

УДК 330.341.1

## СТРУКТУРНАЯ РОЛЬ КОНВЕРГЕНТНЫХ ТЕХНОЛОГИЙ В СОВРЕМЕННОЙ ЭКОНОМИКЕ

Чехлар М.

Технический университет в Кошице, Республика Словакия

### Аннотация.

Технологическая конвергенция – результат ускорения научно-технического прогресса в XXI веке – оказывает трансформирующее влияние на экономику развитых стран, формируя новый тип отраслевого структурообразования. Это связано не с углублением отраслевой специализации или межотраслевого сотрудничества в рамках эволюции базовых технологий, а с появлением технологий принципиально нового типа, сформированных в результате объединения ноу-хау из разных отраслей. В результате конвергентные технологии формируют собственное поле экономических интересов и экономических отношений, устанавливают ориентиры для развития институциональной среды, перераспределяют инвестиции и человеческий потенциал, формируют новые механизмы алокации производительных сил в мировом масштабе. Массовый перелив капитала в нематериальные производства, предстоящая модернизация промышленности на основе слияния nano-, био-, информационных технологий в единую систему, отход от национального принципа при создании инновационных кластеров и переход к кластеризации глобальной сети бизнеса – все это радикально меняет структурную экономики на всех ее уровнях. Структурные сдвиги, возникающие в результате технологической конвергенции, не имеют исторических аналогов и зарекомендовавших себя форм регулирования, разработанных в мейнстриме современной промышленной политики в развитых странах. В статье изложены основные принципы и условия влияния конвергентных технологий на структуру экономики.

### Информация о статье

Принята 05 сентября 2019 г.

**Ключевые слова:** конвергентные технологии, инновации, экономика, структурный сдвиг.

DOI: 10.26730/2587-5574-2019-3-24-31

## THE STRUCTURAL ROLE OF CONVERGENT TECHNOLOGIES IN THE MODERN ECONOMY

Michal Cehlar

Technical University of Kosice, Slovak Republic

### Abstract.

Technological convergence – the result of accelerating scientific and technological progress in the 21st century – has a transformative effect on the economies of developed countries, forming a new type of sectorial genesis. It is not related to the deepening of sectorial specialization or inter-industry cooperation within the framework of the evolution of basic technologies, but to the emergence of technologies of a fundamentally new type, formed as a result of the merger of know-how from different industries. As a result, convergent technologies form their own field of economic interests and economic relations, set guidelines for the development of the institutional environment, redistributing investment and human potential, "drawing" a new map of allocation of productive forces on a global scale. Massive capital outflows in intangible industries, the forthcoming modernization of industry based on nano-, bio-, information technologies merging into a single complex, the estrangement from national innovative clusters and the transition to the global network clustering are all radically changing the structural proportions of the economy. The structural shifts arising from technological convergence do not have the historical analogues and forms of regulation developed by industrial policies of developed countries. The article outlines the key principles and conditions for the impact of convergent technologies on the structure of economy.

### Article info

Received September 05, 2019

### Keywords:

convergent technologies, innovations, economy, structural shift.

## 1 Introduction / Введение

At present, a new type of extended reproduction, which is essentially over-intensive and connected with a new integration of factors of production in new combinations of technology, cooperation and division of labor are being developed the countries of advanced market economies. Technological breakthroughs of the 21st century, new forms of capital attraction and institutions of innovation investment create prerequisites for modernization of the system of productive forces. In this process, the diffusion of convergent technologies is connected with modification of economic relations in investment, innovation, credit spheres, in industry production, and transformation of ownership relations:

- in the process of developing new entities of investment, innovation-implementation relations, developers and commercializers of innovation;
- in the course of emergence of new capital accumulation forms (such as public-private venture, IPO of innovative firms, crowdsource) and investment (blockchain, collective project investments);
- in the process of forming new subjects of intellectual property relations – public-private high-tech partnerships, information product outsourcers, owners of cloud storage and information generation services;
- in the process of sectioning industry entities, networking of development and introduction of innovations in production;
- in the process of reducing the technological gap in those catching-up countries that form effective national convergent-and-technological platforms and implement long-term programs of interaction with universities and innovative firms at the global scale (China, India, Brazil).

