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**SELECTED INSTRUMENTS FOR MANAGEMENT OF TECHNOLOGY
DEVELOPMENT**

1. INTRODUCTION

Poland has ranked very low in the area of technology and innovation for many years (Tab. 1).

Table 1

Poland's competitive position in the area of technology and innovation
(among 142 analysed countries)

Items	Index value (1 to 7 scale)	Position
Technology readiness		
Availability of the latest technologies	4.6	88
Firm-level technology absorption	4.3	100
Foreign direct investments and technology transfer	5.0	37
Innovations		
Innovation potential	3.3	49
Quality of academic and research institutions	4.1	44
Business expenditure on research and development	2.9	80
R&D cooperation between science and industry	3.6	65
Government procurement of high technology products	3.3	100
Availability of scientific and engineering staff	4.1	67
Patents per million population	1.0	56

Source: K. Schwab (ed.), *The Global Competitiveness Report 2011–2012*, World Economic Forum, Geneva 2011.

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As a result, the latest *Innovation Union Competitiveness Report* rates Poland among countries with a low knowledge capacity that specialise in low-tech sectors and make slow progress towards a knowledge-based economy (Box 1) despite the noticeable convergence achieved since the mid-2000s.

Box 1. *Innovation Union Competitiveness Report*: Poland's position

The *Innovation Union Competitiveness Report* covers 27 EU member states, as well as Iceland, Norway, Switzerland, Croatia, Turkey and Israel, dividing them into nine groups based on such criteria as the economic structure and the knowledge capacity (Fig. 1). Group 1 includes: Denmark, Finland, Sweden and Switzerland, characterised as very high knowledge-intensity countries. Group 2 is composed only of Germany, which is characterised as a country with high knowledge-capacity systems, specialised in high tech manufacturing. Group 3 consists of: Austria, Belgium, France and the United Kingdom, characterised as countries with high knowledge-capacity systems and a mixed economic structure. Group 4 comprises Holland, Ireland, Iceland, Luxembourg and Norway, countries with medium-high knowledge-capacity systems and a specialisation in knowledge-intensive services. Group 5 consists of countries with medium knowledge-capacity systems with a specialisation in low-knowledge intensity activities, which include Estonia, Spain and Portugal. Group 6 comprises: Greece, Lithuania, Latvia and Malta, characterised as countries with medium-low knowledge capacity and a strong role of agriculture and low knowledge-intensive services. Group 7 includes only Cyprus, characterised as a country with medium-low knowledge capacity and a strong service sector. Group 8 consists of: the Czech Republic, Slovakia, Slovenia, Hungary and Italy, regarded as countries with medium-low knowledge capacity and a well-developed manufacturing industry. The last group, group 9, comprises countries with low knowledge-capacity systems and a specialisation in low knowledge-intensive sectors, that is, Poland, Bulgaria, Croatia, Romania and Turkey.

Source: *Innovation Union competitiveness report. 2011 edition*, European Commission, Publications Office of the European Union, Luxembourg 2011.

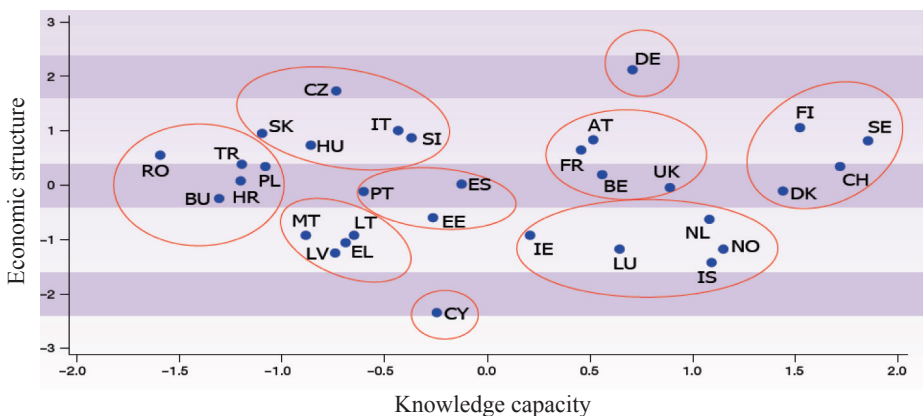


Fig. 1. Typology of countries

Source: *Innovation Union competitiveness report. 2011 edition*, European Commission, Publications Office of the European Union, Luxembourg 2011.

It is estimated that closing this gap may even take decades¹, particularly if the current (very low) dynamics of change in the research and innovation system and in the framework conditions is taken into account².

