Volume 11 • Issue 4 • 2019

Engineering Management in Production and Services

received: 1 June 2019
accepted: 15 November 2019

pages: 7-22

Patterns of digitalisation in machinery-building industries: evidence from Russia

Yulia Turovets, Konstantin Vishnevskiy

ABSTRACT

Digitalisation in machinery-building is expected to enhance productivity and drive the digital transformation of other industries. The extant literature sparsely describes pathways of different sectors in digitalisation, considering the heterogeneous characteristics of firms and sectors. Emerging economies with important state participation represent a particular interest in this area of research. To this end, a multiple case study method was used to describe a set of determinants revealed from the literature on Russian technological development and innovation in manufacturing. Two different patterns were identified. The first one was typical for large leading firms with state participation, which have a global market presence and a substantial level of interoperability, currently turning into a service business model. Private firms that follow the second pattern focus on physical and digital infrastructure upgrading targeted at particular issues to secure connectivity across departments. The state participation does not have a decisive role in digitalisation decisions; however, it affects the participation of companies in national digital initiatives. This study is a preliminary analysis of the determinants associated with corporate digitalisation from the sectoral perspective. Since both national and corporate strategies are ongoing, it seems premature to make generalised conclusions. Instead, the paper provides useful insights for management and policy that refer to digital technology uptake by machinery-building industries.

KEY WORDS
digitalisation, machinery-building industries, Russia

DOI: 10.2478/emj-2019-0029

Corresponding author:

Yulia Turovets

National Research University Higher School of Economics, Russia
e-mail: yturovecz@hse.ru

Konstantin Vishnevskiy

National Research University Higher School of Economics, Russia
e-mail: kvishnevsky@hse.ru

Introduction

Being the core of manufacturing both in developed and developing countries, capital goods industries continue to play an important role in a country's economy. Machines and equipment affect a wide range of fields, contributing to efficiency gains and productivity, improvement in the quality of final goods and its technology intensity, dissemination of spill-over effects (Kwak and Kim, 2014; Rodrik, 1996; Ferris and Gawande, 1998; Min et al., 2018). Moreover, there is a particular interplay between ICT and the machinery equipment industry due to technology convergence that influences the whole value chain in different ways (Min et al., 2018).

Particularly, digital technologies impact on technological imperatives of the machine-building sector by enabling a close interaction between physical and virtual environments (OECD/IEA, 2017; OECD, 2017). Digitisation describes the process of converting analogue data into digital data sets (Rachinger et al., 2018). To pursue new opportunities, technological solutions based on such technologies provide digitalised data to create radically new products and services (Gobble, 2018). Such emerging sets of technologies change the relative efficiency of inputs, as well as the structure of production, and allow for productivity gains. The incorporation of new technologies is influenced by specific parameters, such as size, age, ownership structure or absorptive capacity (e.g. Tether, 2002; Aristei et al., 2016; Fagerberg and Srholec, 2016), but also depends on the expected market potential and the level of competition (Nelson and Winter, 1982; Aristei et al., 2016).

Although Russia is a leading technology producer in several fields, such as space equipment and energy machinery, its machine-building sector still suffers from outdated production methods (Szirmai, 2012). Recently, some papers have started addressing the digitalisation efforts and opportunities in Russia's economy (e.g. Lisovskii et al., 2018; Kudryavtseva et al., 2018). All these contributions stress the robust role of policies in Russia's economy in general as well as an enabler of digital strategies in particular. Two main issues should be considered while analysing the sector. The first refers to the heavy dependence of Russia's machine-building sector on foreign technologies as machines and equipment account for almost half (48.7%) of all Russia's import (Federal Customs Service, 2018). Secondly, the imposed sanctions on fuel and energy, as well as on the financial sector, led to a significant reduction in both investments and production volumes. The overhauled machine-building sector, on the other hand, would open export opportunities to European and Asian markets. This need is urgent as during the years 2014–2016, Russia's exports stagnated due to the decreasing global demand.

In the literature, machine-building sectors are recognised as a homogenous entity with a particular value of implicit knowledge and a business-centred model. A traditional chain of stakeholders encompasses three key groups: enablers (suppliers of digital solutions), machine-builders and customers that use equipment (Sommarberg and Mäkinen, 2019). Nevertheless, technological processes and customer relationships differ immensely.

The remainder of the paper is structured as follows. First, a brief literature review presents the digitalisation in manufacturing. The next part provides the assessment of the current technological level of the Russian machinery-building industries. The discussion investigates different determinants of digitalisation directions chosen by machinery-building companies. The summarised results propose several corporate recommendations and policy issues on possible ways to enhance industrial upgrading with digital technologies and to accelerate its adoption.

1. Literature review

The literature offers several strands with regard to digitalisation in manufacturing industries. The first mainly covers a micro-view and capacities to uptake emerging technologies. Often, articles diagnose a slow pursuit of business opportunities associated with digitalisation (Porter and Heppelmann, 2015; Lenka et al., 2017). However, the literature is still in its infancy as regards the new offerings and processes as a result of digitalisation and the redefinition of value creation between providers, customers, and other actors along the value chain (e.g. Rabetino et al., 2018; Parida et al., 2019). So far, resource-based views dominate the approach to competitive advantages derived from digitalisation (Lenka et al., 2017; Hasselblatt et al., 2018). In particular, the literature on the importance of platform thinking is instrumental in understanding emerging business models and the pursuit of strategic opportunities (Eloranta et al., 2016; Eloranta and Turunen, 2016; Cenamor et al., 2017).

Another strand of research scrutinises technologies that transform manufacturing and its implications, such as computer modelling, cyber-physical systems, the Internet of Things, cloud computing, big data, augmented reality, industrial automation and robotics and additive technologies (Esmaeilian et al., 2016; Ghobakhloo M., 2018; Kang et al., 2016; Strange and Zucchella, 2017; Tao et al., 2017; Szalavetz, 2018; Wang et al., 2017; Witkowski et al., 2017; Ślusarczyk et al. 2019; Alaeddin et al., 2018; Kohnová et al., 2019; Krykavskyy et al., 2019).

The technological and business opportunities offered by digitalisation require efforts that encourage most leading countries to launch government-led industry programmes to orchestrate the upscaling of their industrial base, e.g., China in 2025 (e.g. Chen, 2018), the smart manufacturing initiative of the USA (White House, 2016), and Germany's High Tech 2020 Strategy (e.g. Fuchs, 2018).

Digitalisation facilitates product development and gives an impetus for an overall transformation of outdated production processes in all industries. Numerous studies evidence ICT-sector products and services contribution to economic growth in developing countries, such as Singapore (Vu, 2013), South Korea (Hong et al., 2016; Hong, 2017), India (Mitra et al., 2016), Latin America (Hofman et al., 2016), as well as developed states like Germany (Strobel, 2016). However, economies, which lie below the world technology frontier, should choose a different route towards modern developments.

The first issue is the extensive dependence on foreign solutions. Embracing digital technologies may allow countries to roll out their solutions in prioritised technology fields, and, thus, alleviate often-disproportionate reliance on external technologies. The establishment of demand for own high-technology products is seen as the second greatest difficulty for latecomers (Kim and Lee, 2008). The solution demands an integrated approach to aligning stakeholders with the required financial support at most demanded directions. While government-led initiatives of leading technology producing countries are well researched, attempts of emerging economies to create technology base have received little attention.

Industrial competitiveness relies heavily on machinery and, more broadly, the competitiveness of investment goods as they contribute to the improvement of productivity, quality characteristics of the final goods produced with the help of machines, and higher technological opportunities overall (Kwak and Kim, 2015). In emerging countries, machinery industries are widely studied, to name a few, the latest research plastic injection moulding (Kwak et al., 2018) and military aircraft (Lee and Yoon, 2015) industries. Russian machinery sectors present an interesting case from the sectoral perspective and effects for the economy as a whole. This study closes the gap by presenting an analysis of determinants linked to the investments in digitalisation in machinery industries. It implies different sets of capability and, thus, demonstrates distinct trajectories of industrial upgrading (Lacasa et al., 2019; Lee and Malerba, 2017).