The combination of such processes of modification of economic relations in the reproduction sphere creates conditions for structural shift of a new type, in which the structural-forming factor is not creation and commercialization of new industry technologies, but their interaction.

## 2 Materials and Methods / Материалы и методология

Today, there is a prevailing technocratic approach to exploring the role of convergent technologies in the development of modern economy and disregard to the analysis of reproductive relations, through which technological convergence creates structural-transformative productive forces and modifies economic relations. For example, technological convergence was initially the object of sociological research in the 1990s (M. Castells [1]). Later, M.C. Roco, W.S. Bainbridge [2] identified convergent technologies as a synergistic result of interaction between representatives of four spheres of industry science: nano- and computational technologies, genetic engineering, neuroscience. Since 2001 under the auspices of the National Science Foundation of the United States, the so-called NBIC-initiative (nanotechnologies-biotechnology-IT-cognitive sciences) has been put forward, which denotes a convergent whole. The connection of technological convergence with the development of the national innovation system is seen as a connection of isolated trajectories of sectorial innovation development [3], and as integration of innovative processes in basic and high-tech industries based on digitization (structural-and-technological convergence) [4].

We define technological convergence as a process of transformation of economy structure initiated by the connection of the development of economic relations in the reproduction system (new forms of innovation investment and new sources of capital, modifications of the connection of factors of production) and the fusion of technologies in a new structural genesis.

In terms of the development of productive forces, technological convergence means a new relocation of productive forces – both within production chains and spatially (including extraterritorial, in network form). As a result of this relocation, clusters of a new type are being formed, in which producers of the benefits of modern cycle of scientific and technological progress (such as modern medicines, global information access facilities, clean energy, etc.) create a "centric" network form of organization of the movement of resources, information and know-how, labour, and coordinate their activities on the basis of common economic incentives. Such relocation takes place in the form of the development of global network clusters of convergent technologies, using virtually unlimited sources of investment in the global capital market and a digital market for highly intelligent labour, creating products that exist mainly in intangible form, extraterritorially made and consumed.

In turn, convergent-technological relocation of productive forces is integral to the modification of economic relations in the reproduction system. New forms of capital attraction (IPO of high-tech com-

panies, crowdfunding, public-private high-tech partnerships) and innovation investment (innovative entrepreneurship, co-investment of developers and consumers) are emerging. New relationships of entrepreneurial structures – investors, technology developers, resource owners and finished product (block chain, smart contract) are being developed. As a result, labor and capital become so mobile that the means of production deterioration tends to be zero, and workers constantly increase their competence in the process of combining technologies. In such a system of relocation of productive forces and modification of economic relations, new industries are created congruently with technologies entanglement.

The relocating and modifying role of convergent technologies is due to their innovation-diffuse essence, which makes it impossible to create a single center. On the contrary, their clusters form a polycentric network in which know-how is constantly exchanged and breakthrough innovations are jointly patented, their introduction is gradually becoming widespread. Accordingly, convergent structural shift becomes possible only with the participation of the economy in global clusters of convergent technologies:

1. Global cluster of nanotechnologies (production of super micro objects with size of several nanometers ( $10^{-9}$ ) m from individual molecules, the number of which can reach tens of thousands), in which such benefits as materials with new properties, medical preparations of "full health," reagents of the full cycle of raw materials processing and reduction of energy consumption are created. The examples of European network "centers" of the global cluster of nanotechnologies are Italian "Veneto Nanotech," French "Minalogic," engaged in nanofabrication of electronic devices, creation of embedded "systems on crystal," new environmental reagents.

2. The biotechnology cluster diffuses innovations related to solving new technological problems in the sectors of health care, small energy, food production, information science with the help of living organisms and products of their vital activity. The relocation of the productive forces that support the development of biotechnologies and their industrial applications is associated with such closely interacting clusters as Swedish-Danish "Medicon Valley," Swiss BioValley, French "Paris BioClast," Spanish "Catalonia BioRegion." The role of the state as a partner of non-profit organizations and private business is to provide tax incentives to combine financing of the most breakthrough and promising developments [5].

