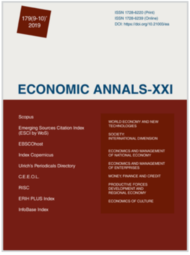

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Leonid Melnyk
D.Sc. (Economics), Professor, Head,
Department of Economics, Entrepreneurship
and Business Administration,
Sumy State University
2 Rymsky Korsakov Str., Sumy, 40007, Ukraine
mealnyksumy@gmail.com
ORCID ID: https://orcid.org/0000-0001-7824-0678

Iryna Dehtyarova
PhD (Economics), Associate Professor,
Department of Economics, Entrepreneurship
and Business Administration,
Sumy State University
2 Rymsky Korsakov Str., Sumy, 40007, Ukraine
i.dehtyarova@econ.sumdu.edu.ua
ORCID ID: https://orcid.org/0000-0003-4615-0437

Oleksandr Kubatko
D.Sc. (Economics), Professor, Associate Professor
of the Department of Economics, Entrepreneurship
and Business Administration,
Sumy State University
2 Rymsky Korsakov Str., Sumy, 40007, Ukraine
okubatko@econ.sumdu.edu.ua
ORCID ID: https://orcid.org/0000-0001-6396-5772

Oleksandra Karintseva
D.Sc. (Economics), Associate Professor,
Department of Economics, Entrepreneurship and Business Administration,
Sumy State University
2 Rymsky Korsakov Str., Sumy, 40007, Ukraine
karintseva@econ.sumdu.edu.ua
ORCID ID: https://orcid.org/0000-0001-9570-3646

Anna Derykolenko
PhD Student (Economics),
Department of Economics, Entrepreneurship and Business Administration,
Sumy State University
2 Rymsky Korsakov Str., Sumy, 40007, Ukraine
annysumy@ukr.net
ORCID ID: https://orcid.org/0000-0003-4971-5472

Disruptive technologies for the transition of digital economies towards sustainability

Abstract. The paper reveals the concept of disruptive technologies as a phenomenon that opens a new cycle of productive forces development. The paper shows essential disruptive technologies which have determined the change of socio-economic formations of human development: from agrarian societies to industrial and post-industrial ones. The authors of the article have analyzed key disruptive technologies which form the basis for the Internet of Things. Thus, it is stated that the innovations created on the basis of personal computers, mobile phones, Internet, Wi-Fi, renewable energy, 3D printers, digital technology, artificial intelligence, RFID tags, GPS, robots, and «cloud» technologies are the original components of the Internet of Things. A prognosis is that 37 billion devices will have been connected to the Internet of Things in the world by 2024. The paper demonstrates the economic view on disruptive technologies as a phenomenon that changes the benefit-cost ratio. The article reveals possible positive and negative effects of the implementation of disruptive technologies. The concept of the so called «the innovator's dilemma» is discussed, and two principles of disruptive technologies are shown (creative, since it opens a new technological cycle, and destructive, since it undermines the production bases). The authors have empirically estimated the effects of key drivers that impact the average global GDP per capita. Thus, energy use, fixed telephone subscriptions (per 100 people), gross capital formation, improvements in life expectancy, and an increase in mobile cellular subscriptions are among the factors that increase the economic performance.

Keywords: Disruptive Technology; Innovation; Industrial Revolution; Internet of Things; Economic System; Development; Cyber-physical System; Gross Domestic Product per capita
JEL Classification: A14; F20; F21; F23
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Мельник Л. Г.
доктор економічних наук, професор, завідувач кафедри,
кафедра економіки підприємництва та бізнес-адміністрування,
Сумський державний університет, Суми, Україна
Дегтярьова І. Б.
кандидат економічних наук, доцент,
кафедра економіки підприємництва та бізнес-адміністрування,
Сумський державний університет, Суми, Україна
Кубатко О. В.
доктор економічних наук, професор,
доцент кафедри економіки підприємництва та бізнес-адміністрування,
Сумський державний університет, Суми, Україна
Карінцева О. І.
доктор економічних наук, доцент, заступник завідувача кафедри,
кафедра економіки підприємництва та бізнес-адміністрування,
Сумський державний університет, Суми, Україна
Дериколенко А. А.
магістр економіки, аспірантка,
кафедра економіки підприємництва та бізнес-адміністрування,
Сумський державний університет, Суми, Україна

