CURRENT STATE AND DEVELOPMENT OF THE BASIC AND APPLIED SCIENCES, NEW TECHNOLOGIES, TECHNOLOGICAL STRUCTURES

ORIGINAL RESEARCH ARTICLE
JEL: B25 B52 O33
https://doi.org/10.22394/2410-132X-2024-10-1-41-53

ECONOMICS OF TECHNOLOGY AS A SCIENTIFIC FIELD: RESTROSPECTIVE AND PROSPECTIVE ASPECTS[1]

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Abstract. This article examines a number of aspects in the development of the economics of technology as an independent research direction. This field falls under the umbrella of a broader discipline of the 'economics of scientific and technological progress', which was founded by a group of outstanding Soviet economists. The article analyses the methodological principles behind the economics of technology as a modern field of science. Additionally, the contribution made by the Soviet and Russian economic schools, as well as the continuity of their studies, are discussed. The research methodology is based on theories of technological change and development factors. Comparative analysis is used to explore the chronology of including technology in the realm of economic analysis. The results obtained indicate that modern works by the Russian economic school, including those on the 'combinatorial growth' of technologies, significantly alter the widely-held concept of technological evolution and most well-known models of technological dynamics, which rely on J. Schumpeter's principle of creative destruction. In this respect, the emerging research direction – economics of technology – continues the traditions of the Soviet economic school of Heynman–L'vov–Anchishkin. While considering the economic impact, renewal, or forecasting of technological development, this direction also focuses on interactions between technologies and their dynamics. Technologies advance at various rates along various areas of production activities, both within their core and periphery. Consequently, the structure of technologies within each type of activity, as well as the structural design of each technology within the 'core–periphery' framework, is of fundamental importance. The conclusion is made that the research direction of the economics of technology consists in studying the effects of combinatorial growth in technological fields, technological duality, and the sensitivity of technological development goals to different industrial policy instruments. This direction also includes modes and models of substituting and adding technologies, as well as technological neutrality and its impact on economic growth.

Keywords: economics of technology, Schumpeterian evolutionary school, theory of technological paradigms, core–periphery model of technology

Funding: This research received no external funding.

For citation: Sukharev, O.S. (2024). Economics of technology as a scientific field: Retrospective and prospective aspects. *Economics of Science,* 10(1), 41–53. https://doi.org/10.22394/2410–132X-2024-10-1-41-53

[1] The article does not claim to provide a detailed account of the history of economics of scientific and technological progress in the USSR. Instead, it aims to examine selected aspects in the history of this field during the decline of the USSR and in modern Russia, focusing on the economics of technology and the theory of technological paradigms. In this regard, the article does not cover the connections between various schools and branches or the questions of their genesis from earlier works. Firstly, this would have significantly increased the length of the article. Secondly, such a goal was neither set nor declared in this study.

СОСТОЯНИЕ И РАЗВИТИЕ ФУНДАМЕНТАЛЬНОЙ И ПРИКЛАДНОЙ НАУКИ, НОВЫЕ ТЕХНОЛОГИИ, ТЕХНОЛОГИЧЕСКИЕ УКЛАДЫ

ОРИГИНАЛЬНАЯ ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ
УДК: 330.83 (330.88)
JEL: B25 B52 O33
https://doi.org/10.22394/2410–132X-2024-10-1-41-53

«ЭКОНОМИКА ТЕХНОЛОГИЙ» КАК НАПРАВЛЕНИЕ НАУКИ: РЕСТРОСПЕКТИВА И ПЕРСПЕКТИВА

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Аннотация. В статье рассматриваются некоторые аспекты становления и развития «экономики технологий» как самостоятельного научного направления анализа, являющегося неотъемлемой частью более широкого направления «экономика научно-технического прогресса», развиваемого плеядой выдающихся советских экономистов. Целью статьи является анализ методологических аспектов «экономики технологий» как современного направления науки. Кроме того, важной задачей выступает демонстрация достижений советско-российской экономической школы и преемственность проводимых исследований. Методологию изучения составляет теория технологических изменений и факторов развития, сравнительный анализ, принцип хронологизма применительно к включению технологий в экономический анализ. Результат анализа состоит в том, что современные работы российской экономической школы, в том числе по исследованию «комбинаторного наращения» технологий, значительно изменяют представление о технологической эволюции согласно главенствующему долгое время принципу «созидательного разрушения» Й. Шумпетера, на котором базируется большая часть широко известных моделей технологической динамики. Тем самым, продолжая традиции советской экономической школы Хейнмана– Львова–Анчишкина, формируется самостоятельное направление «экономика технологий», акцентирующее помимо вопросов экономического эффекта, обновления технологий либо прогноза научно-технического развития, моменты взаимодействия и изменения самих технологий, которые совершенствуются с разной скоростью по различным направлениям производственной деятельности в границах своего ядра или периферии. Тем самым структура технологий в рамках каждого вида деятельности, а также структурное построение каждой технологии в границах «ядро–периферия» имеют принципиальное значение. Общий вывод состоит в том, что содержание научного направления «экономика технологий» составляют изучение эффекта комбинаторного наращения в области технологий, технологического дуализма и чувствительности целей развития технологий к различным инструментам промышленной политики, а также режимов и моделей замещения и дополнения в области технологий, технологической нейтральности, влияния структуры технологий на рост экономики.

