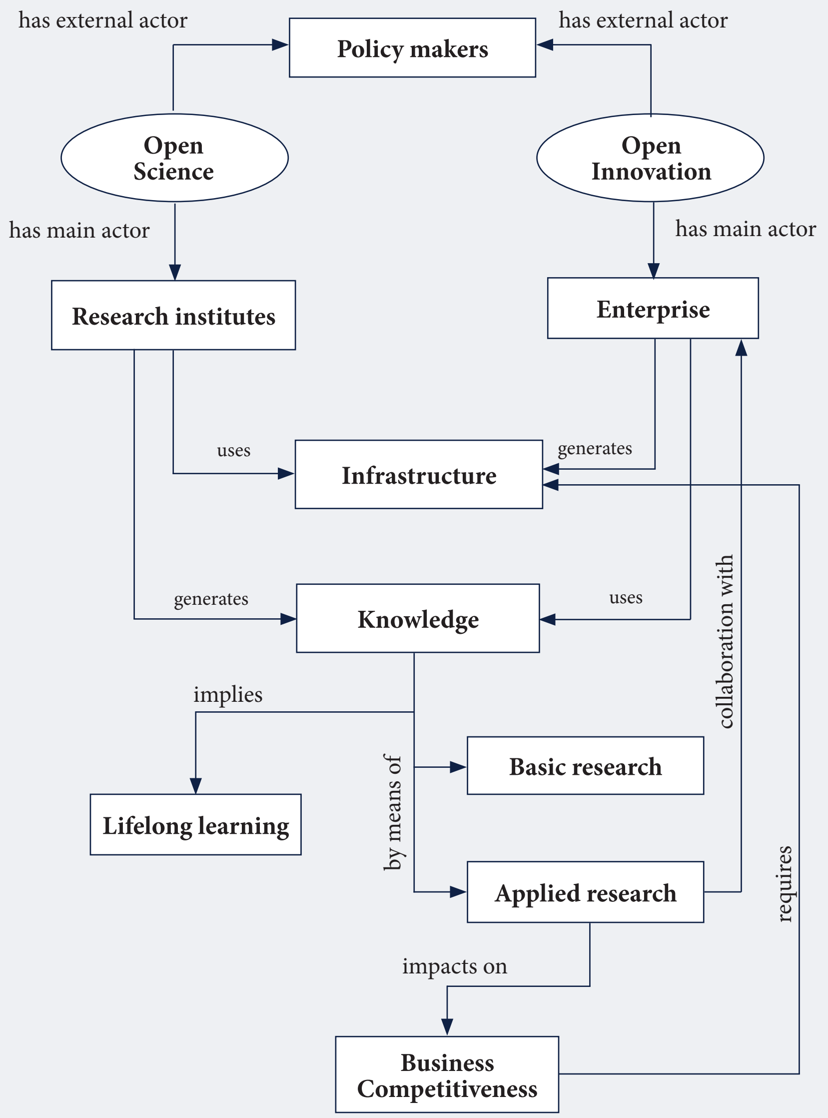
The SLR demonstrated that most papers connect open science and open innovation in "collaborative ecosystems and new tools for "collaboration" and "knowledge dissemination". Only a few papers mentioned the development of open-source software, intellectual property and licenses, and human skills for strategy and organizational culture change. Furthermore, some papers had a multidisciplinary perspective because they identified the relevance of open science to cultural influence and public organization management.

Open science and open innovation can be connected to improve knowledge sharing, stakeholders' partnerships and this can be done in the context of SMEs. Furthermore, the papers explained open science and open innovation as a strategy to achieve competitiveness, financial performance, and the development of human capital focused on creativity, entrepreneurship, disruptive technology, product innovation, and public management.

Open innovation creates a new structure in the ecosystem because it connects businesses, universities, and the government. Open science shares theoretical and practical knowledge in order to feed open innovation. Furthermore, open science provides information for the development of economic policy.

There is a gap in the literature which connects open science and open innovation in developing countries. That type of research is relevant since emerging economies have difficulties related to financial investment and qualified human capital. Furthermore, the major-

Figure 2. **Innovation Flow Combining Open Science and Open Innovation**



Source: elaborated by the authors.

ity of companies are SMEs, so they need to be the focus of economic policy.

The topic of this paper is recent and innovative. There were not a lot of papers that discuss open science and open innovation together. If we restricted our search to only high impact journals there would not be enough evidence for a rigorous analysis. A more exploratory research approach allowed us to look at a broader base.

Furthermore, we used other databases to retrieve papers in French, Portuguese, and Spanish. The SLR in other languages helped us to identify how emerging economies like Latin America have studied the topic to improve their economy. SciELO and BRAPCI are databases that share papers from Latin America, which includes emerging economies.

In conclusion, the connection between open science and open innovation is fundamental to encouraging partnerships between businesses and universities. This kind of partnership contributes to the economy of developing countries. Industry 4.0 is a challenge for developing countries since it demands high investment in smart technology and people training. Open access and open innovation may be used by these countries as part of their economic strategy to overcome these challenges.

This paper is not free from limitations. The first limitation is based on language due to the authors' knowledge, only papers in English, Portuguese, Spanish, and French were considered. Another limitation is that only indexed papers are considered, excluding conference papers and grey literature. The results can be adapted and applied in other developing countries to help foster economic growth.

Future research may develop practical studies about the relationship between businesses and universities in the context of emerging economies. These partnerships can improve the processes, encourage creativity, and contribute to the competitive advantage of both public and private organizations. Furthermore, we highly recommend papers that discuss workflow analysis to share data between businesses and universities, information literacy for information dissemination, and legal licenses for open innovation.

Open science can be used as a tool for individuals to learn new approaches and innovate in a business context. Innovation is fundamental to growth and organizational competitiveness, especially in the context of I4.0. Businesses can be open and relate to other organizations to share knowledge.

We would like to thank the Coordenação de Aperfeiçoamento de Nível Superior (CAPES, Coordination for the Improvement of Higher Education Personnel), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, National Council for Scientific and Technological Development) and The Fonds de Recherche du Québec - Nature et Technologie (FRQNT) for the development of this research.

References

Abbate T., Codini A.P., Aquilani B. (2019) Knowledge Co-creation in Open Innovation Digital Platforms: Processes, Tools and Services. *Journal of Business and Industrial Marketing*, vol. 34, no 7, pp. 1434–1447. Available at: https://doi.org/10.1108/JBIM-09-2018-0276, accessed 07.11.2020.

Ajzen M., Rondeaux G., Pichault F., Taskin, L. (2016) Performance et innovation en PME: Une relation à questioner. *Revue Internationale P.M.E.*, vol. 29, no 2, pp. 65–94. Available at: https://doi.org/10.7202/1037923ar, accessed 07.11.2020.

Akinwale Y.O. (2018) Empirical analysis of inbound open innovation and small and medium-sized enterprises' performance: Evidence from oil and gas industry. *South African Journal of Economic and Management Sciences*, vol. 21, no 1, art. a1608. Available at: https://doi.org/10.4102/sajems.v21i1.1608, accessed 07.11.2020.

Alvarez-Aros E.L., Bernal-Torres C.A. (2017) Modelo de Innovacion Abierta: Enfasis en el Potencial Humano. *Informacion Tecnologica*, vol. 28, no 1, pp. 65–76. Available at: https://doi.org/10.4067/S0718-07642017000100007, accessed 07.11.2020.

Amponsah C.T., Adams S. (2017) Open innovation: Systematisation of knowledge exploration and exploitation for commercialization. *International Journal of Innovation Management,* vol. 21, no 3. Art.1750027. DOI: 10.1142/S136391961750027X.

Armellini F., Kaminski P.C., Beaudry C. (2014) The Open Innovation Journey in Emerging Economies: An Analysis of the Brazilian Aerospace Industry. *Journal of Aerospasce and Technology Management,* vol. 6, no 4, pp. 462–474. DOI: 10.5028/jatm.v6i4.390 .

Arza V., Fressoli M., Sebastian S. (2017) Towards open science in Argentina: From experiences to public policies. *First Monday,* vol. 22, no 7. Available at: https://doi.org/10.5210/fm.v22i7.7876, accessed 07.11.2020.

Ayris P., Bernal I., Cavalli V., Dorch B., Frey J., Hallik M., Hormia-Poutanen K., Labastida I., MacColl J., Ponsati-Obiols A., Sacchi S., Scholze F., Schmidt B., Smit A., Sofronijevic A., Stojanovski J., Svoboda M., Tsakonas G., van Otegem M., Verheusen A., Vilks A., Widmark W., Horstmann W. (2018) *Liber Open Science Roadmap*, Hague: Association of European Research Libraries. Available at: https://doi.org/10.5281/zenodo.1303002, accessed 07.11.2020.

Azmi I.M., Alavi R. (2013) Patents and the practice of open science among government research institutes in Malaysia: The case of Malaysian Rubber Board. *World Patent Information,* vol. 35, no 3, pp. 235–242. Available at: https://doi.org/10.1016/j.wpi.2013.03.005, accessed 07.11.2020.

Bartelsman E., Dobbelaere S., Peters B. (2015) Allocation of human capital and innovation at the frontier: Firm-level evidence on Germany and the Netherlands. *Industrial and Corporate Change,* vol. 24, no 5, pp. 875–949. Available at: https://doi.org/10.1093/icc/dtu038, accessed 07.11.2020.