Considering a wide range of implications and prerequisites required to utilise the effects of digitalisation, the insights of the paper could be useful for policy issues. Such studies are still very limited with the exception of papers by Arens (2019) on the European steel industry and Gauthier et al. (2018) on policy level-changes for digitalisation adaptation. In most cases, such support strategies are discussed within the framework of Industry 4.0, a term that emerged from a policy discourse around the German initiative, which became a part of the new German High Tech Strategy 2025 introduced in 2018 (Bundesregierung, 2018; Luz Martín-Peña et al., 2018).

For traditional industries in developing and developed countries, digital technologies highly contribute to the overall economic growth (Stiroh, 2002). It provides a boost to productivity, which went down due to a decrease in growth rates of the total factor productivity (TFP) (Voskoboynikov, 2017). On average, the effects generated by digitalisation on productivity are higher for manufacturing that is linked to the automation of large part of routine operations (Akerman et al., 2013; Dhyne et al., 2018). Not by chance, national governments are developing digital strategies for production industries. This trend, though, is not new: ICT and technology upgrading were a key milestone for recovering after the financial and economic crisis in 2008. For example, the U.S. government launched the "Manufacturing USA" (formerly known as the National Network for Manufacturing Innovation), while catapult centres were initiated in the United Kingdom, and South Korea started the programme "Manufacturing Industry Innovation 3.0" and a network of 17 Creative Economy and Innovation Centres (ITIF, 2017). Emerging technologies facilitate costs reduction and production losses, enhance labour productivity, etc.

In summary, the study identifies factors of digitalisation pathways in the machine-building industry, with a particular focus on both private firms and companies with state participation.

2. Technological upgrading in the national digital agenda: the Russian perspective

Russia's development is in line with world trends, though it is facing the problem of productivity fall hindered by the need to bridge the technological gap (Voskoboynikov, 2017). Over the last decades, the latter has become a keynote. Since 2010, the Russian innovation and industrial policy has been converged with strategic goals and national technology priorities. This is not limited to the R&D increase but also the efforts targeted at the improvement of the investment climate and the development of new high-tech sectors (Simachev et al., 2014).

The first systemic effort of technology upgrading based on emerging digital technologies was introduced in the National Technology Initiative (NTI) in 2016. Several multi-lateral long-standing public-private partnerships were established in priority markets: AutoNet, AeroNet, EnergiNet, FinNet, FoodNet, HealthNet, MariNet, NeuroNet, SafeNet and TechNet. This was a cutting-edge direction for all industries that should bridge the gap in commercialisation and create the required legislative, organisational and business environments (NTI, 2018). By providing venture capital, the NTI also boosts small firms that develop technological entrepreneurship. However, NTI centres do not have sufficient shared facilities and equipment, which participants could use for the development and testing of new goods and services. However, the initiative is unavailable to all participants as it only covers a limited number of organisations in particular fields that concentrate main activities and resources within the framework of the NTI (Dezhina, 2018). There is a lack of mechanisms that ensure cooperation and, hence, incentives to build close innovative ties between participants.

The national programme (project) "Digital economy of the Russian Federation" is a recent and most comprehensive initiative. Started in 2017, it integrates a range of different projects and measures to create digital solutions and platforms, based mainly on domestically developed technologies and promote its further adoption in industries and public services, including health, education, industry, agriculture, construction, urban economy, transport and energy infrastructure, and financial services (Russian Government, 2019). In terms of innovation policy, the programme bridges digital solutions development with its consumptions by other sectors, which is anticipated to facilitate digital transformation and foster long-run economic growth.

The framework of the initiative specifies main directions to implement digital solutions by strengthening human resources for the digital economy, information infrastructure, information security, digital technologies, normative regulation of the digital environment, and digital public administration. The aforementioned elements and seven main technology blocks (neurotechnologies and artificial intelligence, distributed ledger technologies or blockchain, quantum technologies, new manufacturing technologies, robotics and sensors, wireless technologies, and augmented and virtual reality) stand for three main priority fields: 1) markets and sectors; 2) platforms and technologies; 3) environment (Russian Government, 2019). Such initiatives are mostly synchronised with the more recent NTI measures and substantially enlarge the previous agenda.

However, the digitalisation strategy for manufacturing is still nascent for the policy frame, compared with other countries like China, Japan, Germany, the USA, the UK, South Korea that have launched special industrial programmes starting with 2010. This has particular implications on the level of a company and the export competitiveness of manufacturers. According to representatives of companies, the lack of sufficient budget is the first obstacle in the digitalisation journey of Russian manufacturing companies (ISSEK NRU HSE, 2019a).

In summary, the initiatives of the Russian government aim to consolidate efforts by industry actors and knowledge producers and to provide financial support. Such an approach is in line with the strategic policy and has particular implications on the level of companies.

3. Current technological level of the Russian machine-building industries

In the scope of the current research, we consider machine-building industries broadly, including automobile, agriculture machinery, aircraft, heavy mechanical engineering, machine tool, power engineering, shipbuilding and transport machine-building industries. In the latest decade, the sectoral performance varied greatly. Most segments demonstrated growth after a decline of 2014–2015, which was triggered by sanctions and stagnant global demand, which mirrored in the Russian foreign trade. After the falling export volumes and a drastic drop in 2014, the trend reverted in 2017, and further prospects remain positive (Federal Customs Service, 2018). However, most Russian export is connected to niche high-tech goods with export volumes several times lower compared to those of the import.

Three main factors describe the technological level of machinery industries: 1) high dependence on foreign technologies, components and final machinery goods; 2) low innovative capacity of companies; and 3) insufficient investments in ICT and digital technologies.

3.1. High dependence on foreign technologies

Machines and equipment are the top imported goods in Russia. Despite a significant drop in 2015, the purchase of foreign equipment keeps rising (from a moderate 5% in 2016 to 28.2% in 2017), and now, accounts for almost half of all Russian imports (48.7%) (Federal Customs Service, 2018). Although Russian products in general and in machine-building in particular are improving in terms of their quality, Russian customers have a strong preference for imported products. Major efforts for reducing import dependence are limited to the localisation of foreign parts, components or a final product. This is the case of the automotive industry. Its upgrading is based on a set of measures intended to stimulate foreign investments by means of industrial assembly plants and an increase of duties on second-hand cars (Kuznetsov and Simachev, 2015).

3.2. Low innovation capacity of Russian firms

This preference of foreign products, both physical and digital, stems from the lack of competence in certain fields as well as missing product certification, and, on the other hand, from insufficient R&D activities (Dezhina, 2017; Kuzminov et al., 2018). Special software, such as PLM and MES systems, is delivered by such world leaders. To obtain a high level of automation, companies seek opportunities to ensure a modern physical infrastructure, such as machine tools, machining centres, robotics, etc. As an important part of the digitalisation strategy, companies invest heavily in capital assets through partnerships with foreign industrial robotics producers. Several reasons explain the extensive dependence on foreign technologies. The large part of Russian manufacturing companies faces a high level of special software and the adoption of relevant systems. At the same time, a piecewise digitalisation covers only a part of processes, which hinders efficient internal operation and cooperation with other participants (Dezhina et al., 2015).

Companies find it easier and faster to buy complete solutions abroad than to develop the domestically or internally, which results in low R&D involvement (Dezhina, 2017). The insufficient demand and the lack of technological competences result in low innovation capacity, which is typical for latecomer sectors (Kim and Lee, 2003). In this regard, a primary policy task is to enhance the motivation of companies to invest in new digital solutions for production. A set of policy measures should be broader and create an appropriate environment, where technological upgrading becomes an essential condition of the market success of the company.

An aggregate level of innovation activity, which also encompasses organisation and marketing innovations, amounts to 8.4%, while in Germany, this indicator is 67%. Such low level is a result of a small number of organisations that develop technological innovations (7.3%) in comparison with developed countries like Germany (52.6%), the UK (40.9%), South Korea (34.6%), China (26.9%) and the U.S. (12.8%) (NRU HSE, 2018b). At the same time, the distribution of financial support from the state in Russia almost coincides with the level of Germany, 21.8% and 21% respectively. This indicates a low efficiency of resources that do not lead to market introduction of new technologies and its further usage.