Ключевые слова: экономика технологий, шумпетеровская эволюционная школа, теория технологических укладов, модель технологии типа «ядро – периферия»

Информация о финансировании: Исследование выполнено без внешнего финансирования.

Для цитирования: Сухарев О.С. «Экономика технологий» как направление науки: ретроспектива и перспектива // Экономика науки. 2024. Т. 10, № 1. С. 41–53. DOI: https://doi.org/10.22394/2410–132X-2024-10-1-41-53

INTRODUCTION

The Soviet economic school, alongside the globally recognised econometric direction, actively and successfully developed research in the field of the economics of scientific and technological progress.

Particular attention should be given to the works of S.A. Heynman, who addressed various aspects of the scientific and technological revolution in the USSR. These include its impact on national economic sectors, the growth rates of the Soviet economy, the structure of social production, and forecasting of technological development (Heynman, 1972, 1973, 1977, 2008). Heynman's works present an extended set of ideas that remain relevant today, particularly concerning the description, measurement, and evaluation of the impact of scientific and technological progress (STP) on economy and its growth rate. These ideas can be summarised as follows.

- The foundation of STP lies in revolutions in the natural, social, and engineering sciences, with science taking precedence and technology following the derived engineering laws when taking decisions.
- Progress in science and technology is interconnected but may follow individual trajectories for each component, varying across national economic sectors. However, certain core industries (e.g., energy, transport infrastructure, metallurgy, and engineering) determine the possibilities for scientific and technological development in a given country.
- The economic effect of STP is manifested in the production output growing faster than input costs, leading to savings in the total costs and time. Time as a critical economic resource becomes a limiting factor in technological choice and economic development in the era of technological race.
- The criterion for the intensification of development is resource efficiency (cost reduction), as well as waste-free and automated production. The systemic effect of STP translates into qualitatively new social standards (high living standards in functional terms), high environmental and ergonomic requirements for life and work.
- For a state with planned development and centralised planning, policymakers need a unified technological policy to coordinate the application of scientific and technological achievements across various economic sectors, influencing the creation and transfer of technologies between them.

In the context of a high-tech race accompanied by competition within capitalist economic systems, where the potential for state planning is limited, a unified technological policy as envisioned by S.A. Heynman is unlikely to be feasible. However, planning methods could still prove useful, particularly for mitigating stochastic manifestations of technological development. It is worth noting that there exist some misconceptions about the supposed exponential growth of R&D costs, which are expected to yield both qualitative improvements and structural-technological modernisation. The challenge lies in ensuring that results outpace costs and in intensifying development, including scientific and technological activities.

In some of his works, S.A. Heynman dedicated sections to the analysis of technology, although this was not his exclusive focus. He considered technology as a means of production – creating products using tools and equipment in specific spatial and temporal configurations (Heynman, 2008, Vol. 1, pp. 77–84, 145–154; Vol. 2, pp. 141–143). He acknowledged the independent nature of technology, which, being multifaceted, could generate new technologies and tools. In many cases, the idea of a method precedes the creation of specific tools. Today, this concept has received wide recognition.

Moreover, the technological sphere has distinctively emerged from the economics of scientific and technological progress. The logic of technological knowledge development and the emergence of technological ideas, linked to both fundamental and applied research, revealed their own patterns requiring separate study. This is tacitly evident in Heynman's works, although he neither discussed the economics of technology as a research direction, nor dedicated independent research to technology per se (Heynman, 2008). Nevertheless, the works of this outstanding Soviet economist effectively laid the foundation for the economics of scientific and technological progress as a field of scientific inquiry. In the late 1960s and 1970s, Heynman published several articles under similar titles.

The aforementioned points assume that the successful development of science and technology requires a foundational base, accumulated knowledge, skilled personnel, and a production base. However, many critical technological directions in the Soviet period were developed from scratch. At the same time, policymakers deliberately focused the creation of a foundation for such development through investments in science, energy sectors, and education, including engineering training. In addition, the criterion for evaluating the successful development or the systemic impact of STP on economic parameters is crucial. It should be highlighted that modern technologies, once implemented, do not always meet the criterion of intensification – i.e., relatively low total costs over a given time interval. It is possible that such an effect may emerge over time, but in the foreseeable future, increased costs are most likely. New technologies, representing the cutting edge of science, typically require high costs, including due to the capital intensity of scientific research.

A.I. Anchishkin and D.S. L'vov made significant contributions to the study of technological development, essentially formalising and strengthening the economics of scientific and technological progress as a research direction. While A.I. Anchishkin focused on the factors and sources of economic growth, considering scientific and technological progress (STP) as the most important among them and addressing the task of forecasting its outcomes over long time intervals (Anchishkin, 1986), D. S. L'vov made multifaceted contributions to this field (L'vov, 1966, 1990). L'vov's works encompassed methods for evaluating the effectiveness of implementing a new technology, the quality of manufactured products (including technological applicability in engineering), and the theory of technological paradigms, developed jointly with S.Yu. Glazyev (L'vov & Glazyev, 1986; Glazyev, 1993).