Becker B.A., Eube C. (2018) Open innovation concept: integrating universities and business in digital age. *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 4, art. 12. Available at: https://doi.org/10.1186/s40852-018-0091-6, accessed 07.11.2020.

Belenzon S., Schankerman M., (2015) Motivation and sorting of human capital in open innovation. *Strategic Management Journal*, vol. 36, no 6, pp. 795–820. Available at: https://doi.org/10.1002/smj.2284, accessed 07.11.2020.

Berglund H., Sandström C. (2013) Business model innovation from an open systems perspective: Structural challenges and managerial solutions. *International Journal of Product Development,* vol. 18, no 3–4, pp. 274–285. DOI: 10.1504/IJPD.2013.055011.

Bernius S. (2010) The impact of open access on the management of scientific knowledge. *Online Information Review*, vol. 34, no 4, pp. 583–603. Available at: https://doi.org/10.1108/14684521011072990, accessed 07.11.2020.

Bianchi I., Bigolin F., de Linhares Jacobsen A., 2015. As Tecnologias e Sistemas de Informacao como Ferramentas de apoio no Processo de Inovacao Aberta. *Prisma.com,* vol. 29, pp. 157–172. Available at: http://ojs.letras.up.pt/index.php/prismacom/article/view/1836, accessed 07.11.2020.

Blumel C., Fecher B., Leimuller G. (2018) *Was gewinnen wir durch Open Science und Open Innovation?*, Essen: Edition Stifterverband.

Bravo-Ibarra E.R., Leon-Arenas A.P., Serrano-Cardenas L.F. (2014) Explorando las principales ventajas y factores de exito de la innovacion abierta en las organizaciones. *Entramado,* vol. 10, no 2, pp. 44–59. DOI: 10.18041/entramado.2014v10n2.20220.

Brem A., Nylund P.A., Hitchen E.L. (2017) Open innovation and intellectual property rights: How do SMEs benefit from patents, industrial designs, trademarks and copyrights? *Management Decision,* vol. 55, no 6, pp. 1285–1306. Available at: https://doi.org/10.1108/MD-04-2016-0223, accessed 07.11.2020.

Breunig K.J., Aas T.H., Hydle K.M. (2014) Incentives and performance measures for open innovation practices. *Measuring Business Excellence,* vol. 18, no 1, pp. 45–54. Available at: https://doi.org/10.1108/MBE-10-2013-0049, accessed 07.11.2020.

Bueno B., Balestrin A. (2012) Inovacao colaborativa: Uma abordagem aberta no desenvolvimento de novos produtos. *Revista de Administracao de Empresas,* vol. 52, pp. 517–530. Available at: https://doi.org/10.1590/S0034-75902012000500004, accessed 07.11.2020.

Callon M. (2012) Quel role pour les sciences sociales face a l'emprise grandissante du regime de l'innovation intensive ? *Cahiers de Recherche Sociologique,* vol. 53, pp. 121–165. Available at: https://doi.org/10.7202/1023194ar , accessed 07.11.2020.

Candido A.C., Sousa C. (2017) Open Innovation Practices in Strategic Partnerships of Cloud Computing Providers. *Journal of Technology Management and Innovation,* vol. 12, no 2, pp. 59–67. Available at: https://doi.org/10.4067/S0718-27242017000200007, accessed 07.11.2020.

Cardoso G., Caraca J., Espanha R., Triaes J., Mendonca S. (2009) As politica de Open Access: Res publica cientifica ou autogestao? *Sociologia, Problemas e Praticas,* vol. 60, pp. 53–67.

Carvalho E.G., Sugano J.Y. (2016) Entrepreneurial orientation and open innovation in Brazilian startups: A multicase study. *Interacoes,* vol. 17, no 3, pp. 448–462. Available at: http://dx.doi.org/10.20435/1984-042X-2016-v.17-n.3(08) , accessed 07.11.2020.

Celadon K.L. (2014) Knowledge Integration and Open Innovation in the Brazilian Cosmetics Industry. *Journal of Technology Management and Innovation,* vol. 9, no 4, pp. 34–50. Available at: https://doi.org/10.4067/S0718-27242014000300003, accessed 07.11.2020.

Chaston I., Scott G.J. (2012) Entrepreneurship and open innovation in an emerging economy. *Management Decision*, vol. 50, no 7, pp. 1161–1177. Available at: https://doi.org/10.1108/00251741211246941, accessed 07.11.2020.

Chen J., Zhao X., Wang Y. (2015) A new measurement of intellectual capital and its impact on innovation performance in an open innovation paradigm. *International Journal of Technology Management,* vol. 67, art. 1, pp. 1–25. DOI: 10.1504/IJTM.2015.065885.

Chesbrough H.W. (2003) *Open innovation: The new imperative for creating and profiting from technology,* Boston, MA: Harvard Business School Press.

Chesbrough H.W. (2006) *Open business models: How to thrive in the new innovation landscape*, Boston, MA: Harvard Business School Press.

Chesbrough H.W. (2015) *From Open Science to Open Innovation,* Barcelona: ESADE.

Cook D.J. (1997) Systematic Reviews: Synthesis of Best Evidence for Clinical Decisions. *Annals of Internal Medicine*, vol. 126, pp. 376–380. Available at: https://doi.org/10.7326/0003-4819-126-5-199703010-00006, accessed 07.11.2020.

Cooke P. (2017) 'Digital tech' and the public sector: What new role after public funding? *European Planning Studies*, vol. 25, no 5, pp. 739–754. Available at: https://doi.org/10.1080/09654313.2017.1282067, accessed 07.11.2020.

Crouzier T. (2015) *Science Ecosystem 2.0: How will change occur?* Luxembourg: EU Publications Office. Available at: https://ec.europa.eu/research/innovation-union/pdf/expert-groups/rise/science_ecosystem_2.0-how_will_change_occur_crouzier_072015.pdf, accessed 07.11.2020.

De Pablos-Heredero C., Soret-LosSantos I., Lopez-Eguilaz M.J. (2013) Un modelo de Medicion de Resultados en las Practicas de Innovacion Abierta. *Journal of Technology Management and Innovation*, vol. 8, no 1, pp. 73–74. Available at: https://doi.org/10.4067/S0718-27242013000300037, accessed 07.11.2020.

Dewes M.F., Goncalez O.L., Passaro A. (2010) Open innovation as an alternative for strategic development in the aerospace industry in Brazil. *Journal of Aerospasce and Technology Management,* vol. 2, no 3, pp. 349–360. Available at: https://doi.org/10.5028/jatm.2010.02038910, accessed 07.11.2020.

Dillaerts H. (2017) Ouverture et partage des resultats de la recherche dans l'economie de la connais-sance europeenne: Quelle(s) liberte(s) de circulation pour l'IST? *Communication et Management,* vol. 14, no 1, pp. 39–54. Available at: https://doi.org/10.3917/comma.141.0039, accessed 07.11.2020.

Doyle C., Luczak-Roesch M., Mittal A. (2019) We Need the Open Artefact: Design Science as a Pathway to Open Science in Information Systems Research. *Extending the Boundaries of Design Science Theory and Practice. Proceedings of the DESRIST 2019 Conference* (eds. B. Tulu, S. Djamasbi, G. Leroy), Heidelberg, New York, Dordrecht, London: Springer, pp. 46–60. Available at: https://doi.org/10.1007/978-3-030-19504-5_4, accessed 07.11.2020.

Etzkowitz H., Webster A., Gebhardt C., Terra B.R.C. (2000) The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm. *Research Policy,* vol. 29, no 2, pp. 313–330. Available at: https://doi.org/10.1016/S0048-7333(99)00069-4, accessed 07.11.2020.

European Commission (2016) *Open innovation, open science, open to the world: A vision for Europe,* Luxembourg: Publications Office of the European Union. Available at: https://doi.org/ 10.2777/061652, accessed 07.11.2020.

Faissal Bassis N., Armellini F. (2018) Systems of innovation and innovation ecosystems: a literature review in search of complementarities. *Journal of Evolutionary Economy,* vol. 28, pp. 1053–1080. Available at: https://doi.org/10.1007/s00191-018-0600-6, accessed 07.11.2020.

Federer L., Foster E.D., Glusker A., Henderson M., Read K., Zhao S. (2020) The medical library association data services competency: A framework for data science and open science skills development. *Journal of the Medical Library Association,* vol. 108, no 2, pp. 304–309. DOI: 10.5195/jmla.2020.909.

Feller J., Finnegan P., Nilsson O. (2011) Open innovation and public administration: Transformational typologies and business model impacts. *European Journal of Information Systems,* vol. 20, no 3, pp. 358–374. Available at: https://doi.org/10.1057/ejis.2010.65, accessed 07.11.2020.

Fletcher M.A., Zuber-Skerritt O., Bartlett B., Albertyn R., Kearney J. (2010) Meta-Action Research on a Leadership Development Program: A Process Model for Life-long Learning. *Systemic Practice and Action Research,* vol. 23, no 6, pp. 487–507. Available at: https://doi.org/10.1007/s11213-010-9173-5, accessed 07.11.2020.

Freitas R.K.V., Dacorso A.L.R. (2014) Inovacao aberta na gestao publica: Analise do plano de acao brasileiro para a Open Government Partnership. *Revista de Administracao Publica*, vol. 48, no 4, pp. 869–888. Available at: http://dx.doi.org/10.1590/0034-76121545, accessed 07.11.2020.

Fressoli M., Arza V. (2017) Negotiating Openness in Open Science. An Analysis of Exemplary Cases In Argentina. *Revista CTS,* vol. 12, no 36, pp. 139–162. Available at: http://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S1850-00132017000300007, accessed 07.11.2020.