3.3. Insufficient investments in ICT and digital technologies

Another obstacle to digitalisation is low investment in new technologies. The proportion of spending on digital technologies makes up only 2.2% of the GDP in comparison with 5% in the US, 3.9% in Western Europe and 3.6% in Brazil (Digital McKinsey, 2017). Investment in innovative activities remained stable from 2006 onwards but did not show any signs of improvement (Balagurova et al., 2017). This statement is confirmed by the business. According to the survey of large and medium companies, 2/3 of enterprises estimated investments in digital technologies as low (ISSEK NRU HSE, 2018a).

Nevertheless, a slow digitalisation path is not exceptionally a Russian trend. In spite of high expected economic implications, transformation in European countries is also deploying a moderate path (European Union, 2018). According to the annual monitoring of German Federal Ministry for Economic Affairs and Energy, almost half of respondent enterprises pointed out the absence of necessity of digitalisation projects in 2016. In 2017, the figure changed and accounted for 29% (BMWi, 2018). This was possible partly due to federal policy and relevant initiatives.

Another key trend is a substantial gap between large leading companies and SMEs in the pace and scope of digital adoption. This depends on different requirements in digital technologies and its application field in small firms. As an example, cloud computing is more demanded by small and medium firms, since the solution allows reducing the costs for maintenance of physical parts of the information infrastructure and ensures access to data. Large companies often need solutions that integrate different functional fields into a single system, like Enterprise Resource Planning (ERP), MES, etc. (Gal et al., 2019).

The modernisation agenda is unwrapping on the background of the systemic challenges in the field of science and technology. Still, previous research showed systematic shortfalls in comparison to more developed countries (Gstraunthaler and Proskuryakova, 2012). Several research papers into Russia's national innovation system and notoriously low levels of investment activity revealed the inadequate collaboration between actors within the innovation chain as the main deficiency (e.g. Thurner and Zaichenko, 2016; Vishnevskiy et al., 2019).

4. Current level of Russian manufacturing digitalisation

The overall index of business digitalisation (28) of Russia lags behind most OECD countries, including the leader Finland (50) or Korea (45) as well as Turkey (33) (NRU HSE, 2019b). Companies show misbalance between the use of traditional and new digital solutions: together with wide dissemination of traditional technologies, such as access to broadband Internet, only 23% of firms use cloud technologies. In Finland, this indicator reached 65.3% in 2018. The indicators reflected the use of ERP-systems, which was even lower: 19% of Russian organisations in comparison with 54% in Belgium. In manufacturing, this indicator was higher (27%); however, only 1/3 of enterprises used CRM, ERP, SCM systems (NRU HSE, 2019b). The business survey also confirmed the results mentioned above: according to representatives of companies, every third firm was not prepared for the digital transformation (ISSEK NRU HSE, 2019a).

Official statistics evidence an extremely low rate of domestic development in ICT-related advanced manufacturing technologies (AMT) and a much higher demand for it: created technological solutions roughly account for only 1% of the number of technologies used by countries (NRU HSE, 2019). The largest part of developed solutions is concentrated in computer-aided design, engineering and consulting services. This type of technologies as well as more traditional, simple well-established solutions are also highly demanded by companies. More complex and advanced technologies are still hardly used by companies, including CAM, automatically controlled vehicles, complex robots, systems based on artificial intelligence. Modest innovation capacity and insufficient domestic demand result in a low market share of Russian machine producers. In the near future, they will face even stronger competition. Consequently, low output numbers do not allow for optimising production costs, technology upgrading and innovation activities.

An issue that could contribute to digital upgrading of manufacturing is the fact that Russia worked intensively on building its domestic engineering software platforms (Gershman and Thurner, 2018). These platforms have now reached technological maturity and offer an alternative to the country's dependence on imported technologies. Although software development still depends mainly on access to international technologies, Russia's IT sector is growing stronger. The sector makes a substantial contribution towards the country's digital development as its contribution to the GDP is forecast to reach 4.6% in 2030 when digitalisation in sectors may contribute to 30% of the GDP. In fact, the total factor productivity and capital contribution as major growth factors of the added value could reach up to 5% and, thus, become the greatest in machinery industries among all sectors (ISSEK NRU HSE, 2018c).

5. Methodology

This paper used the case study to verify the assumptions identified on the sectoral and firm-level and reveal patterns of digitalisation in machinery-building industries. A multiple case study was used to reveal different directions of digitalisation in industries with particular attention on state participation in company capital. The choice of method was driven by the intention to make a qualitative description of characteristics that might accelerate digital technology adoption, the transformation of business models and the enhancement of innovation capacities of the incumbent firms. The use of several cases allows identifying a set of practical issues based on heterogeneous data (Coreynen et al., 2017). The study provides a description and reasoning of the factors that interplay in terms of the digital transformation.

Empirical research contributes to theoretical issues of the digital transformation in machinery firms (Dul and Hak, 2008; Kwak et al., 2018). Based on research by Kwak et al. (2018), the study used purposive sampling for case selection that allowed testing the hypothesis and making relevant conclusions. Detailed examination of the cases (Rowley, 2002) was made to answer two main questions: 1) How is the digitalisation deployed in the machinery-building sector, and 2) Which are the factors that determine it. This enabled fruitful insights in the area of the adoption of emerging technology strategies and its implications for business (Vishnevskiy and Yaroslavtsev, 2017).

The reasons behind the choice of a small number of case study firms lie in the necessity of a thorough study of particular digitalisation issues that are currently hardly captured by official statistics. It was important to find cases that matched a set of requirements, namely: size and main activity, digitalisation strategy in a long-lasting period (ten years and more), diverse product portfolio. Another important issue was data availability and reliability. Thus, three segments in machine-building industries were selected — automotive, general machinery production and the transport machinery sector. By using purposive sampling, three firms were chosen. Each firm represented a type of the best practice, which demonstrated a relatively intense digital transformation and was recognised as one of the leading players in the corresponding machinery-building segment. Following the research by Coreynen et al. (2017), key characteristics of the companies were collected (Tab. 1) based on the data from the Bureau Van Dijk database. All companies were listed on the stock exchange.

The company sampling considered data availability and current realisation of the strategy linked to digitalisation. Desk research was used to collect the main sources, which comprised annual companies' official reports, industrial reports and journals, corporate journals, expert and analytical studies, and financial data from the Bureau Van Dijk database.

After the preliminary selection, the focus was directed to three large companies from the main machinery-building segments that represented the major part of the Russian machinery-building sector. Two of them were private and one — state-owned. All of them belonged to the categories "large" or "very large." The firm A was an important player in the automobile and engine market, being a part of one of the vertically integrated state corporations. The firm B produced energy equipment and occupied a strong position on the Russian and CIS markets. Finally, the third case was a private company, a part of a holding, that manufactured passenger cars of motive power. Thus, companies followed different patterns of digitalisation due to corporate and sectoral characteristics.

Based on the approach of Coreynen, Matthyssens and Van Bockhaven (2017), two interviews were conducted with representatives of each firm responsible on digitalisation and supported obtained data with information from official annual reports, brochures and presentations, expert discussions and other sources of open data.

With the aim to exert a comprehensive analysis, three cases were analysed according to the following framework: 1) digitalisation and innovation scope: strategy coverage (product and process transformations due to digital technologies), establishment of digital transformation units within a company, provenance of digital solutions used by a company, current projects related to digitalisation, R&D activities, cooperation with science and research organisations, participation in the National technology initiative (NTI) and other innovation projects; 2) policy scope: state participation in a company, participation in government digital initiatives and government support opportunities seized by a company.

6. Overview of company digitalisation

In this section, each case description is made, which unveils some ways of the firms' digitalisation strategy and gives an opportunity to examine, how

Tab. 1. Main characteristics of the firms

Firms	Ownership	Main activity according to the NACE Rev. 2 classification	Size	Export directions
Firm A	company with state participation	manufacture of motor vehicles	very large	CIS, South Asia, Middle East, Africa, Eastern Europe, Latin America
Firm B	private	manufacture of general-purpose machinery	large	CIS, Europe, South Asia and other
Firm C	private	manufacture of railway locomotives and rolling stock	large	Belarus, CIS

Source: (Bureau Van Dijk, 2019) and company web sites and annual reports.

sectoral issues are mirrored on the level of a particular firm.