Neither D.S. L'vov nor S.Yu. Glazyev explicitly identified the economics of technology as an independent research direction. However, by developing the theory of technological paradigms, they contributed, in my view, to its formation, at least at the macroeconomic level of analysis. The concept of technological evolution as a succession of paradigms provided new arguments for macroeconomic policy, obliging it to purposefully influence the stimulation of technological development (Glazyev, 2018).

The formation of industrial policy must consider the systemic qualities of the existing technological base of a particular economy (L'vov, 1999). However, even years after these works, policymakers do not always take this into consideration in newer versions of the scientific and technological policy. They often neglect the structure of growth and technologies, macrostructural and institutional constraints, e.g., reforms in science (Ivanov, 2022; Sukharev, 2014, 2017). This is due to the complexity of typifying technologies, their interconnections, and the challenges of describing and measuring their impact on development (Chichkanov & Sukharev, 2023).

In summary, it can be noted that in today's Russia, a neo-Schumpeterian tradition[2] of representing technological evolution has emerged (L'vov & Glazyev, 1986; Glazyev, 1993; Sukharev, 2014). However, it does not replicate the developments of Western neo-Schumpeterians (Futia, 1980; Perez, 1983; Breschi et al., 2000; Hanusch & Pyka, 2007; Hartman, Pyka, and Hanush, 2010; Perez, 2011). Instead, it has its own specificity due to the influence of the Soviet economic tradition of the economics of scientific and technological progress, particularly through the works of S.A. Heynman, D.S. L'vov, and A.I. Anchishkin.

Within the emerging field of the economics of technology in Russia, both 'strong' and 'weak' Schumpeterian branches can be identified. The works of L'vov and Glazyev align with the principle of creative destruction (strong Schumpeterian branch) (Schumpeter, 2007). However, this principle requires expansion and, in some cases, replacement by the more significant principle of combinatorial growth, which describes a substantial part of technological changes (Sukharev, 2014, 2017). According to this perspective,

[2] This tradition, for instance, is followed at the macro level of analysis in macroeconomic modelling by Academician V.I. Maevsky. He examines artificial aggregates such as macro-generations (components of GDP). Similarly, Academician A.A. Akaev explores the impact of R&D and other parameters on economic growth. Incidentally, there are currently overestimated, and sometimes even incorrect, assessments regarding the significant or highly substantial influence of domestic research and development expenditures on economic dynamics. These expenditures range from 1.5% to 4.3% of GDP across different countries, as if they sustain a certain level of economic activity among the population. However, such activity is confined exclusively to the research and development sector. For example, in Russia, in 2000 prices, domestic expenditures on research and development declined during the period 2019–2022. The number of researchers also decreased in absolute terms. From a macroeconomic perspective, this cannot fundamentally influence the activity of economic agents. Moreover, its impact on economic growth needs to be assessed separately. It is also important to critically examine the often-exaggerated figures presented by forecasters.

creative destruction ceases to be the dominant force in the process of technological evolution. Among Western economists, J. Sengupta holds a similar viewpoint, emphasising the combinatorial effect in his models (Sengupta, 2001). Since the effect of creative destruction is no longer dominant, and combinatorial growth plays a significant, sometimes greater, role in technological and overall economic evolution, this represents a clear departure from the strong Schumpeterian position. It can be conditionally termed as the 'weak Schumpeterian position'.

A strong Schumpeterian position among Western economists is exemplified by C. Perez. She constructs techno-economic paradigms of development based on the principle of creative destruction, presenting technological revolutions as the process of creating new technological knowledge at the low point of the Kondratiev cycle (Perez, 2011; Menshikov & Klimenko, 1989, pp. 234–236). However, N.D. Kondratiev, in his foundational works, did not provide a detailed explanation of the influence of technological progress on the formation of the wave itself (Menshikov & Klimenko, 1989, pp. 25–26). According to Schumpeter, emerging new combinations (discretely) divert resources from old combinations (i.e., technologies), leading to their stagnation and eventual destruction. This gives rise to the concept of creation through crisis.

This doctrine, somewhat reminiscent of the dialectical law of 'negation of negation', justifies capitalist crises and influences the understanding of technological evolution. However, it simplistically describes this process without considering that technologies can be combined, supplemented, or replaced. Additionally, old technologies may occupy a place in the technological chain that makes their displacement impossible. Moreover, new technologies can create their own resources, while the raw materials used by old technologies may become unsuitable for new ones, making resource diversion problematic.

Schumpeter, being fully aware that economic crises can be caused by non-economic factors (Schumpeter, 2007; Menshikov & Klimenko, 1989), nevertheless did not emphasise combinatorial growth in the field of technologies. Thus, he overlooked an important aspect of economic evolution, reducing it only to the systematic diversion of resources and the displacement of one means of production by another. However, considering evolution in terms of means of production without combinatorial growth (the combination of these means) significantly distorts the process of improving the capital base and technologies.