The relocation of productive forces in clusters of modern nano- and biotechnologies, as well as the relationships between their subjects, takes the form of "nano-bio" convergence, in which the market of new goods and services – biosensors and bio-detectors for health care and medicine, self-generating artificial complexes, microprocessor with biomolecules and proteins for the field of information technologies – is formed. The global result of the development of interactions between clusters of convergent nano- and biotechnologies for 2014 was the production of innovative benefits for more than \$1 trillion and the creation of about 300,000 jobs in more than 30 countries [6].

3. The global network cluster of convergent information technologies is developing in the process of digitalization of traditional sectors of economy – basic and manufacturing industries, education and health care, transport and communications, education and medicine, defense and national security, public administration. The relocation of productive forces of such a global cluster is taking place almost everywhere in technologically developed countries (IT clusters Bangalore in India and Dalian in China, Silicon Valley in the United States, Skolkovo in Russia, etc.).

In such clustering process the creation of the cost of converged information goods is modified. Since up to 60% of computer programs are developed by other programs today ("cloud," or distributed programming"), the monetary form of value is gradually replaced by blockchain (transaction blocks), and as information technologies and material production are merging, alternative transactions expand the scope of application, creating even more demand for new information goods.

As a result, the information market, including as a means of production (cloud software products) reached \$3.4 trillion in 2017, the world block chain market (excluding crypto) – \$400 million. In general, the capitalization of the global IT industry is estimated at \$1.2 trillion, and the contribution to global employment is estimated at 3.5% of all jobs, with these jobs being created overwhelmingly in private sector of economy. In countries with a high IT sector share in the economy (Singapore, Japan, Netherlands – up to 15% of GDP), the cyclical growth of stock market capitalization decreases from 10-12 to 6-7 years, which indicates significant differences in future economic dynamics of the countries with a high level of cognitive technology development from the countries with the dominance of basic industries [7].

4. The global network cluster of cognitive technologies is the result of the relocation of information-computing, intelligent, production resources engaged in the creation of means of production in the 21st century – artificial intelligence systems. The contribution of this cluster to the technological modernization of economy – as the next the 6th technological layer – is the development of fundamentally new means of production (deserted systems, super-productive computers capable of providing high-precision production of material goods). Concentration of innovative activity in the development of cognitive technologies takes place in the USA (Center of Cognitive Technologies Google, ATT Cognitive Research, Cognitive Industries Inc, etc.).

Despite relatively small volumes of the world market of ready-made cognitive technologies (\$11 billion in 2016, according to IBM [8]), they will determine the so-called "post-sixth" technological layer and the future stage of industrial development "Industry 5.0," which will be based on the wide use of "strong" artificial intelligence and "information clones of the brain." Therefore, today the main investors of cognitive technologies are the world's largest corporations in the IT sphere (Apple, Google, Microsoft with a total capitalization of 2.4 trillion dollars). According to the expert estimates, about 5-7% of investment budgets of these corporations, or 11 billion dollars, are annually directed to the development of fundamental cognitive technologies of the future [9].

The relocation of productive forces in clusters of information and cognitive technologies takes place in the form of convergence "info-cognitive," with the creation and market commercialization of computing technologies, which significantly automate the processes of creating new software products, on the one hand (programming without errors, information systems with guaranteed reliability, design of artificial intelligence), on the other – improve management systems in the spheres of production and distribution (factories, banks, investment firms), public administration. Convergence "info-cognitive" will lead to almost five times growth of the IT-technology market by 2040 (up to 15 trillion dollars), which will make it the largest global market [10].

Thus, the development of convergent technologies will inevitably cause profound shifts not only in the structure of industries through the change of dominant technologies, but also in the structure of public reproduction, markets.

The development of technological convergence modifies structural shifts, expanding the boundaries of sectorial industries, changing the market conditions of future relocation of investment flows, sectorial industries, territorial placement of productive forces – the factors of structural shift. At the same time, the self-induction of convergent technologies, their ability to capitalize quickly and expand the share of industries using them in the structure of economy is connected with the interpenetration and recombination of technological innovations developed in different technological platforms, but capable of giving a common product. Therefore, the structural shifts induced by technological convergence are accompanied by the development of economic relations, the regulation of which by the state with the former instruments (state investments, innovative tax incentives, and subsidies) will not lead to the desired effect, but may cause the opposite result.