Friesike S., Widenmayer B., Gassmann O., Schildhauer T. (2015) Opening science: Towards an agenda of open science in academia and industry. *Journal of Technology Transfer,* vol. 40, no 4, pp. 581–601. . Available at: https://doi.org/10.1007/s10961-014-9375-6, accessed 07.11.2020.

Garcia-Penalvo F.J., Garcia de Figuerola C., Merlo J.A. (2010) Open knowledge: Challenges and facts. *Online Information Review,* vol. 34, no 4, pp. 520–539. Available at: https://doi.org/10.1108/14684521011072963, accessed 07.11.2020.

Gerhart B., Wright P.M., McMahan G.C., Snell S.A. (2000) Measurement error in research on human resources and firm performance: How much error is there and how does it influence effect size estimates? *Personnel Psychology,* vol. 53, no 4, pp. 803–834. Available at: https://doi.org/10.1111/j.1744-6570.2000.tb02418.x, accessed 07.11.2020.

Gold E.R. (2016) Accelerating Translational Research through Open Science: The NeuroExperiment. *PLoS Biology*, vol. 14, no 12, art. e2001259. DOI: 10.1371/journal.pbio.2001259.

Griffin A., Noble C.H., Durmusoglu S.S. (2014) *Open Innovation: New Product Development Essentials from the PDMA*, Hoboken, NJ: Wiley.

Grimsdottir E., Edvardsson I.R. (2018) Knowledge Management, Knowledge Creation, and Open Innovation in Icelandic SMEs. *SAGE Open,* vol. 8, no 4. Available at: https://doi.org/10.1177/2158244018807320, accessed 07.11.2020.

Guichard R., Tran S. (2006) L'innovation distribuee: Un modele organisationnel generalisable? *Revue Internationale des PME,* vol. 19, pp. 79–99. Available at: https://hal.archives-ouvertes.fr/hal-00293630, accessed 07.11.2020.

Gulbrandsen M., Smeby J.-C. (2005) Industry funding and university professors' research performance. *Research Policy,* vol. 34, no 6, pp. 932–950. Available at: https://doi.org/10.1016/j.respol.2005.05.004, accessed 07.11.2020.

Gura T. (2013) Citizen science: Amateur experts. *Nature,* no 496 (7444), pp. 259–261. DOI:10.1038/nj7444-259a.

Hagedoorn J., Zobel A.-K. (2015) The role of contracts and intellectual property rights in open innovation. *Technology Analysis and Strategic Management,* vol. 27, no 9, pp. 1050–1067. Available at: https://doi.org/10.1080/09537325.2015.1056134, accessed 07.11.2020.

Harison E., Koski H. (2010) Applying open innovation in business strategies: Evidence from Finnish software firms. *Research Policy,* vol. 39, no 3, pp. 351–359. Available at: https://doi.org/10.1016/j.respol.2010.01.008, accessed 07.11.2020.

Henttonen K., Lehtimaki H. (2017) Open innovation in SMEs: Collaboration modes and strategies for commercialization in technology-intensive companies in forestry industry. *European Journal of Innovation Management,* vol. 20, no 2, pp. 329–347. Available at: https://doi.org/10.1108/EJIM-06-2015-0047, accessed 07.11.2020.

Iglesias-Sanchez P.P., Correia M.B., Jambrino-Maldonado C. (2019) Challenges of Open Innovation in the Tourism Sector. *Tourism Planning and Development,* vol. 16, no 1, pp. 22–42. Available at: https://doi.org/10.1080/21568316.2017.1393773 , accessed 07.11.2020.

Jamett I., Alvarado L., Maturana S. (2017) Analysis of the state of the art of open innovation: Practical implications in engineering. *Revista Ingenieria de Construccion,* vol. 32, no 2, pp. 73–84. Available at: https://doi.org/10.4067/S0718-50732017000200006, accessed 07.11.2020.

Jugend D., de Camargo Fiorini P., Armellini F., Gabriela Ferraria A. (2020) Public support for innovation: A systematic review of the literature andimplications for open innovation. *Technological Forecasting and Social Change,* vol. 156, art. 119985. Available at: https://doi.org/10.1016/j.techfore.2020.119985, accessed 07.11.2020.

Kafouros M.I., Forsans N. (2012) The role of open innovation in emerging economies: Do companies profit from the scientific knowledge of others? *Journal of World Business*, vol. 47, no 3, pp. 362–370. Available at: https://doi.org/10.1016/j.jwb.2011.05.004, accessed 07.11.2020.

Katsikis N., Lang A., Debreczeny C. (2016) Evaluation of Open Innovation in B2B from a Company Culture Perspective. *Journal of Technology Management and Innovation,* vol. 11, no 3, pp. 94–100. Available at: https://doi.org/10.4067/S0718-27242016000300011, accessed 07.11.2020.

Khumalo M., Van der Lingen E. (2017) The open business model in a dynamic business environment: A literature review. *South African Journal of Industrial Engineering,* vol. 28, no 3, pp. 147–160. Available at: https://doi.org/10.7166/28-3-1851, accessed 07.11.2020.

Krause W., Schutte C. (2015) A perspective on Open Innovation in Small and medium-sized enterprises in South Africa, and Design Requirements for an Open Innovation Approach. *The South African Journal of Industrial Engineering*, vol. 26, no 1, pp. 163–178. Available at: https://doi.org/10.7166/26-1-997, accessed 07.11.2020.

Lakeman-Fraser P., Gosling L., Moffat A.J., West S.E., Fradera R., Davies L., Ayamba M.A., Ayamba, M.A., van der Wal R. (2016) To have your citizen science cake and eat it? Delivering research and outreach through Open Air Laboratories (OPAL). *BMC Ecology,* vol. 16, art. 16. Available at: https://doi.org/10.1186/s12898-016-0065-0, accessed 07.11.2020.

Lee G., Benoit-Bryan J., Johnson T.P. (2012) Survey research in public administration: Assessing mainstream journals with a total survey error framework. *Public Administration Review,* vol. 72, no 1, pp. 87–97. Available at: https://doi.org/10.1111/j.1540-6210.2011.02482.x, accessed 07.11.2020.

Lehtimaki T., Simula H., Salo J. (2009) Applying knowledge management to project marketing in a demanding technology transfer project: Convincing the industrial customer over the knowledge gap. *Industrial Marketing Management*, vol. 38, no 2, pp. 228–236. Available at: https://doi.org/10.1016/j.indmarman.2008.12.008, accessed 07.11.2020.

Lewis N.A. (2020) Open Communication Science: A Primer on Why and Some Recommendations for How. *Communication Methods and Measures,* vol. 14, no 2, pp. 71–82. Available at: https://doi.org/10.1080/19312458.2019.1685660, accessed 07.11.2020.

Lichtenthaler U. (2010) Intellectual property and open innovation: An empirical analysis. *International Journal of Technology Management,* vol. 52, no 3–4, pp. 372–391. DOI: 10.1504/IJTM.2010.035981.

Liu M., Hull C.E., Hung Y.-T.C. (2017) Starting open source collaborative innovation: the antecedents of network formation in community source. *Information Systems Journal,* vol. 27, no 5, pp. 643–670. . Available at: https://doi.org/10.1111/isj.12113, accessed 07.11.2020.

Lopes A., Ferrarese A., Carvalho M.M. (2017) Inovacao aberta no processo de pesquisa e desenvolvimento: uma analise da cooperacao entre empresas automotivas e universidades. *Gestao e Producao*, vol. 24, pp. 653–666. Available at: https://doi.org/10.1590/0104-530x2138-16, accessed 07.11.2020.

Lucia O., Burdio J.M., Acero J., Barragan L.A., Garcia J.R. (2012) Educational opportunities based on the university-industry synergies in an open innovation framework. *European Journal of Engineering Education*, vol. 37, no 1, pp. 15–28. Available at: https://doi.org/10.1080/03043797.2011.644762, accessed 07.11.2020.

Martinez-Noya A., Narula R. (2018) What more can we learn from R&D alliances? A review and research agenda. *Business Research Quarterly,* vol. 21, pp. 195–212. Available at: https://doi.org/10.1016/j.brq.2018.04.001, accessed 07.11.2020.

Merino E.A.D. Forcellini F.A., Ariente Neto R., Wagner A.(2018) Modelo para avaliar o comportamento dinamico daevolucao da comercializacao de produtos em umcontexto de inovacao aberta. *Gestao e Producao*, vol. 25, no 3, pp. 645–657. Available at: http://dx.doi.org/10.1590/0104-530X1594-14, accessed 07.11.2020.

Morandi V. (2013) The management of industry-university joint research projects: How do partners coordinate and control R&D activities? *Journal of Technology Transfer,* vol. 38, no 2, pp. 69–92. Available at: https://doi.org/10.1007/s10961-011-9228-5, accessed 07.11.2020.

Nambisan S., Lyytinen K., Majchrzak A., Song M. (2017) Digital Innovation Management: Reinventing Innovation Management Research in a Digital World. *MIS Quarterly,* vol. 41, no 1, art. 03. DOI: 10.25300/MISQ/2017/41:1.03.

Neely A., Gregory M., Platts K. (2005) Performance measurement system design: A literature review and research agenda. *International Journal of Operations and Production Management,* vol. 15, no 4, pp. 80–116. Available at: https://doi.org/10.1108/01443579510083622, accessed 07.11.2020.