Neo-Schumpeterian frameworks within the comprehensive theory developed by H. Hanusch and A. Pyka (2007) assume the evolution of technological innovations within the general approach of creative destruction. The succession of technological paradigms, as described by S.Yu. Glazyev or C. Perez, occurs in a similar manner. Thus, within Schumpeterian economics, theoretical problems arise that require further clarification. They can be addressed within the framework of the economics of technology, which allows for a more realistic representation of technological changes. These changes occur not only or primarily according to a Darwinian scheme but also a Lamarckian one, or, at the very least, a combination of these evolutionary schemes (Hodgson, 2004). Accounting for institutional factors (Davis & North, 2008), which influence both growth and technologies, creates additional difficulties. This is because technology represents a set of rules that transform in the case of substitution or supplementation, experiencing varying degrees of dysfunction[3]. This inevitably affects technological evolution.

It is worth noting that the concept of the economics of technology can be effectively interpreted as the rules of technology. This is because the term 'economics' can be understood as the rules of managing an economy – in this case, the economy of technology.

The high level of technological diversification generates various technological regimes of development. These regimes depend on the initial base and influence both growth and further technological changes (Breschi et al., 2000; Sukharev, 2014).

[3] The theory of dysfunction in economics, management, and institutions was developed by the author between 1998 and 2014.

Finally, it can be argued that technological dynamics can be considered an independent object of study. This is because methods of production, or ways of influencing objects, which constitute various technologies, develop according to their own life cycles and exhibit unique properties and patterns. This supports the need for the formation of a distinct field of research: the economics of technology.

The Soviet and modern Russian economic schools have made significant contributions to the establishment and development of this field. Further, some methodological aspects of the economics of technology as a contemporary scientific field will be examined. Additionally, the structural features of technologies will be described using the core–periphery model of technology. In conclusion, potential prospects for this scientific field will be discussed. The research methodology includes comparative, descriptive, and structural-morphological analysis to consecutively fulfil the following objectives:

1. To reveal the methodological aspects of the economics of technology, distinguishing it from the Schumpeterian methodology of development through creative destruction.
2. To outline the prospects for the economics of technology based on the identified features.

METHODOLOGICAL ASPECTS OF THE 'ECONOMICS OF TECHNOLOGY'

Figure 1 illustrates the position of the economics of technology within the system of the economics of scientific and technological progress. This system connects various scientific inquiries with technological development.

Undoubtedly, the advancement of fundamental science largely determines the possibilities in the field of R&D and applied research. At the same time, the improvement of technologies depends on both the state of machinery, equipment, and devices, as well as the production-oriented infrastructure. To some extent, it also depends on the information infrastructure (see *Figure 1*). Scientific and technological policy aims to influence the science segment, while industrial policy targets the segment of technological development. This includes machinery, technologies, production apparatus, and other elements of its infrastructure. Together, these five basic elements constitute the economics of scientific and technological progress. Education, which forms the personnel base for the development of science and technology, can also be included here.

The economics of technology represents an independent segment of research. While influenced by other segments, it possesses its own set of developmental tasks and, most importantly, exhibits its own inherent patterns and unique properties specific to technologies. The list of issues studied within the economics of technology as a scientific field includes:

- The development, improvement, replacement, and supplementation of technologies.
- The effect of technological dualism in development and the assessment of the technological structure within the framework of identified and analysed economic structures at the macro level (macrostructural analysis[4]). This considers the characteristics of the technologies themselves within the core-periphery model[5].
- The measurement of technologies, their typification, and the identification of stages of technological evolution (technological paradigms, techno-economic paradigms). It also includes the identification of patterns between them, as well as the assessment

[4] For more details, please refer to the author's works from the period 1999–2023.

[5] In a number of works, D.O. Skobelev, Director of the Research Institute "Centre for Environmental Industrial Policy," highlights not only the need to employ the best available technologies to address various aspects of technological development in the Russian economy but also the importance of developing the "core-periphery" model. This model includes relevant assessments across industrial sectors and technological development areas (Skobelev, 2020). In doing so, he supports and expands the author's idea regarding the significance of changes in the technological core and periphery. This approach underscores the need to revise methods in federal statistical accounting of technologies and assessments of the country's technological development. The core of a technology refers to its hard-to-change component, which encompasses the essence of the technology. The periphery, on the other hand, represents the easily modifiable part that does not alter the core (the essence of the technology itself). This structure fundamentally determines technological choice (Sukharev, 2014, pp. 268–300).