The accelerating principle of reproduction process is to erase boundaries between separate industries, to create new benchmarks of productivity growth in the process of interweaving investment flows generated by investors-partners from different industries. We consider the accelerating principle of reproduction process to be crucial in assessing the impact of convergent technologies on structural shifts in economy.

The concept of technological layers based on the ideas of structuralism is widely used to describe the process and results of existing instruments of influence on the structure of economy (in the terminology of "motor industries" and "poles of economic growth" F. Perroux) [11], J.A. Schumpeter's theory of innovative development ("acts of creative destruction") [12], Nikolai Kondratiev's "long waves" [13], the radical change of proportions in the five- and three-sector model of national economy R. Reich [14], D. Bell [15] and C. Clark [16].

In general, for most researchers of technological layers, the process of their changing is considered technocratic as a change in the sectorial structure of economy with the allocation of leading industries, in which the "core" of technological leadership – the complexes of technologically coupled industries or groups of meso-level subjects using common resources – is being formed. Most authors recognize scientific and technological progress as a driving force for technological change, which is often considered outside its economic sources – innovation investment institutions, development of the market for

new technologies, stimulation of high-risk investments, development of intellectual property market, etc.

Summarizing the work of the authors mentioned above, it is possible to distinguish five technological layers formed by now, and forthcoming one, designed to dominate at the end of the next industrial super-cycle (according to the estimates of a number of academic economists its establishment took place in the early 2010s, the end will be by the middle of the 21st century).

The most interesting for us is the transition from the fifth (modern) technological layer to the sixth, expected in the second half of the 21st century. The fifth technological layer (the end in the 20th – the beginning in the 21st centuries) laid the reproductive foundations of future structural shifts caused by fundamental research in the fields of microelectronics, computing, satellite and fibre-optic communication, introduction of information and communication technologies in all spheres of human life. It is within the framework of the fifth layer that technological platforms have begun to be formed, effectively integrating the innovative activities of the entities of scientific sector, business and the state. The growing informatization of financial sphere has laid the ground for mass investment in the development of innovations – start-ups – in the form of a venture, IPO, which has determined the acceleration of reproduction in high-tech industries.

The sixth technological layer, actively emerging in the USA, Western Europe, Japan, Singapore, is expected to be structurally convergent, thanks to the expansion of industries focused on final consumption, social well-being of the population of developed countries (medicine, information technologies of the future, Internet of Things and smart house, environmental protection and waste disposal, dominance of deserted production).

We believe that the reproducible feature of the structural shift in replacing the fifth technological order with the sixth is the modification of the cycle – the Kondratiev wave – with the acceleration of deep changes in the sectorial structure of GDP – 30-40 years in comparison with 75-80 years for early technological layers. As a result, economic development will increasingly be determined by investments in the research (scientific) sector, inspired by the structural policy of the state and the quality of its institutions.

During the transition from the fifth technological layer to the sixth (the first half of the 21st century), a crisis of basic sectors of economy (mining of energy sources, iron and steel, thermal and nuclear energy, railway transport) is expected. At the same time, we believe that it is the convergence of modern technologies based on the growing informatization of economy and the creation of new materials based on nano-technologies of society that can smooth down the sharp decline in production in traditional industries (neo-industrial development of economy with the characteristic deep technological modernization of basic industries, taking into account the needs for resources of a new type).

At the same time, we believe that the concept of technological layers has methodological limitations for analyzing the impact of technological convergence on structural shifts. The main limitation is the use of the term "key industries" defining their "core" in the concept of technological layers. Another limitation is the reliance on the ability of economy to generate technologies of a certain level as a criterion to refer it to a higher layer.

The fact is that technological convergence "erodes" the concepts of "cores" or "key industries" of technological layer, as new industries arise not as a result of evolution of old under the influence of scientific-and technological progress, but as a result of the merger of new technologies, investment mechanisms, ways to involve human capital in innovation process. This makes it difficult to identify structural shift conditions based on industry criteria. Further, with the help of technological layers, it is difficult to explain why countries with a high-tech defense-industrial complex can increase technological lag from other countries, and structurally degrade.