6.1. Firm A

Company A stands out among the Russian machine-building companies that successfully developed a digitalisation strategy. It has a long history of efforts towards digitalisation, which began in the middle of 2000. The strategy was rolled out for several consecutive stages. The first was the most important, lasted ten years and focused on the development of digital models, improving designs and testing products on digital platforms. In the next stage, a digital production facility was created, which integrated the product lifecycle management (PLM), resource planning (ERP), production planning and production management systems (MES). During this period, robotics and automation were also introduced, including CNC machines and machining centres. During the current third stage, the company is moving to servitisation and digital services, introducing a system for ongoing monitoring, diagnosing and transportation of produced vehicles based on an automated control system. The central element of the system will be a compatible development of "digital twins" of all elements — products, processes, machines and equipment — which form an integral system of single digital production space (Production Management, 2017; Gershman et al., 2016).

To upgrade a physical infrastructure and increase the level of automation, the company cooperates with a global supplier. The automation concept is an important part of the company's development strategy, which involves the introduction of almost 1000 robots and robotic elements. Moreover, a smart factory project is planned based on solutions from Siemens.

In addition to in-house R&D facilities, the company cooperates with participants of the National technology initiative on such projects as system engineering, the standardisation of the production process, elements, etc. Also, contacts have been signed with scientists from a federal university, including a laboratory, a technology centre for production automation (Production Management, 2017a). The company is a significant participant of the NTI platform and is involved in the development of fully autonomous vehicles and related applications.

Considering the intense automation of the production workshops of the company, the rate of digitalisation seems to be rather high. This is confirmed by the fact that corporate strategy together with the digitalisation of production and supply chain, sales and services, also contains the transformation of management systems and corporate culture. The latter includes such initiatives as the acceleration of digital transformation projects. Furthermore, efforts are undertaken to internally develop talents in the field of digital technologies. Some projects have been designed for training in management skills as well as monitoring and estimation of the corporate culture transformation.

6.2. Firm B

As a private player in energy machine-building, the current priorities of the firm are related to information integration and design, which cover all elements of a vertically integrated structure. In the middle of 2000, the company heavily invested in the consolidation of process automation and management. At that time, a modern ERP-system was implemented, which allowed standardising major business processes. During the next stage, the goal was to consolidate all processes in functional areas of the company's decision-making units (DMU), which resulted in the creation of a unified information system where all subsidiaries were included. The company established a central department of information technologies with several divisions, including information systems, information infrastructure, CAx tools etc. Moreover, customised sensors developed within the company provide data based on telematics to determine possible malfunctions in operation for planning predictive repairs, etc. (NRU HSE, 2018a).

In its digitalisation strategy, the firm mainly relies on foreign information products. As an ERP-system and 3D-modelling, it opted for the product of the foreign supplier. Currently, it is expected to update the system based on integrated solutions, including large data, machine learning, predictive models, etc. again, with foreign solutions. A single information platform would help to reduce the time spent on the preparation of design and production, which, in turn, would allow performing more projects in a given period.

Together with digital, a substantial budget was allocated for upgrading and modernising machine tools park. Modern high-precision machines embedded with numerical program control (CNC) will be integrated with other production systems. Further steps of digitalisation involve the transformation of the entire organisational architecture, more flexible interaction among departments and testing in a virtual environment. Several dimensions are involved in the field of monitoring systems and digitalisation of a process, which encompasses different systems of equipment diagnostics. Overall, the digitalisation across departments is in progress.

6.3. Firm C

The digital transformation of the company started later compared with the other two cases. The current set of activities is larger and addresses all business and production processes that will be implemented in several stages. An active phase of digitalisation started only several years ago. However, there is no single strategy or an official document. Instead, it is a set of initiatives that enables the deployment of a digital factory. This includes information systems integration, as well as physical modernisation of capital assets. From the physical point of view, the transformation includes industrial robot installation, measures for its productive use as well as solutions for monitoring in real-time and a single system as a part of the deployment of the Internet of Things (Production Management, 2017b).

Some pilots are aimed at the adoption of traceability procedures for products. From the digital point of view, main projects comprise the introduction of a monitoring system for manufacturing equipment, 3D-modeling, and a digital twin. A large share of initiatives is aimed at the compatibility of different systems in the supply chain, including internal planning and control, traceability of goods and materials, interactive digital manuals for employees, etc. All systems and newly adopted solutions should be integrated into a comprehensive ecosystem backed by modern information infrastructure. In doing so, the company relies mostly on already existing and widely used technologies, for example, the MES system in shop factories in different productive domains. Importantly, this solution is internally developed and meets the specific needs of the company.

The firm B does not participate in national digitalisation initiatives. The innovation activity of the company is based not only on internal capacities but also includes the collaboration with research centres and academic organisations of the sector. This is driven mostly by long cooperation ties in the industry but does not expand on newly launch national initiatives.

7. Discussion and findings

This study examined three large firms that represent the best practices in each of the Russian machinery-building segments. Two of them were vertically integrated state-owned companies. Such players are likely to become pioneers in digitalisation and technological upgrading due to their role in the economy and their access to financial resources. These large corporations act as multipliers due to their role in the value chain and facilitate the formation of a capable technological architecture. The firms collect valuable experience, which can be transferred to other enterprises and market segments (Thurner and Proskuryakova, 2014). Such an approach builds on the identification of lead enterprises, which successfully incorporate digital technologies as key learning cases. Such a nuanced policy approach considers the different rates of change in diverse sectors, while the development of industry standards facilitates the integration of lower-level suppliers and SMEs (Blind and Mangelsdorf, 2013; De Vries et al., 2009; Turovets et al., 2019; Turovets and Vishnevskiy, 2019).

Nevertheless, large companies are not the single driver of transformation in machinery-building. In spite of non-favourable external conditions that have been affecting the Russian business in the past several years, there is a trend of successful medium-sized companies, which also operate in some machinery industries, such as instrument-making, electronics etc. A medium company is usually specified according to the annual income, which is from RUB 50 million and up to 10 billion. Such firms actively conduct in-house R&D, have strong market positions (usually, niche) and a portfolio of customers. Also, they have a stable growth of annual income (~15%) and do not extensively depend on state support (Dezhina and Etzkowitz, 2016). Since such companies are often involved in the export of high-value goods, technological upgrading and digitalisation become essential to keep competitiveness on a global scale.

A reverse trend is particular for small enterprises: state support appears an important source of technological upgrading. Currently, their role in the economy is modest, they are not fully included in value chains as suppliers for large companies. To enhance small technology businesses, the current agenda provides several directions, including grants, venture capital, etc. (Dezhina and Etzkowitz, 2016). The key factor for them is the availability of capital. More broadly, a contribution of small firms to digitalisation is restricted due to their current role in the economy.

By the middle of 2019, all three firms, as well as most Russian industrial companies (ISSEK NRU

HSE, 2019a), have started digitalisation initiatives. Most of them are still in their first stages and need substantial investments for further development. Often, there is no single document of digital transformation, and related projects are recorded in the firms' main strategy. Only a few of them have a separate department for digital transformation, e.g. the firm A. Generally, these functions are performed by the IT-department. An absence of such a document could be explained as a vision problem: many firms see digitalisation mainly as a source of technological upgrading of capital assets. Only a small number demonstrates a high level of digitalisation and aims for intangible resources, business process transformation, corporate culture development and servitisation. The Product as a Service (PaaS) model, however, becomes a central part of the firm, where value is created via related services, including predictive analytics and maintenance, monitoring of equipment, etc. (ITIF, 2018). This leads to an increase of intangible assets, such as investments in R&D, training and retraining of personnel, organisational innovations (Bresnahan et al., 2002; Pilat, 2004; van Ark et al., 2008; Bloom 2012; Corrado et al., 2014). In most cases, digitalisation is still at the transitional stage, which includes the integration of different systems (ERP, MES, PLM) into a single frame, its compatibility with each other. Unsurprisingly, firms invest in digital modelling and engineering and dedicate a large part of digitalisation projects to the issue. The main challenge is, thus, to secure a single digital environment among all subsidies and departments.

Three cases show different directions chosen by firms to reach digital transformation. The framework of the study encompasses a set of determinants that affect digitalisation strategies, namely, the digitalisation focus (physical or digital modernisation), investments in machinery and equipment, innovation activity, size of a company, role in a value chain, the current business model, cooperation with universities and scientific organisations, and the servitisation of the business model.