Проривні технології переходу цифрових економік до сталого розвитку

Анотація
У статті розкрито зміст проривних технологій як явища, що відкриває новий цикл розвитку продуктивних сил і суттєво впливає на різні сторони життя суспільства. Показано базові проривні технології, що визначили зміну соціально-економічних формацій у процесі розвитку людської цивілізації: від первісного й аграрного суспільств до індустріальної та постіндустріальної формацій. Проаналізовано різні підходи до оцінювання сучасного характеру розвитку продуктивних сил. Розглянуто базові проривні технології, що забезпечують згадані переходи. Названо ключові проривні технології, що заклали основу такого інноваційного явища, як Інтернет речей. До них, зокрема, відносяться технології, на основі яких виникли такі інноваційні явища, як персональний комп'ютер, мобільний телефон, Інтернет, Wi-Fi, альтернативна енергетика, 3D-принтер, цифрові технології, штучний інтелект, REID-мітки, «хмарні» технології, GPS, роботи.
Подано економічну інтерпретацію проривної технології як явища, що змінює співвідношення витрат і зисків. Проаналізовано поняття «дилеми інноватора». Наведено кількісні оцінки, що характеризують можливі перспективи розвитку економічних систем на основі зазначених технологій і прояву згаданих ефектів.
Ключові слова: проривна технологія; інновація; промислова революція; інтернет речей; економічна система; розвиток; кіберфізична система.

Мельник Л. Г.
доктор экономических наук, профессор, заведующий кафедрой,
кафедра экономики предпринимательства и бизнес-администрирования,
Сумской государственный университет, Сумы, Украина
Дегтярева И. Б.
кандидат экономических наук, доцент,
кафедра экономики предпринимательства и бизнес-администрирования,
Сумской государственный университет, Сумы, Украина
Кубатко А. В.
доктор экономических наук, профессор,
доцент кафедры экономики предпринимательства и бизнес-администрирования,
Сумской государственный университет, Сумы, Украина
Каринцева А. И.
доктор экономических наук, доцент, заместитель заведующего кафедрой,
кафедра экономики предпринимательства и бизнес-администрирования,
Сумской государственный университет, Сумы, Украина

Дериколенко А. А.
магистр экономики, аспирантка,
кафедра экономики предпринимательства и бизнес-администрирования,
Сумской государственный университет, Сумы, Украина
Прорывные технологии перехода цифровых экономик к устойчивому развитию
Аннотация
В статье раскрыто содержание прорывных технологий как явления, которое открывает новый цикл развития производительных сил и существенно влияет на различные стороны жизни общества. Показаны базовые прорывные технологии, которые определили изменение социально-экономических формаций в процессе развития человеческой цивилизации: от первобытного и аграрного обществ к индустриальной и постиндустриальной формации. Проанализированы различные подходы к оценке современного характера развития производительных сил. Рассмотрены базовые прорывные технологии, обеспечивающие упомянутые переходы. Названы ключевые прорывные технологии, которые заложили основу такого инновационного явления, как Интернет вещей. К ним, в частности, относятся технологии, на основе которых возникли такие инновационные явления, как персональный компьютер, мобильный телефон, Wi-Fi, альтернативная энергетика, 3D-принтер, цифровые технологии, искусственный интеллект, REID-метки, «облачные» технологии, GPS, роботы.
Дана экономическая интерпретация прорывной технологии как явления, которое меняет соотношение затрат и выгод. Проанализировано понятие «дилеммы инноватора». Дана количественная оценка, характеризующая возможные перспективы развития экономических систем на основе указанных технологий и проявления упомянутых эффектов.
Ключевые слова: прорывные технологии; инновация; промышленная революция; интернет вещей; экономическая система; развитие; киберфизическая система.