### **3 Results and Discussion / Результаты и обсуждение**

Based on the above approaches to assessing the impact of convergent technologies on the development of national and global economy, we have highlighted the following principles of influence of convergent technologies on structural shifts:

1. The principle of accelerating the reproduction process during the expansion of converged technologies, according to which the connection of individual know-how and technological chains of different industries is accompanied by the connection of their investment flows. Accordingly, with regard to technology platforms, the investment in convergent innovations and the allocation of basic research

take a cross-platform nature, whereby the convergent and technological platform should be an integrator of other technological platforms.

2. The principle of the neo-industrial impact of technological convergence on the structural shift, according to which the separation of high-tech production from the innovative development of basic industries is unacceptable. The possibility of economic crises caused by the bankruptcy of basic industries, rising unemployment and recession caused by the acceleration of cross-sectorial capital flows cannot be ignored. Therefore, making technological convergence neo-industrial means carrying out a systemic policy of technological modernization of basic industries, based on convergent technologies, in order to radically increase productivity and change the connection of workers with the means of production.

3. The principle of modification of economic relations in the system of public reproduction, connected with investment of innovations and their introduction, with creation of tax, financial and credit incentives of technological convergence, with acceleration of fixed capital renewal, with formation of new social relations and patterns of economic behavior. In the course of such modification new subjects of investment, credit, tax relations (for example, network clusters and convergent technologies, intersectoral centers of innovation investment, public-private convergent-technological partnerships) should be formed, as well as their new functions (for example, the function of the state as an investment-innovative partner of business) should be developed.

4. The principle of targeted programming of convergent technologies development and investment in their mass production, diffusion in the basic sector of economy. As a structural and transformative factor of economic development, technological convergence should be carried out systemically and regulated, in the system of national industrial, scientific and innovative, monetary, fiscal, foreign economic and social policy. Therefore, today there is a great need for development and implementation of targeted programs for the creation, commercialization and widespread diffusion of convergent technologies, harmonization of interests of state and private investors, developers of high technologies and raw materials, manufacturing corporations, various social groups. This, in turn, is possible when forming national targeted programs similar to foreign industrial development strategies: in the USA – "Advanced Manufacturing Partnership – Select USA", in the European Union – "Agenda for European Manufacturing on a Changing World", in China – China Industry Challenge.

5. The principle of socializing technological convergence and smoothing out the negative consequences of the resulting structural shift. Forecasts of increasing the share of the sixth technological layer in the global GDP from today's 1.5% to 30% by 2050 mean the release of up to 20% of the labor force in developed countries, expansion of industries with ultra-high productivity, wages in which will outstrip today's median in 2.5-3 times [17]. All this will fundamentally change the structure of the labor market, the distribution of income and the social well-being of the generation already employed. Consequently, it is necessary to synchronize the social policy of the state with the trend of expansion of convergent and technological industries in the structure of economy, development of adaptation mechanisms in the regulation of the labor market, improvement of the distribution of intellectual rents.

Thus, the principles of the impact of convergent technologies on structural shifts reflect such imperatives of economic relations as adaptation of their subjects to accelerate scientific and technological progress, to network innovation, to changing the role of state in the context of accelerating reproduction processes.

The driving forces of technological convergence, such as modification of investment and change of nature of work in the process of development of fundamental research in the fields of NBIC, connection of the market of modern means of production and intellectual capital, transformation of property relations within the framework of collective investments, innovative entrepreneurship, public-private partnership in innovation define a set of conditions of influence of convergent technologies on structural shifts:

A) Reproduction and cluster conditions, which consist in accelerating the reproduction of fixed capital in modern manufacturing industries (mechanical engineering, radio electronics, production of synthetic materials and modern alloys, medicine, etc.), which should become the main consumers of convergent technologies and create investment, material and resource flows necessary for their expansion. This requires increased mobility of production factors and will lay the foundation for a convergent structural shift.