Based on the determinants, two main patterns of digitalisation of Russian machine-building companies may be distinguished (Tab. 2). The first pattern is typical for the firm A. Due to its size, it disposes more resources to perform in-house R&D and, particularly, digital solutions. In terms of state support, companies with state participation engage more in national digitalisation initiatives. Such players demonstrate a high level of current digitalisation that enables to focus on investments in intangibles, which includes software and intellectual property. Gradually, they transformed their business model and became service-oriented.

The second pattern pursued by firms B and C also occurs in firms regardless of their role in the value chain. They purchase digital solutions outside, partly provide their R&D, and still focus more on physical, technological upgrading issues. In doing so, they mostly rely on proper funds. Unsurprisingly, such cooperation with industrial research centres is tighter, which allows obtaining specific solutions, but its scope is still insufficient. Current activities should ensure interoperability and connectivity across departments.

Findings on the level of firms correlate with the results of the survey conducted by the HSE in 2018. According to the assessment of the industrial enterprises that participated in the survey, most of them are currently developing digital strategies that cover cutting-edge automation and integration of production and business processes into a single system (24% of respondents) (NRU HSE, 2019a).

Companies rely on government financial support, most of them use internal resources for technological upgrading. This article argues that state incentives for the modernisation of manufacturing process show a stronger demand for more complex projects that include both physical and digital parts, such as the instalment of new product lines for new products, components and parts. New incentives provided under the national program "Digital Economy" could accelerate a rate of adoption of digital technologies and overcome the fragmentation in supply chains, including SMEs as downward suppliers.

Together with internal R&D reinforcement, there is a substantial room for cooperation between companies and research institutions that helps to mitigate the dependence on foreign technologies. Firm A (with state participation) is conducting R&D more actively with scientific and research organisations. To this end, leading Russian companies in different sectors could generate a strong demand for R&D results from research and academic institutions bringing these innovations to the market, closing the gap in commercialisation and facilitating an upgrade in educational programmes. The lack of skills and digital literacy within companies is a hurdle for business. According to the survey, 20% of enterprises demonstrated slow digitalisation due to the lack of experience and competences in digital technologies (NRU HSE, 2019a). It is worth mentioning that we do not reveal particular features of digitalisation that are

Tab. 2. Determinants of manufacturing digitalisation of Russian machine-building companies

Determinants	Firm A	Firm B	Firm C
Type of company 1. Very large with state participation 2. Large private	**1** 2	1 **2**	1 **2**
Role in a value chain 1. Diversified group of companies 2. Specialised producer of parts and machinery	**1** 2	1 **2**	1 **2**
Sources of digital solutions 1. In-house development of digital solutions 2. Both alternatives 3. Acquisition outside	1 **2** 3	1 **2** 3	1 **2** 3
Main directions of the digitalisation strategy 1. Modernisation of physical and digital infrastructure (hardware) 2. Both alternatives 3. Servitisation model	1 2 **3**	**1** 2 3	**1** 2 3
Provenance of digital technologies 1. Adoption of domestic solutions 2. Both alternatives 3. Adoption of foreign technologies	1 **2** 3	1 2 **3**	1 **2** 3
Sources for investments in digital technologies 1. Government support initiatives 2. Both alternatives 3. Proper resources of the company	1 2 **3**	1 2 **3**	1 **2** 3
Participation in national digital initiatives and projects 1. Participate actively 2. Perform own research	**1** 2	1 **2**	1 **2**
Participation in standards development 1. Member of technical committee 2. Don't participate	**1** 2	1 **2**	1 **2**

induced by sector diversity, which is consistent with other studies, for example, the survey of the U.S. companies (ITIF, 2018).

Knowing a company's profile could assist policymakers in specifying measures that help companies via digitalisation to develop their business, i.e., maintain positions for global leaders and for local leaders, ensure foreign market entry, while for stable longstanding players, give an impetus to strengthen their position on the national and, in the future, in foreign markets.

Conclusions

The transformation with digital technologies as a driver of economic development is a recent phenomenon, and thus, efficiency assessment of corporate strategies is still limited. Research efforts, such as this one, address pathways in different economic settings. This paper closes a gap in the literature as most contributions either look at individual companies or touch upon specific industry approaches. It also contributes to the growing body of literature on technology upgrading in emerging economies with substantial state participation. This study neither aims to provide a generalised approach to machinery firm directions towards digitalisation nor offers policy conclusions. On the contrary, it presents some references and avenues for managers and decision-makers.

Based on three cases selected by purposive sampling, the research identified two different patterns of digitalisation in sectors of the machine-building industry. State participation in a company's ownership positively affects cooperation with research and academic institutions; however, it substantially impacts on the choice of digital solutions developed domestically or abroad. For the majority of Russian machinery firms, the current strategy focuses on the integration and compatibility of a different system of production and business process. Only a limited number of companies achieved a level of digitalisation comparable with global leaders and moved to a service business model. Companies insufficiently participate in the development of standards related to digital technologies. At the same time, standardisation becomes a key issue in the digitalisation discussion that ensures interoperability of elements and systems.

New approaches to policymaking play an important role in encouraging business digitalisation. Russia's policymakers started a series of initiatives to support businesses in the development of digital technologies, to reduce the economy's import dependency and to open new export opportunities for local producers. Previous analyses showed that Russia has systemic weaknesses in its innovation system in comparison with advanced economies. One of these drawbacks is the notoriously low investment into research and development by private corporations and the low level of links among actors. Consequently, the newly established state initiatives aim to consolidate efforts by industry actors and knowledge producers as well as to provide financial support.

The variety of sector digitalisation arising from different types of organisation, corporate and structural characteristics (Andrews et al., 2018; OECD, 2019) should be considered while developing policy tools. Current digital initiatives should facilitate the uptake of digital technologies as they offer a set of mechanisms. Existing measures are not fully exploited by firms; besides, newly introduced instruments should ensure efficiency and long-term implications. The recently introduced national programme "Digital Economy" is expected to overcome existing drawbacks and ensure inclusive opportunities for different participants — small, medium and large firms. The policies described in this paper focus on the close collaboration with domestic academic and scientific organisations, as well as on enhancing the cooperation with international technology providers, both hardware and software. The aim is to integrate different actors in the value chains as well as upgrade production infrastructure and research activities.

Future works could provide insights into how such firms move towards digitalisation and which limitations they meet on this way, namely, the measurement of digitalisation effects on different aspects (organisational, financial, technological, etc.) of corporate performance.

Acknowledgements

The article was prepared within the framework of the Basic Research Program at the National Research University Higher School of Economics (HSE) and supported within the framework of the subsidy by the Russian Academic Excellence Project '5-100'.

This article was prepared as a part of a research project on the topic "Analysis and modelling dynamics of science and technology development with the use of statistical indicators", performed by the HSE in 2019.

Literature

Akerman, A., Gaarder, I., & Mogstad, M. (2015). The Skill Complementarity of Broadband Internet. *The Quarterly Journal of Economics*, *130*(4), 1781-1824. doi: 10.1093/qje/qjv028

Alaeddin, O., Altounjy, R., Zainudin, Z., & Kamarudin, F. (2018). From physical to digital: investigating consumer behaviour of switching to mobile wallet. *Polish Journal of Management Studies*, *17*(2), 18-30.

Andrews, D., Nicoletti, G., & Timiliotis, C. (2018). *Digital technology diffusion: A matter of capabilities, incentives or both?* OECD Economics Department Working Papers 1476. Paris, France: OECD Publishing.

Arens, M. (2019). Policy support for and R&D activities on digitising the European steel industry. *Resources, Conservation and Recycling*, *143*, 244-250.

Aristei, D., Vecchi, M., & Venturini, F. (2016). University and inter-firm R&D collaborations: propensity and intensity of cooperation in Europe. *The Journal of Technology Transfer*, *41*(4), 841-871. doi: 10.1007/s10961-015-9403-1

van Ark O'Mahoney, M., & Timmer, M. (2008). The Productivity Gap between Europe and the United States: Trends and Causes. *Journal of Economic Perspectives*, *22*(1), 25-44. doi: 10.1257/jep.22.1.25

Balagurova, E. A., Borisov, V. N., Orlova, T. G., Pochukaev, K. G., & Pochukaeva, O. V. (2017). Evaluation of the competitiveness of machinery production as a cumulative effect of the innovative investment saturation dynamics. *Scientific works of the Institute of economic forecasting Russian Academy of Sciences*, 294-315.