Ngongoni C.N., Grobbelaar S., Schutte C. (2017) The role of open innovation intermediaries in entrepreneurial ecosystems design. *South African Journal of Industrial Engineering,* vol. 28, no 3, pp. 56–65. Available at: https://doi.org/10.7166/28-3-1839, accessed 07.11.2020.

Ottonicar S.L.C., Nascimento N.M., Mosconi E. (2018) Information Literacy and digital disruption in Industry 4.0. *XIX Encontro de Pesquisadores: Pesquisa Cientifica e Desenvolvimento*, Franca (Sao Paulo): Programa de Pos-Graduacao em Desenvolvimento Regional (UniFAcef), pp. 631–638. Available at: https://www.researchgate.net/publication/328368535_INFORMATION_LITERACY_AND_DIGITAL_DISRUPTION_IN_INDUSTRY_40, accessed 07.11.2020.

Perkmann M., Walsh K. (2007) University-industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews*, vol. 9, no 4, pp. 259–280. Available at: https://doi.org/10.1111/j.1468-2370.2007.00225.x, accessed 07.11.2020.

Piedra N., Suarez J.P. (2018) Hacia la Interoperabilidad Semantica para el Manejo Inteligente y Sostenible de Territorios de Alta Biodiversidad usando SmartLand-LD. *RISTI – Revista Iberica de Sistemas e Tecnologias de Informacao*, vol. 26, pp. 104–121. Available at: https://doi.org/10.17013/risti.26.104-121, accessed 07.11.2020.

Pitassi C. A. (2012) Virtualidade nas estrategias de inovacao aberta: proposta dearticulacao conceitual. *Revista de Administracao Publica*, vol. 46, no 2, pp. 619–641. Available at: https://doi.org/10.1590/S0034-76122012000200013, accessed 07.11.2020.

Ramirez-Montoya M. S., Garcia-Penalvo F.-J. (2018) Co-creation and open innovation: Systematic literature review. *Comunicar,* vol. 26, no 54, pp. 09–18. Available at: https://doi.org/10.3916/C54-2018-0, accessed 07.11.2020.

Remneland-Wikhamn B. (2013) Two different perspectives on open innovation — Libre versus contro. *Creativity and Innovation Management,* vol. 22, no 4, pp. 375–389. Available at: https://doi.org/10.1111/caim.12035, accessed 07.11.2020.

Riley J.M., Klein R., Miller J., Sridharan V. (2016) How internal integration, information sharing, and training affect supply chain risk management capabilities. *International Journal of Physical Distribution and Logistics Management,* vol. 46, no 10, pp. 953–980. DOI:10.1108/IJPDLM-10-2015-0246.

Rodrigues L.C., Maccari E.A., Campanario M.A. (2010). Expanding the Open Innovation Convept: The case of TOT-VS S.A. *Journal of Information Systems and Technology Management,* vol. 7, no 3, pp. 737–754. DOI: 10.4301/S1807-17752010000300011.

Roman M., Liu J., Nyberg T. (2018) Advancing the open science movement through sustainable business model development. *Industry and Higher Education,* vol. 32, no 4, pp. 226–234. Available at: https://doi.org/10.1177/0950422218777913, accessed 07.11.2020.

Rubera G., Chandrasekaran D., Ordanini A. (2016) Open innovation, product portfolio innovativeness and firm performance: the dual role of new product development capabilities. *Journal of the Academy of Marketing Science,* vol. 44, pp. 166–184. Available at: https://doi.org/10.1007/s11747-014-0423-4, accessed 07.11.2020.

Sa C., Grieco J. (2016) Open Data for Science, Policy, and the Public Good. *Review of Policy Research*, vol. 33, no 5, pp. 526–543. Available at: https://doi.org/10.1111/ropr.12188, accessed 07.11.2020.

Saebi T., Foss N.J. (2015) Business models for open innovation: Matching heterogeneous open innovation strategies with business model dimensions. *European Management Journal,* vol. 33, no 3, pp. 201–213. Available at: https://doi.org/10.1016/j.emj.2014.11.002, accessed 07.11.2020.

Sanchez-Gonzalez G., Herrera L. (2014) Effects of customer cooperation on knowledge generation activities and innovation results of firms. *Business Research Quarterly,* vol. 17, pp. 292–302. Available at: https://doi.org/10.1016/j.brq.2013.11.002, accessed 07.11.2020.

Schenk E., Guittard C. (2012) Une typologie des pratiques de Crowdsourcing: l'externalisation vers la foule, au-dela du processus d'innovation. *Management International,* vol. 16, pp. 89–100. Available at: https://doi.org/10.7202/1012395ar , accessed 07.11.2020.

Schlagwein D., Conboy K., Feller J., Leimeister J.M., Morgan L. (2017) "Openness" with and without Information Technology: A Framework and a Brief History. *Journal of Information Technology,* vol. 32, pp. 297–305. Available at: https://doi.org/10.1057/s41265-017-0049-3, accessed 07.11.2020.

Schuster G., Brem A. (2015) How to benefit from open innovation? An empirical investigation of open innovation, external partnerships and firm capabilities in the automotive industry. *International Journal of Technology Management,* vol. 69, no 1, pp. 54–76. DOI: 10.1504/IJTM.2015.071031

Schwab K. (2016) *The fourth industrial revolution,* New York: Crown Business.

Scuotto V., Beatrice O., Valentina C., Nicotra V., Di Gioia L., Farina Briamonte M. (2020) Uncovering the micro-foundations of knowledge sharing in open innovation partnerships: An intention-based perspective of technology transfer. *Technological Forecasting and Social Change,* vol. 152, art. 119906. Available at: https://doi.org/10.1016/j.techfore.2019.119906, accessed 07.11.2020.

Secundo G., Toma A., Schiuma G., Passiante G. (2019) Knowledge transfer in open innovation: A classification framework for healthcare ecosystems. *Business Process Management Journal,* vol. 25, no 1, pp. 144–163. Available at: https://doi.org/10.1108/BPMJ-06-2017-0173, accessed 07.11.2020.

Serrano-Bedia A.M., Lopez-Fernandez M.C., Garcia-Piqueres G., Sharratt J., McMurdo A. (2018) Complementarity between innovation knowledge sources: Does the innovation performance measure matter? *Business Research Quarterly,* vol. 21, no 1, pp. 53–67. Available at: https://doi.org/10.1016/j.brq.2017.09.001, accessed 07.11.2020.

Simeth M., Raffo J.D. (2013) What makes companies pursue an Open Science strategy? *Research Policy,* vol. 42, pp. 1531–1543. Available at: https://doi.org/10.1016/j.respol.2013.05.007, accessed 07.11.2020.

Smith M.L., Seward R. (2017) Openness as social praxis. *First Monday,* vol. 22, no 4, art. 7073. Available at: https://doi.org/10.5210/fm.v22i4.7073, accessed 07.11.2020.

Stodden V. (2010) Open science: Policy implications for the evolving phenomenon of user-led scientific innovation. *Journal of Science Communication,* vol. 9, no 1, art. 05. Available at: https://doi.org/10.22323/2.09010205, accessed 07.11.2020.

Strasak A.M., Zaman Q., Pfeiffer K.P., Göbel G., Ulmer H. (2007) Statistical errors in medical research — A review of common pitfalls. *Swiss Medical Weekly,* vol. 137, no 3–4, pp. 44–49. Available at: https://pubmed.ncbi.nlm.nih.gov/17299669/, accessed 07.11.2020.

Touati N., Denis J. (2013) Analyse critique de la litterature scientifique portant sur l'innovation dans le secteur public: Bilan et perspectives de recherche prometteuses. *Telescope: Revue d'analyse comparee en administration publique,* vol. 19, no 2, pp. 1–21. Available at: https://doi.org/10.7202/1023837ar, accessed 07.11.2020.

Tranfield D., Denyer D., Smart P. (2003) Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management,* vol. 14, pp. 207–222. Available at: https://doi.org/10.1111/1467-8551.00375, accessed 07.11.2020.

Valencia-Vazquez R., Perez-Lopez M.E., Vicencio-De-La-Rosa M.G., Martinez-Prado M.A., Rubio-Hernandez R. (2014) Knowledge and technology transfer to improve the municipal solid waste management system of Durango City, Mexico. *Waste Management and Research,* vol. 32, no 9, pp. 848–856. Available at: https://doi.org/10.1177%2F0734242X14546035, accessed 07.11.2020.

Vercueil J. (2012) *Les pays emergents. Bresil – Russie – Inde – Chine… Mutations economiques et nouveaux defies* (3rd ed.), Paris: Breal.

Vicente-Saez R., Martinez-Fuentes C. (2018) Open Science now: A systematic literature review for an integrated definition. *Journal of Business Research,* vol. 88, pp. 428–436. https://doi.org/10.1016/j.jbusres.2017.12.043, accessed 07.11.2020.

Viseur R. (2015) Open Science – Practical Issues in Open Research Data. *Proceedings of 4th International Conference on Data Management Technologies and Applications (DATA-2015),* Colmar (France) SCITEPRESS – Science and Technology Publications, pp. 201–206. Available at: https://doi.org/10.5220/0005558802010206, accessed 07.11.2020.

Vlaisavljevic V., Medina C.C., Van Looy B. (2020) The role of policies and the contribution of cluster agency in the development of biotech open innovation ecosystem. *Technological Forecasting and Social Change*, vol. 155, art. 119987. Available at: https://doi.org/10.1016/j.techfore.2020.119987, accessed 07.11.2020.