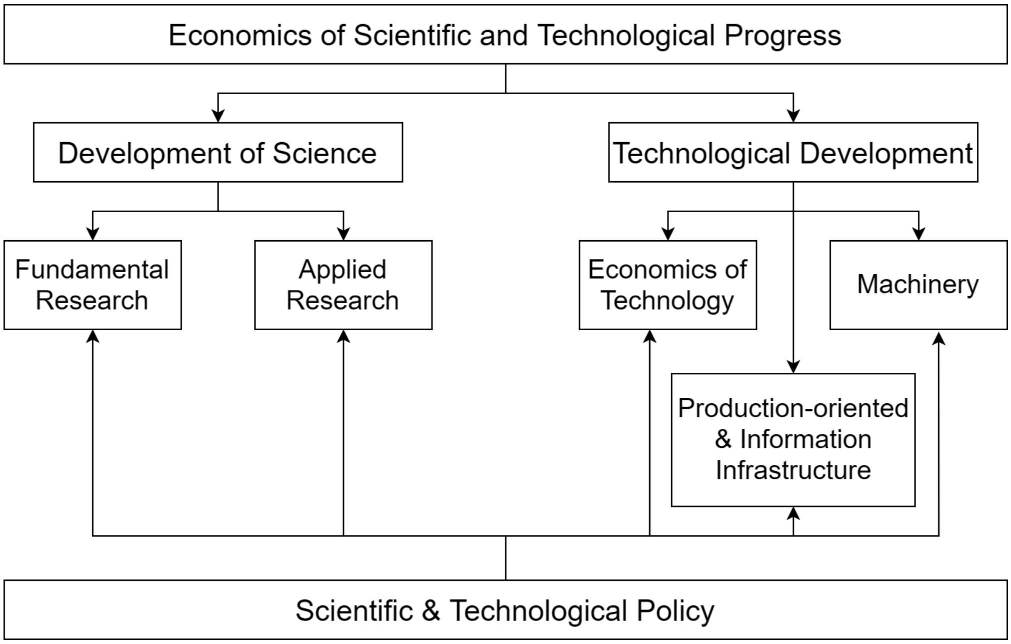

Figure 1. Scope of the economics of technology as a scientific field
Рисунок 1. Место «экономики технологий» как научного направления

of the level of technological advancement in production, industry aggregates, types of activities, and large economic systems – regions and countries.

- The competition of technologies, the determination of technological choices at various levels of economic organisation (firm, corporation, country), and the establishment of criteria for evaluating economic (losses, reserves, sources) and other types of efficiency in technological development.
- The formation of state policies that stimulate technological development (renewal) based on the macrostructural analysis of the economy and technologies.

It is important to note that developing policy instruments to influence technologies and their development requires setting clear goals and assessing their sensitivity to these instruments. This approach is useful not only for measures in scientific, technical, or industrial policy but also for macroeconomic policy, which can restrain the development of science and technology. Systemic institutional interventions, such as privatisation, can, in principle, have a destructive impact on such economic systems.

Thus, a wide range of issues emerge for studying the technological sphere from the perspective of economic content and consequences. These issues can be considered as part of an independent field: the economics of technology. Tasks of particular importance arise when studying the effects of technological substitution and supplementation. These effects occur at the microeconomic level but have clear macroeconomic consequences. Macrostructural analysis allows policymakers to account for and consider these effects in economic policy planning.

In an earlier work, the author (Sukharev, 2014)[6] proposed a model for examining technology from the perspective of its core and periphery. The core represents the unchangeable part that determines the essence of the technology – such as the physics or chemistry of the process. The periphery, on the other hand, is the changeable part that does not alter the basic principle. This model not only allows for the description of a specific technology but also identifies opportunities for its modification,

[6] This book includes articles from previous years, covering the period 2012–2013, where the aforementioned model was first outlined.

Table 1. Technologies for producing thin films on solid surfaces (three basic cores)
Таблица 1. Технологии получения тонких плёнок на твёрдой поверхности (три базовых ядра)

Core 1	Core 2	Core 3
Formation of films on solid surfaces from electrolyte solutions	Obtaining films from the gas phase (thermodiffusion deposition)	Mechanical application of films onto solid surfaces
Two peripheral technologies for each core:		
Electrochemical deposition of films from an electrolyte solution (electroplating) – without affecting the surface of the underlying solid material	Deposition of layers obtained through chemical reactions between gaseous reactants onto a solid surface	Application of a reagent solution to the surface followed by solvent evaporation
Film formation using the substrate material itself (e.g., anodized oxidation of aluminum in a high-voltage discharge, in an alkaline solution)	Formation of films on the surface via chemical interaction between the gas phase and the base material	Spray deposition of liquid onto the coated surface

improvement, or replacement through structural and morphological analysis. Furthermore, it enables the application of the model itself to analyse a set of technologies that form the core of a technological paradigm, including the periphery. This includes assessing the state of each activity area and the peak level of advancement achieved in the existing set of technologies. The method of technological mapping and the assessment of technological coverage can be applied here. These methods answer the question of how many economic entities use a particular technology and how widespread it is. Moreover, entities may apply the same technology in terms of its core but with different peripheries. *Table 1* presents three technologies (three cores) for producing thin films on solid surfaces.

For each technology, two peripheries are provided as examples. These peripheries can be easily modified without changing the physics of the technology itself. Of course, in each case, there may be more peripheries (not all are listed in *Table 1*, as it is provided for illustrative purposes). Thus, *Table 1* immediately provides an understanding of the complexity of technological choice – between three cores and, for each core, two peripheries. The application of a technology's core is largely determined by the conditions and purpose of its use, as well as the technical requirements that define the task. For example, if the first core assumes the presence of ions in a solution, the peripheries may vary depending on factors such as the required film thickness. The second core represents a gaseous medium, while the third core involves mechanical spraying, where there may be more peripheries than in the previous technologies (cores 1–2) (see *Table 1*). In fact, *Table 1* defines two basic types of technological choice: horizontal (between cores) and vertical (between peripheries).

The higher the technical requirements (TR) for the object of the technology or the result (the applied films), the lower the possibilities for vertical technological choice – the peripheries of the technology (narrower periphery – smaller scale) (see *Figure 2*). If the TRs are too high, the application of technologies according to cores 2–3 becomes impossible due to the limitations of the periphery's scale. Sometimes, even the core – the physics of the process – becomes unsuitable. As a result, only the technology based on core 1 remains viable, meeting the technical task requirements (see *Figure 2*, which reflects the qualitative relationships between these parameters).