Blind, K., & Mangelsdorf, A. (2013). Alliance Formation of SMEs: Empirical Evidence From Standardization Committees. *IEEE Transactions on Engineering Management*, *60*(1), 148-156. doi: 10.1109/TEM.2012.2192935

Bloom, N., Sadun, R., & van Reenen, J. (2012). The Organization of Firms Across Countries. *The Quarterly Journal of Economics*, *127*(4), 1663-1705. doi: 10.1093/qje/qje029

BMWi. (2018). *Monitoring-Report Wirtshchaft DIGITAL 2018*. Retrieved from https://www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/monitoring-report-wirtschaft-digital-2018-langfassung.html

Bresnahan, T. F., Brynjolfsson, E., & Hitt, L. M. (2002). Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm–Level Evidence. Q*uarterly Journal of Economics, 117*, 339-376.

Bundesregierung. (2018). *Forschung und Innovation für die Menschen. Die Hightech-Strategie 2025*. Retrieved from https://www.bmbf.de/upload_filestore/pub/Forschung_und_Innovation_fuer_die_Menschen.pdf

Cenamor, J., Sjödin, D. R., & Parida, V. (2017). Adopting a platform approach in servitization: Leveraging the value of digitalization. *International Journal of Production Economics*, *192*, 54-65. doi: 10.1016/j.ijpe.2016.12.033

Chen, J. L. (2018). The Cases Study of "One Belt and One Road" and "Made in China 2025" Impact on the Development of Taiwan's Machine Tool Industry. *International Business Research*, *11*(2), 189. doi: 10.5539/ibr.v11n2p189

Coreynen, W., Matthyssens, P., & Van Bockhaven, W. (2017). Boosting servitization through digitization: Pathways and dynamic resource configurations for manufacturers. *Industrial Marketing Management*, 60, p. 42–53. doi: 10.1016/j.indmarman.2016.04.012

Corrado, C., Haskel, J., & Jona-Lasinio, C. (2014). *Knowledge Spillovers, ICT and Productivity Growth*. Discussion Paper No. 8274. Retrieved from http://ftp.iza.org/dp8274.pdf

Dezhina, I. (2018). Innovation policy in Russia and the development of university–industry linkages. *Industry and Higher Education*, *32*(4), 245-252. doi: 10.1177/0950422218774974

Dezhina, I. G. (2017). Science and innovation policy of Russian Government: a variety of instruments with uncertain outcome? *Public Administration Issues*, 7-26. doi: 10.17323/1999-5431-2017-0-5-7-26

Dezhina, I., & Etzkowitz, H. (2016). Path dependence and novelties in Russian innovation. *Triple Helix*, *3*(11). doi: 10.1186/s40604-016-0042-9

Dezhina, I., Ponomarev, A., & Frolov, A. (2015). Advanced Manufacturing Technologies in Russia: Outlines of a New Policy. *Foresight-Russia*, *9*(1), 20-31. doi: 10.17323/1995-459X.2015.1.20.31

Dhyne, E., Konings, J., Konings, J., & Vanormelingen, S. (2018). *IT and productivity: A firm level analysis.* Working Paper Research, No. 346, National Bank of Belgium. Retrieved from https://www.nbb.be/doc/oc/repec/reswpp/wp346en.pdf

Digital McKinsey. (2017). *Cifrovaya Rossiya: novaya real'nost' [Digital Russia: a new reality]*. Retrieved from http://www.tadviser.ru/images/c/c2/Digital-Russia-report.pdf

Digital Transformation Monitor. (2017). *Germany Industrie 4.0*. Retrieved from https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Industrie%204.0.pdf

Dul, J., & Hak, T. (2008). *Case Study Methodology in Business Research*. Oxford, Great Britain: Butterworth-Heinemann.

Eloranta, V., & Turunen, T. (2016). Platforms in service-driven manufacturing: Leveraging complexity by connecting, sharing, and integrating. *Industrial Marketing Management*, *55*, 178-186. doi: 10.1016/j.indmarman.2015.10.003

Eloranta, V., Orkoneva, L., Hakanen, E., & Turunen, T. (2016). Using platforms to pursue strategic opportunities in service-driven manufacturing. *Service Science*, *8*(3), 344-357. doi: 10.1287/serv.2016.0155

Esmaeilian, B., Behdad, S., & Wang, B. (2016). The evolution and future of manufacturing: A review. *Journal of Manufacturing Systems*, *39*, 79-100. doi: 10.13140/RG.2.1.2720.0402

European Union. (2018). *Digital Transformation Scoreboard 2018: EU businesses go digital: Opportunities, outcomes and uptake*. Retrieved from https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/Digital%20Transformation%20Scoreboard%202018_0.pdf

Fagerberg, J., & Srholec, M. (2016). Explaining regional economic performance: The role of competitiveness, specialization and capabilities. In R. Huggins (Ed.), *Handbook of Regions and Competitiveness* (pp. 117-135). Northampton, Great Britain: Edward Elgar Publishing.

Federal Customs Service. (2018). *Tamozhennaya statistika vneshnej torgovli* [*Customs statistics of the foreign trade*]. Retrieved from http://stat.customs.ru/apex/f?p=201:7:507656887394057::NO

Ferris, S., & Gawande, K. (1998). Coordination Failures and Government Policy: Evidence from Emerging Countries. *Carleton Economic Papers*, 98-03.

Fuchs, C. (2018). Industry 4.0: The Digital German Ideology. Triple C: Communication, Capitalism & Critique. *Journal for a Global Sustainable Information Society*, *16*(1), 280-289. doi: 10.31269/triplec.v16i1.1010

Gal, P., Nicoletti, G., Renault, T., Sorbe, S., & Timiliotis, C. (2019). *Digitalization and Productivity: In Search of The Holy Grail - Firm-Level Empirical Evidence From European Countries Economics.* Department Working Papers No. 1533. Paris, France: OECD Publishing.

Gauthier, C., Bastianutti, J., & Haggège, M. (2018). Managerial capabilities to address digital business models: The case of digital health. *Strategic Change*, *27*(2), 173-180. doi: 10.1002/jsc.2192

Gershman, M., & Thurner, T. (2018). New development: Reinventing industrial policy — a Russian study in engineering and design. *Public Money and Management*, *38*(2), 157-160. doi: 10.1080/09540962.2018.1407166

Gershman, M., Bredikhin, S. V., & Vishnevskiy, K. (2016) The Role of Corporate Foresight and Technology Roadmapping in Companies' Innovation Development: the Case of Russian State-Owned Enterprises. *Technological Forecasting and Social Change*, *110*, 187-195. doi: 10.1016/j.techfore.2015.11.018

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0.

Manufacturing Technology Management, *29*(6), 910-936. doi: 10.1108/JMTM-02-2018-0057

Gobble, M. M. (2018). Digitalization, Digitization, and Innovation. *Research-Technology Management, 61*(4), 56-59. doi: 10.1080/08956308.2018.1471280

GOV.UK. (2017). *UK Digital Strategy 2017*. Retrieved from https://www.gov.uk/government/publications/uk-digital-strategy/uk-digital-strategy

Gstraunthaler, T., & Proskuryakova, L. (2012). Enabling innovation in extractive industries in commodity-based economies. *Innovation*, *14*(1), 19-32. doi: 10.5172/impp.2012.14.1.19

Hasselblatt, M., Huikkola, T., Kohtamäki, M., & Nickell, D. (2018). Modeling manufacturer's capabilities for the Internet of Things. *Journal of Business & Industrial Marketing*, *33*(6), 822-836. doi: 10.1108/JBIM-11-2015-0225

Hofman, A., Aravena, C., & Aliaga, V. (2016). Information and communication technologies and their impact in the economic growth of Latin America, 1990–2013. *Telecommunications Policy*, *40*(5), 485-501. doi: 10.1016/j.telpol.2016.02.002

Hong, J. (2017). Causal relationship between ICT R&D investment and economic growth in Korea. *Technological Forecasting and Social Change*, *116*(C), 70-75. doi: 10.1016/j.techfore.2016.11.005