Vrgovic P., Vidicki P., Glassman B., Walton A. (2012) Open innovation for SMEs in developing countries – An intermediated communication network model for collaboration beyond obstacles. *Innovation: Management, Policy and Practice*, vol. 14, no 3, pp. 290–302. Available at: https://doi.org/10.5172/impp.2012.14.3.290, accessed 07.11.2020.

Watson M. (2015) When will 'open science' become simply 'science'? *Genome Biology,* vol. 16, art. 101. Available at: https://doi.org/10.1186/s13059-015-0669-2, accessed 07.11.2020.

West J., Gallaguer S. (2006) Patterns of Open Innovation in Open Source Software // Open Innovation: Researching a New Paradigm (eds. H. Chesbrough, W.Vanhaverbeke, J. West), Oxford: Oxford University Press, pp. 82–106.

Wu I.-L., Hu Y.-P. (2018) Open innovation based knowledge management implementation: A mediating role of knowledge management design. *Journal of Knowledge Management,* vol. 22, no 8, pp. 1736–1756. Available at: https://doi.org/10.1108/JKM-06-2016-0238, accessed 07.11.2020.

Yoon D. (2017) The information science policy for the public open data of the national research institute. *Cogent Business and Management*, vol. 4, no 1, art. 1406321. DOI: 10.1080/23311975.2017.1406321.

Yun J.J., Yang J., Park K. (2016) Open Innovation to Business Model: New Perspective to Connect between Technology and Market. *Science, Technology and Society,* vol. 21, no 3, pp. 324–348. Available at: https://doi.org/10.1177%2F0971721816661784, accessed 07.11.2020.

The "Linked Prosperity" Model as an Integrated Response to Corporate Management Challenges in a Network Society

Vladimir Milovidov
Head of Chair, vmilovidov@hotmail.com

MGIMO University, 76, Vernadsky ave., Moscow, 119454, Russian Federation

Abstract

In the context of technological and social changes, business faces the challenges of a more complex operating environment. New business models are required that take into account an unprecedentedly wide range of emerging factors. Among such approaches, an integral model stands out, which allows one to adapt to a new level of development of society and master a new context. The approaches to the development of an integral model are still in the process of formation, since a deeper study of the modern network society, its values, guidelines, and preferences is required. Taking into account such complexity requires non-linear approaches and thinking in terms of complex, dynamic systems. From this point of view, when interacting with the increasingly complex environment, it is advisable for companies to view themselves as an element of a large-scale system of horizontal, social ties, in which the idea of social responsibility acquires new meanings.

It is especially difficult to implement integral approaches within the framework of traditional thinking due to the variety and multi-layered factors that change the context of companies' activities. The transformation of corporate governance and approaches to social responsibility is a non-linear process driven by a chain of events related to changes in consumer behavior and other aspects. Such exponential changes are characterized by profound and cumulative consequences, radically changing the spheres of activity, social relations, and institutions. This article demonstrates the case of a company that, despite the difficulties, managed to implement a similar approach and maintain a dynamic pace of development.

eywords: integrated management model; corporate governance; business model; sustainability; network society; stakeholders; corporate citizenship; linked prosperity; joint-stock companies; corporate social responsibility

Citation: ilovidov V. (2020) The "Linked Prosperity" Model as an Integrated Response to Corporate Management Challenges in a Network Society. *Foresight and STI Governance*, vol. 14, no 4, pp. 112–120. DOI: 10.17323/2500-2597.2020.4.112.120

The Integrated Business Model and the COVID-19 Pandemic

The social relations system is one of the most complicated study objects whose complexity and the number of dimensions increase as it develops. The modern, ever more complex society is frequently defined as a network society, where direct "peer-to-peer" connections begin to dominate the traditional vertical relations system. The transformation process is far from complete and develops nonlinearly. Global network companies and decentralized autonomous organizations (DAOs), based on distributed ledger technology (DLT) and operating exclusively in a virtual environment, are emerging and rapidly growing. In an increasingly complex context, the ability to anticipate future managerial, social, and technological innovations becomes critical. In recent decades, the following areas have emerged in the literature: the development of new corporate governance theory; transformation factors of traditional business models; and business performance assessment criteria in changing conditions. Today these areas converge in corporate social responsibility (CSR) and sustainable business model studies. Actually, the whole range of approaches to managing business processes and building relationships with external and internal actors is being consolidated.

Initially, ensuring companies' transparency and accountability was on the agenda. Between 1988 and 2008 the corpus of English-language publications in the US and UK containing the term "corporate governance" or the abbreviation "CSR" increased at least ten-fold. By now not only quantitative indicators of public and scientific interest in the topic have changed, but also qualitative ones.

Other new concepts have emerged in addition to CSR, such as stakeholders and "corporate citizenship", along with the "corporate governance 2.0" concept [*van der Elst, Vermeulen* 2011; *Visser*, 2011; *Subramanian*, 2015] which takes into account all technological advances and radical shifts in public mentality, including those reflected in the "sustainable development" model. In another area, an attempt was made to rethink and suggest a new business model which would take into account changing consumer preferences, increased global competition, aggravated climate and environmental issues, a shift in social values, and the emergence of a new generation interested in radically different consumer properties of products and services [*Drucker*, 1994; *Porter* 1996; *Johnson et al.* 2008; *Upward, Jones*, 2015]. As the number of publications increased, it became more closely related to sustainability [*Boons, Ludeke-Freund*, 2013; *Geissdoerfer et al.* 2018], which is a key marker of the transformation taking place in the public mind and corporate governance *[Page, Spira*, 2016].

The Web of Science and Scopus databases currently comprise over 4,000 publications whose titles include the term "business model", and about 470 articles with the term "sustainable business model" [*Geissdoerfer et al.* 2018]. The convergence of business model and corporate governance studies allows one to assess the relationship and complementarities between these concepts. The development of long-term strategies, business planning, modeling, and improvement of corporate governance essentially addresses common issues, which among other things suggests that the social structure is becoming more complicated, with its numerous levels increasingly connected with one another. According to a basic principle of the UK Corporate Governance Code updated in 2018, a successful company aims to achieve long-term sustainable success, increase its capitalization, and create social benefits [FRC, 2018]. Thus, the goal of top company management merges in three aspects: social responsibility, sustainability, and profitability. At the current stage, this traditional objective acquires a new dimension, so it is being accomplished in the scope of the complex dynamic systems concept. This means social benefits must be taken into account when making decisions at different levels. The criteria for achieving this goal are so diverse, they are difficult to formalize. Qualitative, volatile psychological aspects of assessing entrepreneurial activity and strategies' effectiveness are becoming no less important than financial and economic performance indicators. Problems also arise with setting priorities for a wide range of stakeholders.

Accordingly, it would make sense to address not corporate governance and business models separately, but an integrated management model (IMM). Along with the traditional objectives of achieving financial stability, reducing costs, and increasing value, it is aimed at building relationships between the company and society, and promoting social development.

Despite the significant number of publications on the subject, practical examples of IMM application are few, though some experience in this area has been accumulated, while attempts to design such a model were made long before the need for it was realized. One of the case studies, the company Ben & Jerry's, will be presented below.

Let us consider the components of such an integrated model suitable for meeting current and future challenges, including the changing social attitude towards business activities, companies' social responsibility, and company management's attempts to make the IMM the basis of long-term development strategies and corporate governance systems' transformation. These cases have the potential to become the mainstream of a new governance concept in the medium term. The consistent transformation of corporate governance and approaches to responsibility is a nonlinear process triggered by a series of changes in consumer behavior and company management, which can be described in complex system terms. The starting points of nonlinear changes can be called exponentially scalable events (ESE), which bring about profound and cumulative consequences and, at a certain time, will radically change a particular area of activities, the established social relations, or institutions [*Milovidov*, 2015a,b, 2017, 2019]. ESEs include the ongoing transformations in the theory and practice of corporate governance, often caused by unexpected and unpredictable external factors, especially those that emerged in 2020.

The World Economic Forum (WEF) report "The Universal Purpose of a Company in the Fourth Industrial Revolution" published at the end of 2019 summarizes the evolution of corporate social responsibility over more than the past two decades [*Schwab*, 2019]. However, just three months after its release, the outbreak and the rapid spread of the COVID-19 coronavirus pandemic highlighted the need to adjust this and other documents describing corporate responsibility standards. COVID-19 is an example of an ESE which has affected all areas of public life, especially consumer choice and behavior. The interdependence of participants in global supply chains becomes quite evident. Many companies are faced with the need to cut jobs or even terminate their operations; remote employment has proliferated while biological safety problems have become very much relevant. Accordingly, business models and corporate responsibility criteria have changed too. Already in April 2020 the WEF suggested the "Stakeholder Principles in the COVID Era" which clarify and adjust the approaches to responsible business conduct [WEF, 2020].

The Organisation for Economic Cooperation and Development (OECD) came up with a similar initiative in response to the rising COVID-19 coronavirus crisis [OECD, 2020], focusing on supporting and strengthening relationships between key economic agents: employees, suppliers, consumers, authorities, shareholders, and other actors. The need to preserve the existing business ecosystems, strengthen security, and take into account the interests of all stakeholders, even at the cost of short-term economic benefits, was recognized. In turbulent crisis conditions, such measures make it possible to balance the expectations of business and society, thus confirming the viability of the previously adopted integrated management models, including the one under consideration here. The coronavirus crisis has shown that the traditional corporate governance model based on a relatively narrow understanding of productivity, which did not take into account the interests of various parties, was no longer viable. Moreover, its shortcomings hinder the transition to a new business model. Companies cannot build up benefits for themselves without providing them for society as a whole. It would also be impossible to maintain one's positions after a sudden disruption of economic and social ties due to unexpected crises.