Of course, there may be cases where the application of a particular technology, either by core or by a specific periphery, is non-negotiable. This depends on the size of the object, the state of the surface (material), the size of the film, and the materials of the film itself. These parameters also determine the costs in the example presented in *Table 1*.

Therefore, the choice of technology is not always determined by the criterion of intensification – total costs, which should be lower than

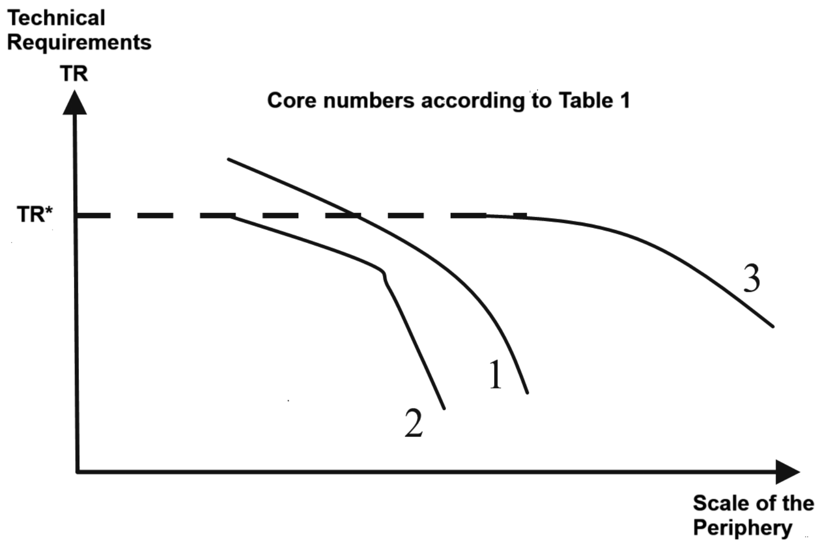

Figure 2. Technical requirements and technology periphery scale
Рисунок 2. Технические требования и масштаб периферии технологии

those of another core. Moreover, R&D, and especially its costs, may not necessarily lead to the emergence of a new technology. Sometimes, years of accumulated R&D results are needed to create a new technology. Consequently, an accelerated increase in R&D expenditures may not enhance their specific efficiency, which must also be correctly assessed (calculated). This is similar to how an increase in the savings rate does not guarantee growth, as the structure of fixed capital accumulation and many other conditions are important as well[7].

Depending on the tasks (TRs), the complexity of technical solutions, and the conditions of technology application, the costs may turn out to be much higher than expected. Therefore, technological choice, like technological development, becomes a multicriteria, multiparameter task, often with an uncertain solution.

Thus, the combinatorial effect may also be limited by the technical requirements of technology application. However, within the core-periphery model, it is clearly visible and more significant than creative destruction, which is not observed in this case.

In conclusion, this study outlines the prospects for the economics of technology and formulates the main highlights.

PROSPECTS OF THE ECONOMICS OF TECHNOLOGY: DISCUSSION OF THE FINDINGS

The aforementioned points illustrate the complexity and ambiguity of technological choice. This choice influences the development of technologies, as well as the processes of substitution and supplementation. We must also take this circumstance into account when evaluating the phenomenon of technological dualism[8].

In summary, the contours of a new scientific field, referred to here as the 'economics of technology,' are becoming visible. This field is characterised by its own methodology and approaches to measurement and analysis. Its scientific evolution has included incorporating technological progress as a residual factor in classical growth models, as well as identifying various types of technological progress within such modelling (e.g., Hicks-neutral, Harrod-neutral, and Solow-neutral technological progress). By the 1970s,

[7] These circumstances are often overlooked by modern economic growth forecasters and analysts, who debate future scenarios for the development of the Russian economy.

[8] For more information, please refer to the author's publications from the period 2019–2023.

the broader field of the economics of scientific and technological progress had taken shape[9]. In the 1990s and 2000s, research increasingly focused on the effects of the technological race and the independent tasks of technological development. These tasks are determined by the state of education, science, and production-technical systems, including the level of industrialisation and its technological component.

The current stage of technological development can be described as the expansion of virtual technologies that enhance the performance of 'real technologies' (Sukharev, 2014), as well as technologies that facilitate or replace the work of 'natural intelligence.' However, for any type of technology, the core-periphery concept retains its methodological significance. It allows researchers to examine the structural features of the technology itself. This approach creates prospects not only for improving technology but also for understanding the consequences of its application, its limitations, potential negative outcomes, and the development of methods to mitigate them.

The issues of technological substitution, supplementation, and the emerging demand for these two processes represent a promising area of research within the 'economics of technology.' Of particular importance is the search for criteria for technological choice and the variability of these criteria depending on goals, tasks, technical solutions, and economic possibilities.

CONCLUSION

To summarise the conducted analysis, the following conclusions regarding the prospects of the research direction known as the 'economics of technology' can be formulated.