1. Introduction

Today, mankind is undergoing a complex of innovative systemic transformations that demonstrate a phase transition to a new socio-economic formation. The driving forces behind the changes are the disruptive technologies. They fundamentally transform the production basis and, at the same time, radically affect the lifestyle and human activities. This paper reveals the content of disruptive technologies and analyzes the role of economic factors determining the conditions for their implementation.

2. Brief Literature Review

Publications by various scientists prove that currently humanity has to live simultaneously in the condition of three industrial revolutions. In particular, Rifkin (2013, 2015) describes the Third Industrial Revolution, which ensures the formation of a green economy and harmonizes industrial metabolism with the metabolism of the biosphere. C. Schwab and N. Davis (2018) justify the need for the Fourth Industrial Revolution that forms the basis for cyber-physical systems capable of performing production functions independently. Rada (2018) and Vollmer (2018) have formed the contours of the Fifth Industrial Revolution aimed at achieving the harmony of man and technical systems. Disruptive technologies are the key nodes of socio-economic development in general and industrial revolutions in particular. Christensen (2016) has shown the leading role of economic factors in the implementation of disruptive technologies. At the same time, the inconsistency of the implementation processes regarding disruptive technologies should be mentioned. Along with positive effects, there are also risks of negative consequences. This paper is aimed at analyzing such possible effects.

3. The Purpose of the paper is to study the systemic nature of disruptive technologies, including the analysis of possible positive and negative consequences of their implementation.

4. Results

4.1. The concept of disruptive technologies

In the broadest sense, a disruptive technology is understood as a technological innovation, which opens up a new technological cycle for the development of production systems. The examples of «disruptive technologies» are the invention of the car based on an internal combustion engine, which replaced horse-drawn vehicles, the introduction of semiconductors which replaced vacuum equipment, the creation of digital cameras which replaced traditional film and film cameras. Disruptive technologies are prerequisites of transitions to new methods of production and consumption.

On their basis, tools, product design, communications, knowledge and skills of workers are changing (see Melnyk, Kubatko, Dehtyarova et al. (2019) and Melnyk, Derykolenko et al. (2019)).

Thus, the transition to machine production, the electrification of production systems and people's lives, the introduction of production lines, the computerization of society and other innovations have fundamentally changed the living conditions and human activities. Disruptive technologies are a basis of all innovations.

Emerging innovations and disruptive technologies which generated them form unique hierarchical structures that can be compared with the ecosystem hierarchy. The ecosystems of individual cells in a tree also feed biological elements of a higher level and, accordingly, participate in the formation of ecosystems successively: leaves, branches, plants, forests, continental ecosystems, and the planet's biosphere. Similarly, smaller disruptive technologies form innovations, which drive more significant changes. At the very top of this innovative pyramid are disruptive technologies that fundamentally change the nature of the metabolism between man and nature. The innovations created on the basis of the personal computer, the mobile phone, the Internet, Wi-Fi, renewable energy, the 3D printer, digital technologies, the artificial intelligence, RFID tags, GPS, robots, and the «cloud» technology are the original components for assembling the Internet of Things. The creation of each of these phenomena was itself a landmark event in the history of the development of human civilization. We call the results of these innovations precisely phenomena because of their scale and versatility. In particular, a variety of objects and technologies that are constantly changing in space and time stand behind the terms «mobile phone» or «3D printer».

The Internet of Things could not have appeared before the production and use of each of the mentioned phenomena (from the personal computer to «cloud» technologies) reached industrial maturity. The latter involves at least two circumstances: firstly, the achievement of their significant cheapness, which ensures the profitability of mass production and uses; secondly, the achievement of the massive scale of the application of relevant items.

Camarinha-Matos (2013) and Z. Meng et al. (2017) date the beginning of the IoT Cycle in 2012, when all the necessary prerequisites for a large-scale «assembly» of IoT have appeared, and all the 12 «component» IoT phenomena had reached maturity. Based on Statista (2019) and Lozhka M. (2019), we have made a prognosis regarding the number of IoT devices in use worldwide from 2020 to 2024 (Figure 1.) It is expected that 37 billion devices will have been connected to the Internet in the world by 2024.