B) Innovation and investment conditions of effect of convergent technologies on structural shifts are connected with neo-industrial development and modernization of industry, which should guarantee demand for NBIC-convergence products in the process of formation of post-oil energy (super-powerful power sources, bio-generators, etc.), technologies of superconductivity, recycling and energy-minimized industry, biochemical materials, nano-computers. However, it should be noted that convergent technologies are only part of the reproduction process, as they create the prerequisites for accelerating it, but do not guarantee structural change by them. Implementation of innovation and production conditions is possible only in complex with reproduction-cluster and institutional measures.

C) Institutional conditions include purposeful development of state and business institutions capable of reorienting investment, labor, and intellectual resources from extractive and manufacturing industries to industries in which convergent technologies are created and find demand. This means that innovations generated in the fields of information, bio-, nano-, cognitive technologies should be demanded in the traditional industries - biochemistry, radio electronics, light, food industry, polymer production, etc. This requires the targeted development by the state of a favorable environment for the development of economic relations in the market of intellectual capital, high-productivity labor, modern resources and information. Such an environment should not replace the market, but be much less entropic, not associated with the speculative promotion that has developed since the beginning of market reforms and has not been overcome so far in the Russian economy. The Institute of Property Rights will transform into public-private partnerships as convergent and technological production develops in the industries which are most sensitive to scientific and technological progress. They reduce market entropy and, at the same time, maintain market principles of competition and economic efficiency. In many ways due to this high-tech industries are emerging as leaders of investment attractiveness in technologically advanced countries today. The implementation of institutional conditions can take various forms, and include lobbying the interests of convergent and technological producers in domestic and foreign markets, public guarantees of private investment in R&D, commercialization of breakthrough innovations through public guarantees and subsidies, harmonization of the interests of innovative firms and natural monopolies.

D) The social conditions of the impact of technological convergence on structural shifts imply the purposeful formation of a sustainable social group of convergent technology developers, innovative entrepreneurs and start-up managers. Realization of social conditions is connected with modification of economic relations in the labor market, in which at acceleration of scientific and technical progress the relations between employees and employers take a network form, and the nature of work becomes more creative, informational. For this social group to be sustainable, it is necessary to transform the state employment policy, stimulating the growth of employees' income depending on the intellectual integration of work.

#### **4 Conclusion / Заключение**

Structural shifts caused by the effects of convergent technologies on reproductive, distributional and redistributive, social processes greatly enhance the convergence of economies in which they become structural determinants. At the same time, in an economy in which the commercialization and diffusion of convergent technologies is constrained by structural problems, the prerequisites for a new divergent shift are formed, which will finally consolidate the technological lag and cause a long-term depressive trend in macroeconomics.

Technological convergence will be able to initiate a convergent structural shift only when its conditions and principles are met and the factors will be involved:

- In the course of interconnection of multiplatform innovations, the mobility of factors of production (intellectual labor, private investment in new technologies) will increase dramatically;
- As a result of mass organization of innovative and entrepreneurial start-ups of new technologies, combined by a common digital form of design, commercialization and diffusion;
- Using structural policy instruments that increase the attractiveness of investment and the production of convergent and technological goods over traditional commodity industries;
- In the process of stimulating import substitution of finite elements of modern global production chains – industry integration technologies.

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**Авторы**

*Чехлар Михал* – доктор наук, профессор, Технический университет в Кошице, г. Кошице, Республика Словакия.  
042 00 Кошице, Словакия, ул. Летняя 9  
E-mail: [michal.cehlar@tuke.sk](mailto:michal.cehlar@tuke.sk)

**Authors**

*Michal Cehlar* – Dr.h.c., Professor, Technical University of Kosice, Slovak Republic  
042 00 9 Letna, Kosice  
e-mail: [michal.cehlar@tuke.sk](mailto:michal.cehlar@tuke.sk)

**Библиографическое описание статьи**

Чехлар М. Структурная роль конвергентных технологий в современной экономике // Экономика и управление инновациями — 2019. — № 3 (10). — С. 24-31.

**Reference to article**

Cehlar M. The structural role of convergent technologies in the modern economy. Economics and Innovation Management, 2019, no. 3 (10), pp. 24-31.