Firstly, the Soviet-Russian economic school has made a defining contribution to the establishment and development of the economics of scientific and technological progress. Contemporary researchers have further contributed to the formation of the economics of technology as a distinct field. Since this role is significantly underappreciated in scientific and historical literature, the present article highlights the fundamental results obtained by the Heynman–L'vov–Anchishkin school. The article also explored various aspects of the economics of technology at the macro level (Glazyev, 2018) and in the structural-technological domain (Sukharev, 2014). These findings significantly advance macrostructural analysis, the topic broadly discussed today by forecasters. However, they tend to neglect systems theory and structural dynamics as the foundation of structural analysis, which includes the macro level.

Secondly, the specifics of technologies often undermines purely economic criteria for evaluation and decision-making in the realm of technological choice. This task, within the framework of horizontal and vertical choice, remains unresolved to date.

Thirdly, the core–periphery model of technology allows researchers to identify methodological specifics in studying the impact of technologies on economic growth and development. It emphasises the significance of combinatorial growth over creative destruction, without entirely dismissing the latter.

Thus, the economics of technology as a research direction holds broad prospects. It extends the knowledge derived therein beyond the boundaries of the stereotypical Schumpeterian approach and creative destruction. Additionally, it makes a substantial contribution to the development of structural analysis methods at the micro-, meso-, and macroeconomic levels.

[9] In 1985, the Institute of Economics and Forecasting of Scientific and Technological Progress was founded in the USSR. It was headed by Academician Anchishkin A.I. (Anchishkin, 1986).

REFERENCES

1. Anchishkin, A.I. (1986). *Science, technology, economics*. Moscow: Economics. (In Russian)
2. Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal, 110*(463), 388–410. https://doi.org/10.1111/1468–0297.00530
3. Chichkanov, V.P., & Sukharev, O.S. (2023). Possibilities of science in innovative development: "Measuring technologies." *Economics of Science, 9*(1), 36–44. (In Russian) https://doi.org/10.22394/2410–132X-2023-9-1-36-44
4. Davis, L.E., & North, D.S. (2008). *Institutional change and American economic growth*. Cambridge University Press.
5. Futia, C.A. (1980). Schumpeterian competition. *The Quarterly Journal of Economics, 94*(4), 675–695. https://doi.org/10.2307/1885663
6. Glazyev, S.Yu. (1993). *Theory of long-term technical and economic development*. Moscow: Vladar. (In Russian)
7. Glazyev, S.Yu. (2018). *Leap into the future: Russia in new technological and world economic structures*. Moscow: Knizhnyi mir. (In Russian)
8. Hanusch, H., & Pyka, A. (2007). "Manifesto" for comprehensive neo-Schumpeterian economics. *History of Economic Ideas, 15*(1), 23–41.
9. Hartmann, D., Pyka, A., & Hanusch, H. (2010). Applying comprehensive neo-Schumpeterian economics to Latin American economies. *Structural Change and Economic Dynamics, 21*(1), 70–83. https://doi.org/10.1016/j.strueco.2009.11.003
10. Heynman, S.A. (1972). Some issues of forecasting scientific and technological progress. *Bulletin of the USSR Academy of Sciences, 6*, 57–63.
11. Heynman, S.A. (1973). Scientific and technological progress and the structure of social production. *Economic Issues, 1*, 15–26. (In Russian)
12. Heynman, S.A. (1977). *Scientific and technological revolution today and tomorrow*. Moscow: Politizdat. (In Russian)
13. Heynman, S.A. (2008). *Efficiency of the national economy: Sources of growth, losses and reserves* (Vols. 1–2). Institute of Economics RAS. (In Russian)
14. Hodgson, G. (2004). *The evolution of institutional economics: Agency, structure and Darwinism in American institutionalism*. Routledge.
15. Ivanov, V.V. (2022). New science and technology policy. *Economic Revival of Russia, 3*(73), 24–28. (In Russian) https://doi.org/10.37930/1990-9780-2022-3-73-24-28
16. L'vov, D.S. (1966). *Fundamentals of economic design of machines*. Moscow: Economics. (In Russian)
17. L'vov, D.S. (1990). *Effective management of technological development*. Moscow: Economics. (In Russian)
18. L'vov, D.S. (1999). *Development of the Russian economy and tasks of economic science*. Moscow: Economics. (In Russian)
19. L'vov, D.S., & Glazyev, S.Yu. (1986). Theoretical and applied aspects of scientific and technological progress management. *Economics and Mathematical Methods, 5*, 793–804. (In Russian)
20. Menshikov, S.M., & Klimenko, L.A. (1989). *Long waves in economics: When society changes its skin*. Moscow: International Relations. (In Russian)
21. Perez, C. (1983). Structural change and assimilation of new technologies in the economic and social systems. *Futures, 15*(4), 357–375. https://doi.org/10.1016/0016–3287(83)90050-2
22. Perez, C. (2011). *Technological revolutions and financial capital: Dynamics of bubbles and periods of prosperity*. Moscow: Delo. (In Russian)
23. Schumpeter, J.A. (2007). *Theory of economic development: Capitalism, socialism and democracy*. Moscow: Eksmo. (In Russian)
24. Sengupta, J.K. (2001). A model of Schumpeterian dynamics. *Applied Economics Letters, 8*(2), 81–84. https://doi.org/10.1080/13504850150204101
25. Skobelev, D.O. (2020). *Best available technologies: Experience in improving resource and environmental efficiency of production*. Moscow: AST. (In Russian)
26. Sukharev, O.S. (2014). *Economic growth, institutions and technologies*. Moscow: Finance and Statistics. (In Russian)
27. Sukharev, O.S. (2017). *An evolutionary economic theory of institutions and technology: Modeling problems*. Moscow: Lenand. (In Russian)