It is important to consider the interdependence and complementarity of these disruptive technologies. The development of computer technologies depends on the development of the artificial intelligence, which relies on the progress of information technology. A similar relationship, to one degree or another, is observed between all the components of the presented system.

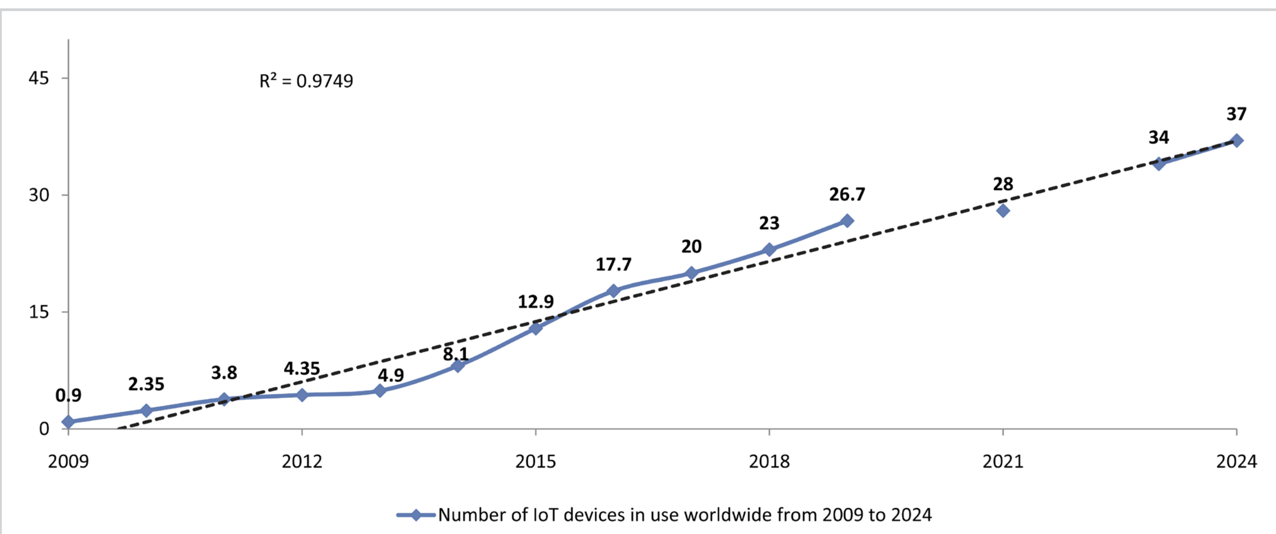

Figure 1:
Expectations of IoT devices in use worldwide from 2020 to 2024
Source: Compiled by the authors based on data from Statista (2019); Lozhka (2019)

We showed the creation of the Internet of Things at the top of the pyramid. It should be mentioned that the presented scheme is very conditional. If desired, it can be changed in such a way that the Internet of Things will be a serving component concerning other components under consideration, for example, «cloud» technologies, artificial intelligence, GPS, or computer systems. Life is changing. Causes are continually changing places with consequences. Basic structures of the Internet of Things improve other disruptive technologies.

4.2. Economic aspects of the formation of disruptive technologies

Disruptive technologies are most closely associated with the development of economic systems. In the economic environment, the term «disruptive innovation» is used more widely. The influence of economic factors on the advancement of disruptive technologies is caused by two main circumstances. Firstly, a disruptive technology is not only an impetus for the innovative development of technical systems but also opens up a new business cycle. Disruptive technologies are not aimed at improving the existing industries and the goods they produce but are aimed at a radical change in the technical basis and the corresponding business transformations. The second circumstance that determines the impact of economic factors on disruptive technologies is the dependence on market reaction. Even the most ingenious innovation cannot be fully realized until it finds its consumers in the market. Market success provides the cash receipts necessary for the development and promotion of new products to the mass buyer. Christensen (2016) has popularized the economic role of disruptive technologies in his work «The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail». One explanation for the innovator's dilemma is as follows: sooner or later, a company faces a dilemma: to continue to develop its success, introducing technologies to improve the already profitable production or consolidate its success in the market (such technologies can be called sustainable), or apply disruptive technologies that mean creating a fundamentally new product.