Hong, J. P., Byun, J. E., & Kim, P. R. (2016). Structural changes and growth factors of the ICT industry in Korea: 1995-2009. *Telecommunications Policy*, *40*(5), 502-513. doi: 10.1016/j.telpol.2015.08.001

ISSEK NRU HSE. (2018a). *Delovye tendencii i cifrovaya aktivnost' predpriyatij obrabatyvayushchej promyshlennosti* [*Business trends and digital activity of manufacturing enterprises*]. Retrieved from https://issek.hse.ru/data/2019/01/14/1146819625/Delovye_tendencii_i_cifrovaya_aktivnost'..abatyvayushchej_promyshlennosti.pdf

ISSEK NRU HSE. (2018b). *Faktory, Ogranichivayushchie Deyatel'nost'organizacij Bazovyh otraslejehkonomiki V 2017 godu* [*Limiting factors the activities of organizations of the basic sectors of the economy in 2017*]. Retrieved from https://issek.hse.ru/data/2018/03/23/1163992811/faktory_ogranichivaushie_deyatelnost_2017.pdf

ISSEK NRU HSE. (2018c). *Vklad cifrovizacii v rost rossijskoj ehkonomiki* [*Contribution of digitalization to the growth of the Russian economy*]. Retrieved from https://issek.hse.ru/data/2018/07/04/1152915836/NTI_N_91_04072018.pdf

ISSEK NRU HSE. (2019a). *Cifrovaya aktivnost' predpriyatij obrabatyvayushchej promyshlennosti v 2018 godu* [*Digital enterprise activity manufacturing industry in 2018*]. Retrieved from https://issek.hse.ru/data/2019/03/06/1198898189/NTI_N_122_06032019.pdf

ISSEK NRU HSE. (2019b). *Indeks cifrovizacii biznesa* [T*he index of the digitalization of business*]. Retrieved from https://issek.hse.ru/data/2019/02/27/1193920132/NTI_N_121_27022019.pdf

ITIF. (2017). *The Competitive Edge: A Policymaker's Guide to Developing a National Strategy*. Retrieved from http://www2.itif.org/2017-competitive-edge.pdf?_ga=2.185036321.948272023.1542447096-497218199.1542447096

ITIF. (2018). *Why Manufacturing Digitalization Matters and How Countries Are Supporting It.* Retrieved from http://www2.itif.org/2018-manufacturing-digitalization.pdf

Kang, H. S., Lee, J. Y., Choi, S. S., Park, J. H., Son, J. Y., Kim, H., & Noh, S. D. (2016). Smart Manufacturing: Past Research, Present Findings, and Future Directions. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *3*(1), 111-128. doi: 10.1007/s40684-016-0015-5

Kim, Y.-Z., & Lee, K. (2008). Sectoral Innovation System and a Technological Catch-up: The Case of the Capital Goods Industry in Korea. *Global Economic Review*, *37*(2), 135-155. doi: 10.1080/12265080802021151

Kohnová, L., Papula, J., Salajová, N. (2019). Internal factors supporting business and technological transformation in the context of Industry 4.0. *Business: Theory and Practice*, *20*, 137-145. doi: 10.3846/btp.2019.13

Krykavskyy, Y., Pokhylchenko, O., & Hayvanovych, N. (2019). Supply chain development drivers in industry 4.0 in Ukrainian enterprises. *Oeconomia Copernicana*, *10*(2), 273-290. doi: 10.24136/oc.2019.014

Kudryavtseva, T. J., Skhvediani, A. E., & Bondarev, A. A. (2018). *Digitalization of banking in Russia: Overview.* 2018 International Conference on Information Networking (ICOIN) IEEE.

Kuzminov, I., Gokhberg, L., Thurner, T., & Khabirova, E. (2018). The Current State of the Russian Agricultural Sector. *EuroChoices*, *17*(1), 52-57. doi: 10.1111/1746-692X.12184

Kuznetsov, B. V., & Simachev, Yu. V. (2015). Evolution of the state industrial policy in Russia. *Journal of the New Economic Association*, *2*(22), 152-178.

Kwak, K., & Kim, W. (2014). Productivity growth of newly industrializing economies in heterogeneous capital goods markets: the case of the Korean machinery and equipment industry. *Journal Applied Economics*, *47*(7), 654-668.

Kwak, K., & Kim, W. (2015). Productivity growth of newly industrializing economies in heterogeneous capital goods markets: the case of the Korean machinery and equipment industry. *Applied Economics*, *47*(7), 654-668. doi: 10.1080/00036846.2014.978075

Kwak, K., & Kim, W., Kim, K. (2018). Latecomer Firms' Combination of Strategies in a Specialized Suppliers Sector: A Comparative Case Study of the Korean Plastic Injection Molding Machine Industry. *Technological Forecasting and Social Change*, *133*, 190-205. doi: 10.1016/j.techfore.2018.04.004

Lacasa, I. D., Jindrab, B., Radosevic, S., & Shubbak, M. (2019). Paths of technology upgrading in the BRICS economies. *Research Policy*, *48*, 262-280. doi: 10.1016/j.respol.2018.08.016

Lee K., & Malerba, F. (2017). Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems. *Research Policy*, *46*(2), 338-351. doi: 10.1016/j.respol.2016.09.006

Lee, J. J., & Yoon, H. (2015). A comparative study of technological learning and organizational capability development in complex products systems: Distinctive paths of three latecomers in military aircraft industry. *Research Policy*, *44*(7), 1296-1313. doi: 10.1016/j.respol.2015.03.007

Lenka, S., Parida, V., & Wincent, J. (2017). Digitalization capabilities as enablers of value co-creation in servitizing. *Psychology and Marketing*, *34*(1), 92-100. doi: 10.1002/mar.20975

Lisovskii, A. L., Belovitskii, K. B., & Skomoroshchenko, A. A. (2018). Consequences of digitalization of the Russian Economy for human capital. *Quality-Access to Success*, *19*, 15-19.

Martín-Peña, M. L., Díaz-Garrido, E., & Sánchez-López, J. M. (2018). The digitalization and servitization of manufacturing: A review on digital business models. *Strategic Change*, *27*(2), 91-99. doi 10.1108/JBIM-12-2018-0400

Min, Y., Lee, S., & Aoshima, Y. (2019). A comparative study on industrial spillover effects among Korea, China, the USA, Germany and Japan. *Industrial Management & Data Systems*, *119*(3), 454-472. doi: 10.1108/IMDS-05-2018-0215

Mitra, A., Sharma, C., & Veganzones-Varoudakis, M. A. (2016). *Infrastructure, ICT and Firms' Productivity and Efficiency: An Application to the Indian Manufacturing*. Singapore: Springer Singapore.

Nelson, R. R., & Winter, S. G. (1982). The Schumpeterian tradeoff revisited. *The American Economic Review, 72*(1), 114-132.

NRU HSE. (2018a). *Cifrovaya ehkonomika: global'nye trendy i praktika rossijskogo biznesa* [*Digital economy: global trends and practice of Russian business*]. Retrieved from https://imi.hse.ru/pr2017_1

NRU HSE. (2018b). *Indikatory innovacionnoj deyatel'nosti: 2018. Statisticheskij sbornik* [*Indicators of innovation activities; 2018. Statistical compendium*]. Retrieved from https://www.hse.ru/data/2018/03/23/1164003717/Indicators_of_Innovation_2018.pdf

NRU HSE. (2018b). *Indikatory innovacionnoj deyatel'nosti: 2018. Statisticheskij sbornik* [*Indicators of innovation activities; 2018. Statistical compendium*]. Retrieved from https://www.hse.ru/data/2018/03/23/1164003717/Indicators_of_Innovation_2018.pdf

NRU HSE. (2019). *Indikatory cifrovoj ekonomiki: 2019: statisticheskij sbornik* [*Digital Economy Indicators in the Russian Federation: 2019: Data Book*]. Retrieved from https://www.hse.ru/data/2019/06/25/1490054019/ice2019.pdf

NTI. (2018). *Technologies. Description of the Technet*. Retrieved from http://www.nti2035.ru/technology/technet

OECD. (2017). *The next Production Revolution — A report for the G20*. Retrieved from https://www.oecd.org/g20/summits/hamburg/the-next-production-revolution-G20-report.pdf

OECD. (2019). *Vectors of Digital Transformation*. OECD Digital Economy Papers, 273, 26-27. Retrieved from https://www.oecd-ilibrary.org/docserver/5ade2bba-en.pdf?expires=1548433207&id=id&accname=guest&checksum=0B987517F2C54426F43A96F10B784C2B

OECD/IEA. (2017). *Digitalization and Energy*. Retrieved from https://www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf

Parida, V., Sjödin, D., & Reim, W (2019). Reviewing Literature on Digitalization, Business Model Innovation, and Sustainable Industry. Past Achievements and Future Promises. *Sustainability*, *11*(2), 391. doi: 10.3390/su11020391

Pilat, D. (2004). The ICT Productivity Paradox: Insights from Micro Data. *OECD Economic Studies*, *1*, 37-65.