All this draws attention to the urgent need to increase the efficiency of technology development management³, both at the company and sectoral level (management of technological change) and at the level of the whole economy (the science and technology policy and the innovation policy). Each of these cases requires proficiency in using such instruments as monitoring of emerging technologies, technology life cycle with the accompanying accelerated innovation model and technology roadmapping. These instruments are presented further on in this chapter.

2. EMERGING TECHNOLOGY MONITORING: THE RESULTS OF POLAND'S TECHNOLOGY FORESIGHTS

One of the most effective instruments for emerging technology monitoring is technology foresight, which has been widely discussed in Poland⁴. Thus, not foresight itself but the results of Poland's foresights are the subject of this paper.

Technology foresight is a kind of systematic, long-term thinking about the areas of strategic research and technologies with the potential of generating economic and social benefits. Foresight emerged in this role at the beginning of the 2000s and has become one of the experimental instruments to shape science, technology and innovation policy. One of the first Polish foresights was the National Foresight

¹ R. Veugelaers, M. Mrak, *Catching-up Member States and the Knowledge Economy of the European Union*, "Knowledge Economists Policy Brief" 2009, No. 5, http://ec.europa.eu/invest-in-research/pdf/download_en/kfg_policy_briefs_no_5_9.pdf, 10.11.2010.

² *Innovation Union Competitiveness Report 2011. Country profile – Poland*, European Commission, Publications Office of the European Union, Luxembourg 2011; see also *Science and Technology in Poland in 2009*, Central Statistical Office of Poland, Warsaw 2011.

³ E. Huergo, *The role of technological management as a source of innovation: Evidence from Spanish manufacturing firms*, "Research Policy" 2006, Vol. 35; M. Nieto, *From R&D management to knowledge management. An overview of studies of innovation management*, "Technological Forecasting & Social Change" 2003, Vol. 70; B. C. B. Viñas et al., *A conceptual model for the development of technological management processes in manufacturing companies in developing countries*, "Technovation" 2001, Vol. 21.

⁴ E.g., *Metodologia foresightu technologicznego w obszarze zrównoważonego rozwoju*, Instytut Technologii Eksploatacji – Państwowy Instytut Badawczy, Radom 2011; A. Rogut, B. Piasecki, *LORIS Wizja. Regionalny foresight technologiczny. Przewodnik metodologiczny*, Społeczna Wyższa Szkoła Przedsiębiorczości i Zarządzania, Łódź 2007; *Żywność i żywienie w XXI wieku – wizja rozwoju polskiego sektora spożywczego. Przewodnik metodologiczny*, Społeczna Wyższa Szkoła Przedsiębiorczości i Zarządzania, Łódź 2009; *Foresight technologiczny. Organizacja i metody. Podręcznik*, vol. 1, Polska Agencja Rozwoju Przedsiębiorczości, Warszawa 2005.

Programme (NFP) encompassing four strategic areas: health and life; sustainable development; information and telecommunication technologies; and economic, intellectual, social, technical and technological security as well as the security of civil society development⁵.

NFP identified dozens of technology groups and hundreds of specific technologies (Box 2).

Box 2. Research directions and technologies identified within the framework of NFP

Only one area – Health and Life – comprised 26 research and technology development directions, the first three positions were taken by: i) the creation of effective screening systems; ii) the development of pre-natal care, early detection of genetic and development defects and iii) the development of methods and emergency medical techniques.

The area of Sustainable Development of Poland covered 19 directions of research and technology development, including, for example: unique technological devices as well as testing and measuring equipment for advanced new generation technologies; new generation of structural and functional materials and surface engineering technologies, including nanomaterials and nanotechnologies; advanced, non-waste material technologies and biodegradable engineering materials for the industry, transport and energetics with a closed-loop life cycle safe for the environment; advanced materials and technologies for biomedical engineering, etc.

In the area of Information and Telecommunication Technologies, the most important were the following directions: selected information systems, selected network solutions and data transmission, certain elements of information product engineering, and some areas of computational, basic and social sciences.

In the last area, Security, the study of the knowledge and innovation-based economy was seen as the most important.

Additionally, NFP defined certain systemic research directions including innovative methods of knowledge transformation, technology transfer and commercialisation of research solutions as well as systems and technologies of educational services oriented toward virtual technologies that enable customisation and dissemination of civilisation skills.

Source: on the basis of A. Matczewski, *Raport końcowy z realizacji Pilotażowego Projektu Foresight w polu badawczym Zdrowie i Życie* [2005], http://www.nauka.gov.pl/fileadmin/user_upload/12/34/12344.pdf, 12.03.2007; *Narodowy Program Foresight Polska 2020. Wyniki Narodowego Programu Foresight Polska 2020* [2009], http://www.nauka.gov.pl/fileadmin/user_upload/Nauka/Polityka_naukowa_panstwa/Prognozy_rozwoju/20100104_Wyniki_NPF-Polska_2020.pdf, 8.03.2010.