For a successful large enterprise (large - primarily by its market share), the decision to introduce a disruptive technology is rather painful and risky. Such a decision essentially ruins any successful business. However, we do not know whether the innovation can bring similar success and compensate for possible losses in the market. It is no coincidence that in literature one can come across the expression «cannibalism of disruptive technologies». It means that disruptive technologies «eat up» their predecessors, i.e. already existing in the technology market. A significant number of manufacturers of universal computers disappeared as personal computers (PCs) appeared. The PC market is largely affected by manufacturers of laptops, and those were forced to squeeze under the pressure of manufacturers of tablet PC and smartphones. The more successful the company's position on the market is, the less the wish to abandon the technologies in use is. Its success is a kind of a slowdown concerning new disruptive technologies. Enough is as good as a feast. We cannot predict the adverse consequences in the future from the appearance of new generation technologies. Such a forecast is most often the decisive factor in making risky decisions in favour of the implementation of disruptive technologies. From an economic point of view, any disruptive technology has two principles: creative (since it initiates the beginning of a new development cycle) and destructive (since it undermines the bases of existing production).

If the innovator introducing the new technology is a new enterprise, then it is unlikely to experience similar problems with the adoption of an appropriate decision. Such an enterprise does not have to lose its market segment, if provided with successfully functioning technology. This, however, does not reduce other forms of risk that are usually associated with the implementation of startups. Such impudent and «easy-going» beginners usually become «grave-diggers» for the market's old-timers. This happens only if disruptive technologies help to succeed in market selection. Such healthy adventurism of newcomers usually assists in pioneering the development of next-generation products of the company with a strong market position.

This allows understanding the deep essence of another definition of disruptive technology formulated by K. Christensen. «Technologies that radically change the algorithm for generating benefits and pricing belong to the disruptive category» (Christensen, 2016). In fact, it is expected that the majority of disruptive technologies would boost the economic growth of the global economy. To test the abovementioned hypothesis, we have collected a data set based on world development indicators. Thus, to estimate the key drivers of the global economy, the theoretical concept of the model is presented by formula (1):

$$YPC_t = F\ (EPC_t\ ;\ FT_t\ ;\ GCF_t\ ;\ IUI_t\ ;\ LE_t\ ;\ MU_t\ ;\ Cons.)\ , \quad (1)$$

where:
YPC_t - the global average GDP per capita (constant 2010 US$) in year t;
EPC_t - the global average energy use (kg of oil equivalent per capita);
FT_t - the global average fixed telephone subscriptions (per 100 people) in year t;
GCF_t - the global average gross capital formation (current USD) in year t;
IUI_t - the global average individuals using the Internet (% of population) in year t;
LE_t - the global average life expectancy at birth, total (years) in year t;
MU_t - the quantity of mobile cellular subscriptions in year t;
$Cons.$ - constant term of model.

The empirical estimations of the selected factors on the global economy are presented in Table 1. It should be mentioned that the dependent variable of our econometric model is the world average GDP per capita (in USD).

It is seen from the table that the energy use (kg of oil equivalent per capita, fixed telephone subscriptions (per 100 people), gross capital formation (current USD prices), life expectancy at birth (years) and mobile cellular subscriptions are the factors that positively impact the average world GDP per capita. While the table states that individuals using the Internet (% of the population) is a statistically significant factor that negatively influences the average world GDP per capita. One of the possible explanations is that after a certain point of the Internet usage, the population reduces productivity and, thus, reduces the average world GDP per capita.

Disruptive technologies are gradually forcing consumers to reconsider their views on the market value of goods. At the same time, old goods become noncompetitive, since the value of the previous parameters and functions that previously brought product success in the market changes.