An IMM is designed to balance corporate and public interests, that is, high profit margins and an acceptable level of the company's social responsibility.

Ignoring the need to integrate the business model and corporate governance is fraught with serious risks and, as a result, with long-term and nonlinear negative consequences for the company and society as a whole.

The Transformation of Public Mentality

The integrated business model concept emerged due to the natural evolution of the relationship between business and society. In recent decades, a clear trend towards management innovation became apparent. The advances of big data technologies and content analysis allow one to consider the public's changing interests, its openness to certain ideas, scientific trends, and everyday narratives which define the public mentality.

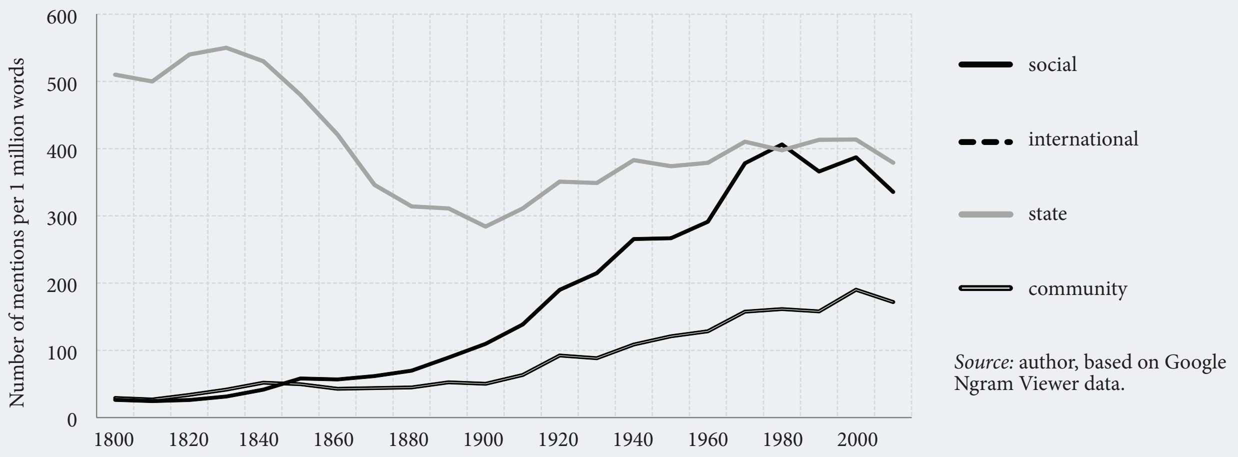
Google Trends (GT) and Google Ngram Viewer (GNV)[1] are among the most effective and accessible tools for studying the dynamics of collective mentality. The first allows one to track changes in the content of the most frequent search queries since 2004, while the second makes it possible to assess the frequency of terms' and concepts' use in book publications (the coverage period ranges from 1800 to 2008).

At present the database of publications processed by the GNV algorithm exceeds 8.1 million titles (8% of all books published in the world), with a total volume of over 860 billion tokens [*Michel et al.*, 2011]. Figure 1 shows the number of mentions of such concepts as "social", "international", "state", and "community" per 1 million words in English-language books in the Google collection published in the respective year. For example, in 2008, the term "state" was used 379 times per million words, "social" 336 times, "community" 172, and "international" 112 times. They are closely associated with the main development trends including changing attitudes toward the state, attention to social issues, internationalization of economic activities, and the increased role and activity of local communities including civic associations, self-government bodies, and so on.

Another cross-section of social change is shown in Figure 2: it compares the frequency of using the words "network", "industrial", "digital", and "global". These terms are also strongly associated with the current internationalization processes and the rapid development of digital technologies.

[1] For more see: https://books.google.com/ngrams, accessed on: 30.06.2020.

Figure 1. **Frequency of Mentions of the Words** *Social, International, State*, **and** *Community* **per 1 Million Words in English-Language Publications in 1800–2008**



Source: author, based on Google Ngram Viewer data.

The presented data becomes especially useful when the two graphs are combined. Figure 3 illustrates the transformation of societal attitudes over more than two centuries. For example, the word "state" was most frequently mentioned in 1830, "industrial" in 1970, "social" in 1980, "network", "international", and "community" in 2000, and "global" in 2008. The changes in the frequency of mentioning the terms in question allow one to assess the changes in the essential characteristics of societies of the 19th-early 21st centuries.

The first type, which dominated until the 1970s, can be called the state-industrial society, and the one that replaced it at the turn of the 21st century is the global network society. These characteristics are notional and do not match the common periodization of the industrial and post-industrial structures. However, this typology seems to be valid and is confirmed by many contemporary facts which are not reflected in the "post-industrial" concept.

At the state-industrial stage, individual countries interacted with each other. Physical boundaries, spheres of influence, and international competition were of fundamental importance. The modern global network context is based on "peer-to-peer" connections on the global scale and various forms of social self-organization including social networks. Physical boundaries remain but become permeable in the virtual environment of the internet, international communications, and trans-boundary knowledge and idea exchanges. In the new context, rigidly hierarchical connections do not make up the entire system of values of the participants in the global socio-humanitarian environment.

The new type of society gives rise to appropriate attitudes, behavioral rules, and values that transform the traditional approaches to business management. Radical changes are expected in this area, the signs of which are already apparent in the activities of companies more perceptive to disruptive innovations. However, the first serious attempts to adapt management practices to the changing business environment can be traced back to the 1980s. One such model is "linked prosperity", which implies sharing benefits between companies, stakeholders, customers, and the general public. In other words, the linked prosperity model merges three aspects: companies' profits, their sustainability, and social responsibility.

The food industry company Ben & Jerry's was one of the first to apply the new approach, having made it its mission to "create linked prosperity for everyone".[2] A holistic vision allowed it to anticipate the radical changes in business process management. Ben & Jerry's new strategy can be seen as a unique IMM which made it possible to detect the deep systemic shifts in social values that were radically changing the nature of fundamental classical economics concepts such as utility, profit, costs, property, and so on.

The company merged the elements of two business models: a classic one, aimed at increasing profitability indicators, and a new model that takes into account the interests of many parties including shareholders, suppliers, contractors, customers, local communities, and others, with an emphasis upon CSR. Ben & Jerry's simultaneously pursues three goals: production (making high-quality, constantly

[2] Available on: https://www.benjerry.com/values, accessed on: 12.06.2020.

Table 1. **Innovative Elements of the Linked Prosperity Model**

Innovations	Production process	Business sustainability and productivity	Social responsibility
Product	Invention, R&D	Competitiveness, market leadership	Socially determined use value
Management	Cooperation, division of labor	Productivity, maximizing revenues and profits, CSR	Optimizing total social benefits (TSB)
Marketing	Context, perception, experience	Increasing sales	Emergence of intangible social values
Source: author.			

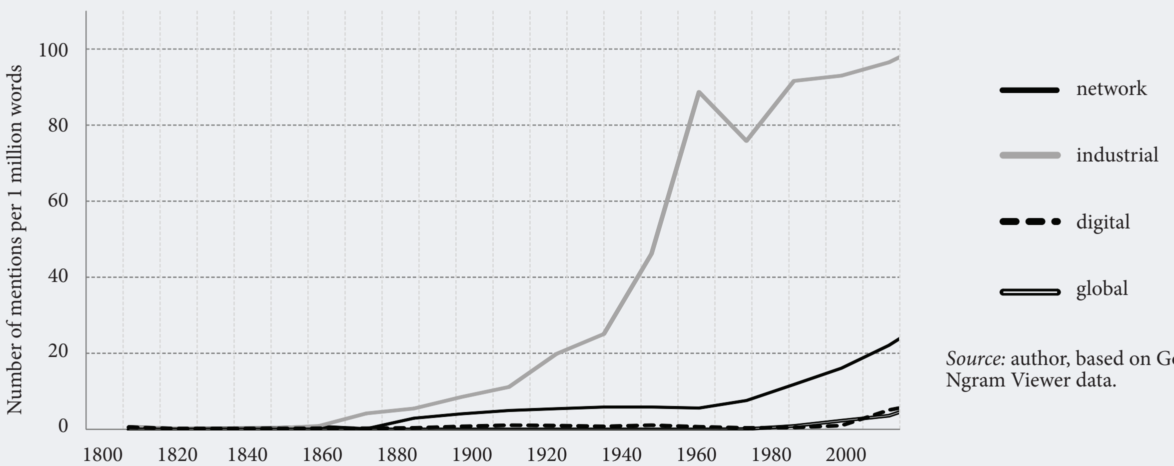
improved products), economic (increasing sales), and social (supporting employment, implementing local social programs, etc.) [*Michalak*, 2019]. This broad formula benefits all participants in the value chain: company employees, suppliers, customers, local communities, and so on. The company came up with this approach back in 1988, when the ideas of CSR, corporate citizenship, and stake holding were in their infancy, and even the very concept of a business model had not yet become the focus of academic research. Though product, management, and marketing innovations have emerged in response to global challenges, Ben & Jerry's has been able to quickly conquer a large segment of consumers who share social justice, equality, and responsibility ideas (Table 1). By introducing the linked prosperity model, Ben & Jerry's made the product significantly more complex, enriching it with new social content and turning it into a kind of cultural phenomenon. In this case the product concept went beyond meeting a simple nutritional need. The consumer value became a socially determined use value.