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СПИСОК ИСТОЧНИКОВ

1. *Анчишкин А.И.* Наука, техника, экономика. Москва: Экономика, 1986. 383 с.
2. *Глазьев С.Ю.* Рывок в будущее. Россия в новых технологическом и мирохозяйственном укладах. Москва: Книжный мир, 2018. 768 с.
3. *Глазьев С.Ю.* Теория долгосрочного технико-экономического развития. Москва: Владар, 1993. 310 с.
4. *Иванов В.В.* Новая научно-техническая политика // Экономическое возрождение России. 2022. № 3 (73). С. 24–28. doi: 10.37930/1990-9780-2022-3-73-24-28
5. *Львов Д.С.* Развитие экономики России и задачи экономической науки. Москва: Экономика, 1999. 79 с.
6. *Львов Д.С.* Эффективное управление техническим развитием. Москва: Экономика, 1990. 255 с.
7. *Львов Д.С., Глазьев С.Ю.* Теоретические и прикладные аспекты управления НТП // Экономика и математические методы. 1986. № 5. С. 793–804.
8. *Львов Д.С.* Основы экономического проектирования машин. Москва: Экономика, 1966. 296 с.
9. *Меньшиков С.М., Клименко Л.А.* Длинные волны в экономике. Когда общество меняет кожу. Москва: Международные отношения, 1989. 272 с.
10. *Перес К.* Технологические революции и финансовый капитал. Динамика пузырей и периодов процветания. Москва: Изд. дом «ДЕЛО», 2011. 232 с.
11. *Скобелев Д.О.* Наилучшие доступные технологии: опыт повышения эффективности ресурсной и экологической эффективности производства. Москва: АСТ, 2020. 257 с.
12. *Сухарев О.С.* Эволюционная экономическая теория институтов и технологий. Проблемы моделирования. Москва: Ленанд, 2017. 144 с.
13. *Сухарев О.С.* Экономический рост, институты и технологии. Москва: Финансы и статистика, 2014. 464 с.
14. *Хейнман С.А.* Научно-техническая революция сегодня и завтра. Москва: Политиздат, 1977. 328 с.
15. *Хейнман С.А.* Научно-технический прогресс и структура общественного производства // Вопросы экономики. 1973. № 1. С. 15–26.
16. *Хейнман С.А.* Некоторые вопросы прогнозирования научно-технического прогресса // Вестник АН СССР. 1972. № 6. С. 57–63.
17. *Хейнман С.А.* Эффективность национальной экономики: источники роста, потери и резервы // Сборник научных трудов в 2-х т. Москва: Институт экономики РАН, 2008. Т. 1. 241 с.; Т. 2. 308 с.
18. *Чичканов В.П., Сухарев О.С.* Возможности науки в инновационном процессе: «измерение технологий» // Экономика науки. 2023. Т. 9. № 1. С. 36–44. doi: 10.22394/2410–132X-2023-9-1-36-44
19. *Шумпетер Й.* Теория экономического развития. Капитализм, социализм и демократия. Москва: Эксмо, 2007. 864 с. (Серия «Антология экономической мысли»).
20. *Breschi S., Malerba F., Orsenigo L.* Technological Regimes and Schumpeterian Patterns of Innovation // The Economic Journal. 2000. Vol. 110. № 463. P. 388–410. doi: 10.1111/1468–0297.00530
21. *Davis L.E., North D.C.* Institutional Change and American Economic Growth. Cambridge: Cambridge University Press, 2008. 292 p.
22. *Futia C.A.* Schumpeterian Competition // The Quarterly Journal of Economics. 1980. Vol. 94. № 4. P. 675–695. doi: 10.2307/1885663
23. *Hanusch H., Pyka A.* Manifesto for Comprehensive Neo-Schumpeterian Economics // History of Economic Ideas. 2007. Vol. 15. № 1. P. 23–41.
24. *Hartmann D., Pyka A., Hanusch H.* Applying Comprehensive Neo-Schumpeterian Economics to Latin American Economies // Structural Change and Economic Dynamics. 2010. Vol. 21. № 1. P. 70–83. doi: 10.1016/j.strueco.2009.11.003

25. *Hodgson G.* The Evolution of Institutional Economics: Agency, Structure and Darwinism in American Institutionalism. London: Routledge, 2004. 560 p.
26. *Perez C.* Structural change and assimilation of new technologies in the economic and social systems // Futures. 1983. Vol. 15. № 4. P. 357–375. doi: 10.1016/0016–3287 (83) 90050-2
27. *Sengupta Jati K.* A model of Schumpeterian dynamics // Applied Economics Letters. 2001. Vol. 8. № 2. P. 81–84. doi: 10.1080/13504850150204101

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The author declares no conflict of interest.
Автор заявляет об отсутствии конфликта интересов.
Received 21.12.2023
Revised 29.01.2024
Accepted 06.02.2024