The most typical scenario of introducing disruptive technologies is associated with the promotion of products on the market, which are inferior in some parameters to the goods dominating there. Their shortcomings are compensated with other advantages. Most often, the latter is associated with size reduction, simplicity, convenience and low cost. Tablets, losing to PCs in memory and other technical parameters, were able to prove their competitive advantages for those consumers for whom the mentioned characteristics are less significant in their activities.

The Third and the Fourth Industrial Revolutions have brought new disruptive technologies which, in turn, have brought humanity to the frontier of unprecedented changes. In short, the outcome of the Fourth Industrial Revolution (Industry 4.0) should be the formation of a society built on the work of cyber-physical systems. These cyber-physical systems will implement the main production functions (Piccarozzi, Aquilani, & Gatti (2018); Oztemel & Gursev (2018)). Moreover, machines will be able to execute them without the direct participation of humans. Such prospects are now clearly visible in the development of the Internet of Things as a key phenomenon of Industry 4.0.

Table 1:
Influence of key drivers on global economy development

Source	SS	df	MS		
Model	322271563	6	53711927.1	Number of obs = 39	F(6, 32) = 598.42
Residual	2872197.59	32	89756.1748	Prob > F = 0.0000	R-squared = 0.9912
Total	325143760	38	8556414.74	Adj R-squared = 0.9895	Root MSE = 299.59

YPCt	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
EPC_t	4.063209	1.251861	3.25	0.003	1.51325	6.613167
FT_t	75.9969	33.30894	2.28	0.029	8.148816	143.845
GCF_t	2.39e-10	1.02e-10	2.34	0.025	3.14e-11	4.47e-10
IUI_t	-106.3129	26.97961	-3.94	0.000	-161.2686	-51.35726
LE_t	189.7453	146.5638	1.29	0.205	-108.7955	488.286
MU_t	7.71e-07	1.44e-07	5.37	0.000	4.79e-07	1.06e-06
cons	-17524.99	8400.014	-2.09	0.045	-34635.26	-414.7233

Source: Compiled by the authors based on data by World Bank, 2020

The most important task that humanity will have to solve is the harmonization of industrial and biosphere metabolism. Steps to this are being taken as part of the Third Industrial Revolution in two key areas. The first of them is the cardinal dematerialization of technical systems. The basic tools are formed based on alternative energy, additive technologies using 3D printers (Greenhalgh (2016); Tleppayev (2019); Xu et al. (2019); Sotnyk (2015); Sotnyk et al. (2019)), and the so-called «smart» (digitalized) systems. They all allow an increase in the efficiency of the functioning of economic systems. The second direction is associated with the creation and active use of materials that harmoniously fit into ecosystem metabolic processes. The people themselves face a massive range of possibilities. Two polar trends represent extreme trajectories. The first involves the social progress of a person emancipated from routine production operations through his personal development. The second allows the transformation of a cybered person into a creature whose life and the global meta-mind system will tightly control activity. The latter may develop the reality of all-planetary memory emerging today based on the «cloud».

All current and future achievements of the humanity are the results of disruptive technologies created by man. Their significance is growing, and Europe leads in many scientific and technological areas. Many publications (Rada (2018); Vollmer (2018); Rossi (2018); Østergaard (2019); Mihardjo et al. (2019)) conventionally called it the Fifth Industrial Revolution (Industry 5.0). This direction foresees the formation of a synergetic unity of a man and cyber-physical systems. B. Rossi (2018) explains the essence of the Fifth Industrial Revolution in such a way: «It is aimed at achieving the interaction between man and machine, the harmony of man's mental work and cognitive computer. A person must return to industrial production in collaboration with robots ... This should ensure, among other things, mass customization and personalization for consumers» (Rossi, 2018). Also, we should mention some positive characteristics of disruptive technologies in the nearest future (Table 2).

Assessment of the possible consequences of introducing disruptive technologies is greatly important. This allows measuring the costs of their development and implementation along with the effects that they can bring. Justification of the most effective investments in innovative projects plays an important role comparing to the costs that are invested in disruptive technologies.