The management model under consideration also incorporates the fair-trade principle: minimizing the economic inequality of integral production participants. Cooperation ties are supplemented by supporting small and medium-sized businesses, introducing limits on the difference in compensation for junior and senior employee positions (no more than five times), and social programs to support local communities in the regions where the company and its partners operate. Social benefits and CSR were combined with consumer value. Increasing profits gave way to a new goal: maximizing total social benefits.

In line with the traditional business modeling principles, Ben & Jerry's was increasing sales to recoup the costs and accomplish its social mission. At the same time the intangible values of its corporate culture promoted demand for its products. In "experience economy" terms [*Pine, Gilmore*, 1998], to promote its products on the market, the company offered both new products and unique consumer experience.

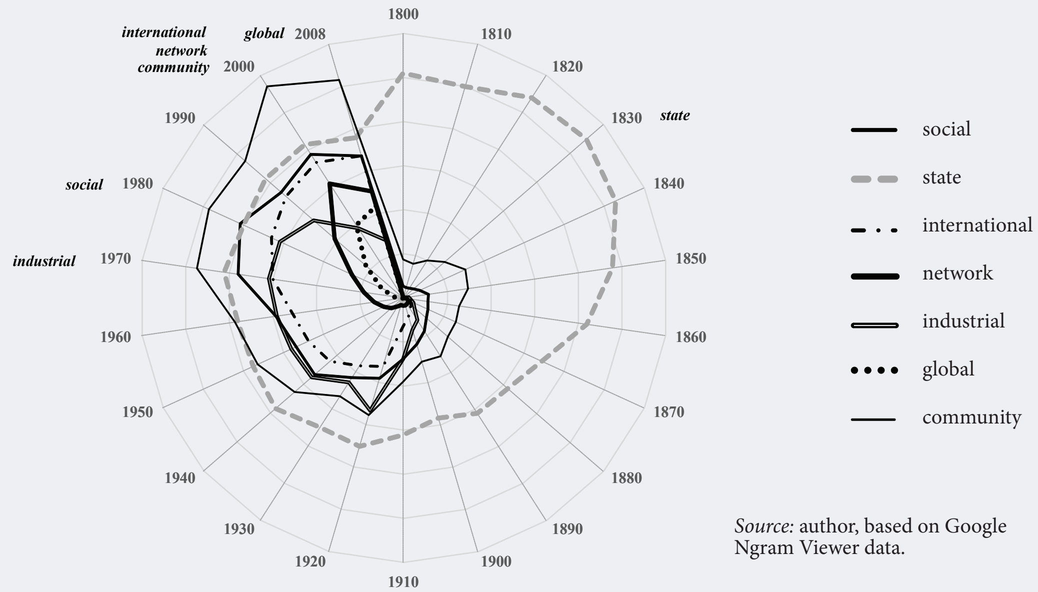
Let us take a closer look at specific elements of the linked prosperity model as reference points for implementing an IMM in the emerging network society, namely creating TSB, maximizing it, and generating and monetizing intangible social values. Both social goal-setting and consumer value are important. Product innovations are expected to complement objective consumer properties of products with value dimension, which increases demand for them. The end result of such innovations is the production of TSB, while products turn into

Figure 2. **Frequency of Mentions of the Words** *Network, Industrial, Digital*, **and** *Global* **per 1 Million Words in English-Language Publications in 1800–2008**



Source: author, based on Google Ngram Viewer data.

Figure 3. **Frequency of Mentions of the Words** *Social, State, International* **(main scale from 0 to 600 words), and** *Network, Industrial, Global*, **and** *Community* **(auxiliary scale from 0 to 120 words) per 1 Million words in English-Language Publications in 1800-2008**



Source: author, based on Google Ngram Viewer data.

a social self-identification mechanism (joining the group), which is demonstrated by the example of the younger generation. Intangible factors such as quality of life, state of environment, interpersonal relations, and overall social context of products and services are becoming increasingly important for younger people. Members of new generations starting with millennials (born in 1981 and onwards) are convinced that producers must make qualitative changes to society [Deloitte, 2018, 2019; *Goleman*, 2019]. Attempts to take into account the changes in their values have obvious economic implications: annual expenditures of this social group are estimated at about $600 billion and expected to reach $1.4 trillion by 2020 [Gallup, 2016].

Maximizing Social Benefits and Optimizing Profits

The shift in emphasis in assessing products' consumer properties, the incorporation of social content into their physical characteristics also affect entrepreneurial goals, which is reflected in the frequency of mentions of the terms "profit", "revenue" and "benefits". Figure 4 shows the gradual decrease in the frequency of mentions of the word "revenue". The popularity of the term "profit" in English-language literature grew until the 1920s and began to steadily decline after 1940. At the same time, there was an exponential growth in the frequency of mentions of the word "benefit", which today is actually at its historic maximum. The presented data also reflects the changes in the consumer attitudes of younger generations, which prompt companies to create managerial innovations, including increasing the total social benefits of their activities.

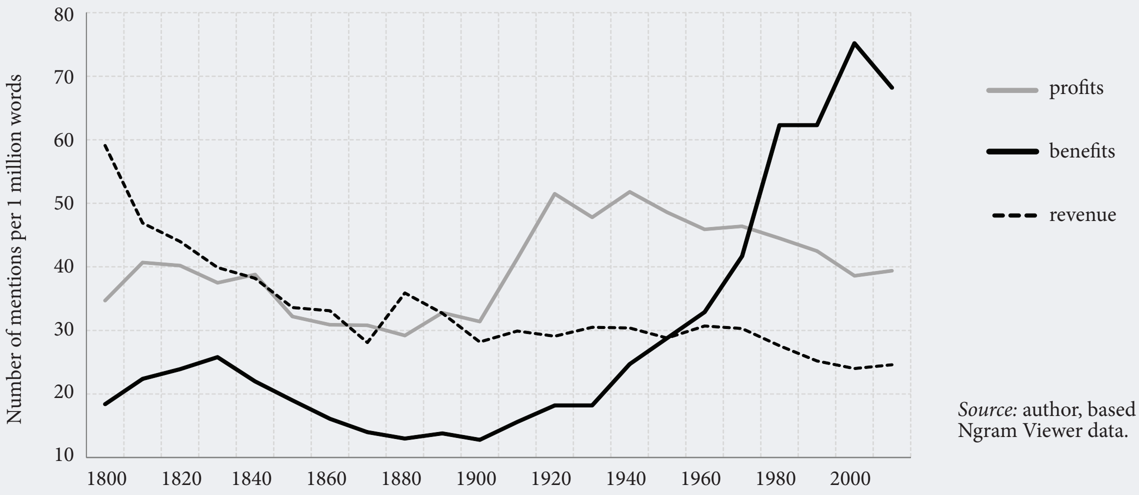
Finding a balance of interests that can promote the growth of companies' profits and total social benefits at the same time remains an important task. The example of Ben & Jerry's shows that betting on the linked prosperity model at a certain stage may negatively affect economic indicators for a certain amount of time, but then it will be possible to achieve equilibrium followed by growth.

Intangible Values and Tangible Assets

Incorporating social content into consumer value requires businesses to implement a broad set of measures which go beyond marketing innovations and take into account the nonlinear patterns of complex systems.

Whereas previously it was enough for companies to accomplish the objective of maximizing profits, now the context has become more complicated: they must also take into account a variety of social signals. The CSR factor as a corporate governance system element should be taken into account in strategic business planning, assessed, and balanced against the expected additional profits. Unlike the usual intangible resources, CSR emerges during companies' interaction with society. The result is a positive or negative assessment of the company's social responsibility, and thus of its products' matching public interests. In the first case this can promote demand for products, and the willingness to pay a premium reflecting the higher socially determined use value

Figure 4. **Frequency of Mentions of the Words** *Profit, Revenue*, **and** *Benefits* **per 1 Million Words in English-Language Publications in 1800-2008**



Source: author, based on Google Ngram Viewer data.

[*Laroche et al.*, 2001]. In the second case, the interest in products will decline, followed by a decline in profits. The company will have to cut costs and output or apply compensatory measures that would increase the consumer value of the product. The network society factor enhances all effects (positive or negative alike), since information about and user reviews of the company and its products are instantly disseminated across the global network. CSR affects pricing: young consumers are willing to pay more for products of companies which adhere to appropriate standards (in Ben & Jerry's case, its ice cream). On the financial market, despite trend volatility, companies that follow CSR standards tend to have a higher potential for profitability.

Sustainable investments vary widely by country or by CSR program profile. In 2018 they amounted to $30.7 trillion in total, the bulk of which was made in Europe (46%) and the US (39%), and smaller shares in Japan (7%), Canada (6%), and Australia and New Zealand (2%) [GSIA, 2019]. The highest growth of social investments was noted in Japan: a record 6,700% in 2014-2017. Companies' socially responsible behavior has a positive effect on decision-making, both by buyers and investors, while CSR becomes an intangible asset that generates added value [*Hellsten, Mallin*, 2006].

Conclusions

The development of digital technologies leads to the transformation of both economic actors and social values. New, more complex development patterns emerge, which include the integrated corporate governance model. It takes into account a wider range of various factors and trends: the emergence of socially determined demand and the corresponding consumer value; increased demand for greater total social benefit from entrepreneurial activities; and a greater role for social values in the production of goods and services. These aspects are important in forecasting profits, creating corporate value, and interacting with partners, customers, and the external environment.