Porter, M. E., & Heppelmann, J. E. (2015). How smart, connected products are transforming companies. *Harvard Business Review*, *93*, 96-114.

Production management. (2017a). *Cifrovoe Proizvodstvo: Segodnya I Zavtra Rossijskoj Promyshlennosti* [*Special issue of the almanac "Digital production: today and tomorrow of the Russian industry"*]. Retrieved from http://up-pro.ru/imgs/specprojects/digital-pro/Digital_production.pdf

Production management. (2017b). *Cifrovoe Proizvodstvo: Segodnya I Zavtra Rossijskoj Promyshlennosti, 2 "Digital production: today and tomorrow of the Russian industry", 2*]. Retrieved from http://up-pro.ru/imgs/specprojects/digital-pro/Digital_production_3.pdf

Rabetino, R., Harmsen, W., Kohtamäki, M., & Sihvonen, J. (2018). Structuring servitization-related research. *International Journal of Operations & Production Management*, *38*(2), 350-371. doi: 10.1108/IJOPM-03-2017-0175

Rachinger, M., Rauter, R., Müller, C., Vorraber, W., & Schirgi, E. (2018). Digitalization and its influence on business model innovation. *Journal of Manufacturing Technology Management*. doi: 10.1108/JMTM-01-2018-0020

Rodrik, D. (1996). Understanding Economic Policy Reform. *Journal of Economic Literature*, *34*(1), 9-41.

Rowley, J. (1987). Using Case Studies in Research. *Management Research News, 25*(1). doi: 10.1108/01409170210782990

Russian Government. (2019). *Nacional'naya programma "Cifrovaya ekonomika Rossijskoj Federacii"* [*The National Program "Digital economy of the Russian Federation"*]. Retrieved from http://static.government.ru/media/files/urKHm0gTPPnzJlaKw3M5cNLo6gczMkPF.pdf

Simachev, Yu., Kuzyk, M., Kuznetsov, B., & Pogrebnyak, E. (2014). Russia on the Path Towards a New Technology: Industrial Policy: Exciting Prospects and Fatal Traps. *Foresight-Russia*, *8*(4), 6-23.

Ślusarczyk, B., Haseeb, M., & Hussain, H. I. (2019). Fourth industrial revolution: a way forward to attain better performance in the textile industry. *Engineering Management in Production and Services*, *11*(2), 52-69. doi: 10.2478/emj-2019-0011

Sommarberg, M., & Mäkinen, S. (2019). A method for anticipating the disruptive nature of digitalization in the machine-building industry. *Technological Forecasting and Social Change*, *146*, 808-819. doi: 10.1016/j.techfore.2018.07.044

Stiroh, K. J. (2002). Are ICT Spillovers Driving the New Economy? *The Review of Income and Wealth*, *48*(1), 33-57. doi: 10.1111/1475-4991.00039

Strange, R., & Zucchella, A. (2017). Industry 4.0, global value chains and international business. *Multinational Business Review*, *25*(3), 174-184. doi: 10.1108/MBR-05-2017-0028

Strobel, Th. (2016). ICT intermediates and productivity spillovers—Evidence from German and US manufacturing sectors. *Structural Change and Economic Dynamics*, *37*(C), 147-163. doi: 10.1016/j.strueco.2016.04.003

Szalavetz, A. (2018). Industry 4.0 and capability development in manufacturing subsidiaries. *Technological Forecasting and Social Change*, *145*, 384-395. doi: 10.1016/j.techfore.2018.06.027

Szirmai, A. (2012). Industrialisation as an engine of growth in developing countries, 1950–2005. *Structural Change and Economic Dynamics*, *23*, 406-420. doi: 10.1016/j.strueco.2011.01.005

Tao, F., & Qi, Q. (2017). Data-driven smart manufacturing. *Journal of Manufacturing Systems*, *48*(part C), 157-169. doi: 10.1016/j.procir.2019.03.156

Tether, B. S., & Hipp, C. (2002). Knowledge intensive, technical and other services: patterns of competitiveness and innovation compared. *Technology Analysis & Strategic Management*, *14*(2), 163-182. doi: 10.1080/09537320220133848

The Government of the Republic of Korea. (2017). *People-Centered "Plan for the Fourth Industrial Revolution" to Promote Innovative Growth*. Retrieved from www.4th-ir2018.co.kr/bbs/download.php%3Fbo_table%3Dreference_en%26wr_id%3D6%26no%3D1+&cd=1&hl=ru&ct=clnk&gl=ru

Thurner, T. W., & Zaichenko, S. (2016) Sectoral differences in technology transfer. *International Journal of Innovation Management*, *20*(02). doi: 10.1142/S1363919616500201

Thurner, T., & Proskuryakova, L. N. (2014). Out of the cold–the rising importance of environmental management in the corporate governance of Russian oil and gas producers. *Business Strategy and the Environment*, *23*(5), 318-332. doi: 10.1002/bse.1787

Turovets, J., Vishnevskiy, K., Tokareva, M. S., & Kukushkin, K. (2019). *Technology foresight for digital manufacturing: Russian case*. 2nd International Scientific Conference on Digital Transformation on Manufacturing, Infrastructure and Service, Institute of Physics Publishing (IOP), 012062, 1-6. doi:10.1088/1757-899X/497/1/012062

Turovets, Yu. V., & Vishnevskiy, K. O. (2019) Standardization in digital manufacturing: implications for Russia and the EAEU. *Business Informatics*, *13*(3), 78-96. doi: 10.17323/1998-0663.2019.3.78.96

Vishnevskiy, K., & Yaroslavtsev, A. B. (2017). Russian S&T Foresight 2030: case of nanotechnologies and new materials. *Foresight*, *19*(2), 198-217. doi: 10.1108/FS-08-2016-0041

Vishnevskiy, K., Calof, J. L., & Meissner, D. (2019). Corporate Foresight and Roadmapping for Innovation in Russia: A Joint University Corporate Experience. In D. A. Schreiber, Z. L. Berge (Eds.), *Futures Thinking and Organizational Policy: Case Studies for Managing Rapid Change in Technology, Globalization and Workforce Diversity*. Cham, Swtizerland: Palgrave Macmillan.

Voskoboynikov. I. (2017). Sources of long run economic growth in Russia before and after the global financial crisis. *Russian Journal of Economics*, *3*(4), 348-365. doi: 10.1016/j.ruje.2017.12.003

De Vries, H., Blind, K., Mangelsdorf, A., Verheul, H., & Van der Zwan, J. (2009) *SME access to European standardization. Enabling small and medium-sized enterprises to achieve greater benefit from standards and from involvement in standardization*. Retrieved from http://www.unms.sk/swift_data/source/dokumenty/technicka_normalizacia/msp/SME-AccessReport.pdf

Vu, K. (2013). Information and Communication Technology (ICT) and Singapore's Economic Growth. *Information Economics and Policy*, *25*(4), 284-300. doi: 10.1016/j.infoecopol.2013.08.002

Wang, Y. (2017). Industry 4.0: a way from mass customization to mass personalization production. *Advances in Manufacturing*, *4*, 311-320. doi: 10.1007/s40436-017-0204-7

Witkowski, J. Cheba, K., & Kiba-Janiak, M. (2017). The macro-and micro-environmental factors of decisions of production facility location by Japanese companies in Poland. *Forum Scientiae Oeconomia*, *5*, 43-56.