The expected positive effects of disruptive innovations are powerful incentives for their implementation, promising investors a very fast and tangible increase in their income. However, as a rule, a person has to pay a high price for achieving a scientific and technological progress in the form of undesirable negative consequences. Any of the disruptive technologies is a genie that cannot be «pushed» back «into the bottle». The whole history of socio-economic development clearly shows this. The fruits of civilization (either machines, electricity, cars, assembly lines, computers or the Internet) are so exciting that humanity is no longer able to refuse from them - no matter what negative consequences they may cause - destruction of the natural

Table 2:
Potential economic characteristics of disruptive technologies for 2025

Technology	Potential effects
Mobile Internet	A 10-20% reduction in the cost of treating chronic diseases through remote health monitoring
Automation of knowledge work	Increased labour productivity equivalent to the additional use of 110-140 million full-time workers
Internet of Things	Reduction of operating costs to USD 36 trillion, due to increased efficiency in processing, healthcare, and mining
«Cloud»	A 15-20% increase in productivity due to the creation of IT infrastructure, development of necessary applications and programs
Advanced Robotics	Potential to improve the lives of 50 million amputees and those with impaired mobility
Autonomous and near-autonomous vehicles	30-150 thousand saved lives due to the prevention of fatal traffic accidents
Energy saving	Expected 40-100% of vehicles to be electric or hybrid
3D printing	Saving from 35 to 60% of operating costs per one unit of manufactured products with a very high level of customization (i.e. manufacturing according to individual customer requirements)
Advanced materials	Successful treatment of up to 20 million newly diagnosed cases of cancer due to the use of new nanomedical drugs
Renewable energy sources	Possible reduction of 1 to 2 million tons of CO_2 emissions until 2025.
Genetics for future generations to come	Increased life quality for 75% of potential recipients

Source: Compiled by the authors based on the studies by McKinsey (2013); Schwab et al. (2018); Skinner (2018); Stram (2016); Yang (2017); Zhang (2019) environment, loss of individual freedom, the unification of a person, information dependence, or creative degradation (Shkarupa & Kharchenko (2017); Sotnyk, Dehtyarova, & Kovalenko (2015); Melnyk, Kubatko, & Kubatko (2016); Sotnyk & Kulyk (2014)). Unlike positive effects, negative effects are much more difficult to predict. Positive effects are usually calculated based on already known indicators (in particular, growth in labour productivity, reduction of certain types of costs, etc.) extrapolated to the future. A significant part of the negative consequences can be caused by phenomena whose character is much less deterministic and difficult to predict in terms of quantitative estimates, for example, phenomena such as personal freedom, degradation of a person's creative potential in a social network.

The second feature that distinguishes positive and negative effects is the different status of economic agents. Most of the positive effects are internal. In particular, they appear in the form of income of some agents that bear the costs of implementing certain disruptive innovations. Most of the negative consequences are external. They can manifest themselves in economic agents, which have nothing to do with the initiation of disruptive technologies. The revenues that some companies receive can be paid by other entities that do not receive any benefits from the mentioned innovations - or by the whole society. Thus, an analysis of the relevant benefits and costs should come before the implementation of disruptive innovations.

5. Conclusions

Today, mankind has entered the era of a phase transition to a new socio-economic formation. It is characterized by a radical greening of energy production (See, Sineviciene et al. (2018)) and processing of materials, the formation of autonomous cyber-physical production systems and personalization of human social development. The driving force of the ongoing transformational processes is disruptive technologies, i.e. technological innovations opening a new technological cycle of the development of the production systems. Disruptive technologies underlie new methods of production and consumption. They change tools, design, manufacturing technologies, communications, knowledge and skills of both producers and consumers.

Among the leading disruptive technologies, we should mention artificial intelligence, the Internet of Things, methods for producing renewable energy, additive technologies of material production with the use of 3D printers, «cloud» technologies, blockchain, virtual and augmented reality.

The positive effects of disruptive technologies form powerful incentives for their implementation. However, we should not forget that both positive and negative effects may occur, especially in the form of information dependence, creative destruction, etc. Further in-depth research is to predict the economic and social consequences of the implementation of disruptive technologies.

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