In the near future, the integrated approach to management will reach a new level due to the continuous development of digital technologies, and thus of society. This will lead to a radical revision of business performance criteria. Given the growing importance of business reputation as an intangible social value, the methodology for its quantitative assessment will be improved, along with the approaches to forecasting risks, opportunities, and changing preferences and values of potential target audiences. Active customer groups' priorities are changing by becoming more complex and multi-layered.

The emergence of new business models must be taken into account, such as product and service sharing, minimizing the negative impact upon the environment, and so on. Company executives will have to build up their competencies and knowledge of complex systems and take them into account in strategy development. Meanwhile their responsibilities are expanding and the role of the social component in company reporting is growing.

New corporate standards allow one to adequately assess financial aspects of sustainable development initiatives such as environmental and social programs, or new responsible governance techniques. Entrepreneurial success will largely depend upon how flexible and responsive companies are to social innovations prompted by the development of the network society.

References

Boons F., Ludeke-Freund F. (2013) Business model for sustainable innovation: state-of-the-art and steps toward a research agenda. *Journal of Cleaner Production*, vol. 45, pp. 9–19. DOI: 10.1016/j.jclepro.2012.07.007.

Deloitte (2018) *Deloitte Millennial Survey. Millennials Disappointed in Business Unprepeared for Industry 4.0*. Available at: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/gx-2018-millennial-survey-report.pdf, accessed 26.06.2020.

Deloitte (2019) *The Deloitte Global Millennial Survey 2019. Societal Discord and Technological Transformation Create a "Generation Disrupted"*. Available at: https://www2.deloitte.com/global/en/pages/about-deloitte/articles/millennialsurvey, accessed 26.06.2020.

Drucker P.F. (1994) The Theory of the Business. *Harvard Business Review*, vol. 72 (September-October), pp. 95–104.

FRC (2018) *UK Corporate Governance Code*, London: Financial Reporting Council. Available at: https://www.frc.org.uk/getattachment/88bd8c45-50ea-4841-95b0-d2f4f48069a2/2018-UK-Corporate-Governance-Code-FINAL.pdf, accessed 06.01.2020.

Gallup (2016) *How Millennials Want to Work and Live*. Available at: https://www.gallup.com/workplace/238073/millennials-work-live.aspx, accessed 26.06.2020.

Geissdoerfer M., Vladimirova D., Evans S. (2018) Sustainable business model innovation: A review. *Journal of Cleaner Production*, vol. 198, pp. 401–416. DOI: 10.1016/j.jclepro.2018.06.240.

Goleman D. (2019) *Millennials: The purpose generation*. Available at: https://www.kornferry.com/institute/millennials-purpose-generation, accessed 26.06.2020.

GSIA (2019) *Global Sustainable Investment Review. Global Sustainable Investment Alliance Report 2019*, Brussels, Sydney, London, Utrecht, Washington D.C.: Global Sustainable Investment Alliance Available at: http://www.gsi-alliance.org/wp-content/uploads/2019/03/GSIR_Review2018.3.28.pdf, accessed 30.10.2019.

Hellsten S., Mallin Ch. (2006) Are "Ethical" or "Socially Responsible" Investments Socially Responsible? *Journal of Business Ethics*, vol. 66, no 4, pp. 393–406. DOI: 10.1007/s10551-006-0001-x.

Johnson M.W., Christensen C.M., Kagermann H. (2008) Reinventing Your Business Model. *Harvard Business Review*, vol. 87, December issue, pp. 52–60.

Laroche M., Bergeron J., Barbaro-Forleo G. (2001) Targeting consumers who are willing to pay more for environmentally friendly products. *Journal of Consumer Marketing*, vol. 18, no 6, pp. 503–520. DOI: 10.1108/EUM0000000006155.

Michalak R. (2019) The key metric is how Ben & Jerry's measures success. *Fast Company*, 01.05.2019. Available at: https://www.fastcompany.com/90287777/this-key-metric-is-how-ben-jerrys-measures-success, accessed 26.06.2020.

Michel J.B., Shen Y.K., Aiden A.P., Veres A., Gray M.K. (2011) Quantitative Analysis of Culture using Millions of Digitized Books. *Science*, vol. 331, no 6014, pp. 176–182. DOI: 10.1126/science.1199644.

Milovidov V.D. (2015a) Upravlenie innovatsionnym protsessom: kak effektivno ispol'zovat' informatsiyu [Management of Innovation: How to Effectively Use the Information]. *Neftyanoe Khozyaistvo*, no 6, pp. 10–16 (in Russian).

Milovidov V.D. (2015b) Upravlenie riskami v uslovijah asimmetrii informatsii: otlichai otlichimoe" [Risk management under information asymmetry: To differentiate those distinguishable], *World Economy and International Relations*, no 8, pp. 14–24 (in Russian).

Milovidov V.D. (2017) Informacionnaya asimmetriya i "bol'shie dannye": gryadet li peresmotr paradigmy finansovogo rynka [Information Asemmetry and Big Data: Should Financial Market Paradigm Be Revised]. *World Economy and International Relations*, vol. 61, no 3, pp. 5–14. DOI: 10.20542/0131-2227-2017-61-3-5-14 (in Russian).

Milovidov V.D. (2019) *Symmetry of Delusions: Factors of the Financial Market Uncertainty under the Technological Revolution*, Moscow: Magistr (in Russian).

OECD (2020) *Tackling Coronavirus (COVID-19). Contributing to a Global Effort. COVID-19 and Responsible Business Conduct*, Paris: OECD. Available at: http://www.oecd.org/coronavirus/policy-responses/covid-19-and-responsible-business-conduct-02150b06/, accessed 02.06.2020.

Page M., Spira L.F. (2016) Corporate governance as custodianship of the business model. *Journal of Management and Governance*, vol. 20, no 2, pp. 213–228. DOI: 10.1007/s10997-016-9343-7.

Pine II B.J., Gilmore J.H. (1998) Welcome to the experience economy. *Harvard Business Review* (July-August), pp. 97–105.

Porter M.E. (1996) What is the strategy? *Harvard Business Review*, vol. 74, November-December issue, pp. 61–78.

Schwab K. (2019) *Davos Manifesto 2020: The Universal Purpose of a Company in the Fourth Industrial Revolution*, Geneva: World Economic Forum. Available at: https://www.weforum.org/agenda/2019/12/davos-manifesto-2020-the-universal-purpose-of-a-company-in-the-fourth-industrial-revolution/ accessed 02.06.2020.

Subramanian G. (2015) Corporate Governance 2.0. *Harvard Business Review*, vol. 93, no 3, pp. 96–105.

Upward A., Jones P.H. (2015) An ontology for strongly sustainable business models: Defining an enterprise framework compatible with natural and social science. *Organization & Environment*, vol. 29, no 1, pp. 97–123. DOI:10.1177/1086026615592933.

van der Elst Ch., Vermeulen E.P.M. (2011) Corporate Governance 2.0: Assessing the Corporate Governance Green Paper of the European Commission. *European Company Law*, vol. 8, no 4, pp. 165–174. Available at: https://research.tilburguniversity.edu/en/publications/corporate-governance-20-assessing-the-green-paper-of-the-european, accessed 06.01.2020.

Visser W. (2011) CSR 2.0: Transforming the Role of Business in Society. *Social Space*, no 4, pp. 26–35. Available at: https://ink.library.smu.edu.sg/lien_research/87/, accessed 06.01.2020.

WEF (2020) *COVID Action Plan. Stakeholder principles in the COVID era*, Geneva: World Economic Forum. Available at: http://www3.weforum.org/docs/WEF_Stakeholder_Principles_COVID_Era.pdf, accessed 02.06.2020.

NATIONAL RESEARCH UNIVERSITY

XXII APRIL INTERNATIONAL ACADEMIC CONFERENCE ON ECONOMIC AND SOCIAL DEVELOPMENT

April 13-23, 2021

On April 13 – 23, 2021 National Research University Higher School of Economics (HSE University) will be hosting the XXII April International Academic Conference on Economic and Social Development. The Conference's Programme Committee will be chaired by Professor Evgeny Yasin, HSE University's academic supervisor.

The Conference features a diverse agenda concerning social and economic development in Russia. The Conference programme will include presentations by Russian and international academics, roundtables and plenary sessions with participation of members of the Government of the Russian Federation, government officials, business representatives, and leading Russian and foreign experts.

The most recent April Conference took place in a distributed format, thus ensuring maximum opportunities and extended timeframes for discussion and debate about key developments and trends in the economy and society with various sessions held online. We plan to hold the conference from April, 13 until 23, 2021, likely using both online and offline formats. We also hope to confirm the Conference's format (online, offline or blended) by February 1, 2021.

The April International Academic Conference on Economic and Social Development once again invites participants from the global academic and expert community! We are looking forward to seeing you at the next Conference!

Information about previous conferences can be viewed here: https://conf.hse.ru/2019/

Online registration to attend the Conference (without presentation) will be open until March 22, 2021. The Call for Applications with presentations is closed.

WORKING LANGUAGES of the conference: Russian and English.

PARTICIPATION FEE: Information about the participation fees, payments deadlines and procedures is available on the following page of the Conference's website: https://conf.hse.ru/en/2021/fees/

The Conference Organizing Committee
interconf@hse.ru

ISSN 1995-459X

Website

Download on the App Store

GET IT ON Google Play