NFP was followed by dozens of completed and/or continued projects (Box 2) and their outcomes are the subject of many publicly available detailed reports.

⁵ *Informacja dla Rady Ministrów w sprawie Uruchomienia Narodowego Programu Foresight dla Polski*, [in:] *Ministerstwo Rozwoju Regionalnego* [2006], http://www.nauka.gov.pl/fileadmin/user_upload/16/05/16059/Informacja_dla_RM_o_NPF.pdf, 8.03.2009.

Box 3. Foresight projects completed and under implementation in the years 2006–2013

Ten sectoral foresights were carried out within the framework of the Sectoral Operational Programme “Improvement of the Competitiveness of Enterprises” (for: moulding; polymeric materials; brown coal mining and processing; advanced metallic, ceramic and composite materials; satellite techniques and space technologies; material technologies for the needs of the aerospace cluster “Aviation Valley”; core ore and associated materials mining; medical technologies; the coal mining industry; a fuel and energy complex to ensure national energy security) and 8 regional ones (for the following voivodeships: Dolnośląskie, Łódzkie, Małopolskie, Mazowieckie, Opolskie, Podkarpackie, Śląskie and Świętokrzyskie).

Within the framework of the Innovative Economy Operational Programme, 22 foresights have been completed or are still under implementation, including Food and nutrition in the 21st c. – a vision for the development of Polish food industry; Advanced industrial and ecological technologies for the sustainable development of Poland; Modern technologies for the textile industry. The opportunity for Poland.

Additionally, “Foresight of Personnel in Modern Economy” commissioned by the Polish Agency for Enterprise Development and “Technology Foresight of Industry” commissioned by the Ministry of Economy have been implemented.

3. TECHNOLOGY LIFE CYCLE

The most popular model of technology life cycle (Fig. 2) distinguishes “science-push” measures and “market-pull” measures. The former include: i) discovery and exploration (the discovery of new knowledge and the exploration of new opportunities and new technological rules); ii) euphoria (enthusiasm for new solutions and their possible applications) and iii) disillusionment (doubts arising from limited socio-economic as well as technical and technological deployment possibilities). The latter include: i) reorientation (seeking new opportunities for technological development, possible breakthrough); ii) growth (the first products accepted by the market, return achieved on technological novelty) and iii) diffusion (the diffusion of technology and economies of scale; the emergence of new areas of application).

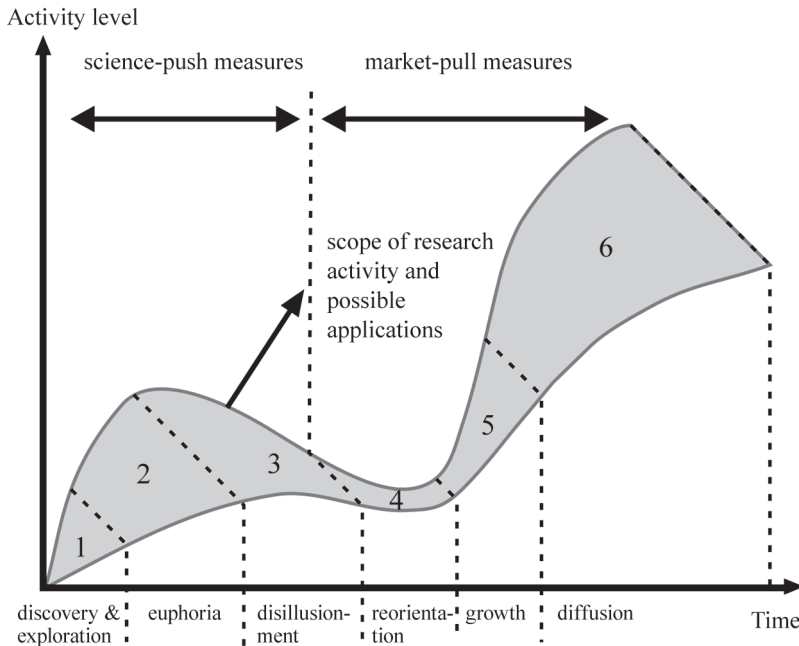


Fig. 2. Technology life cycle model

Source: H. Armbruster *et al.*, *ManVis Report No. 3. Manufacturing Visions – Integrating Diverse Perspectives into Pan-European Foresight (ManVis). Delphi Interpretation Report* [2005], http://www.forera.jrc.ec.europa.eu/documents/Final_Report_final.pdf, 12.10.2007.

The technology life cycle defined in this way is a starting point for determining the degree of difficulty of research and development and technology readiness. The first one is related to assessment of the level of difficulty of research and development work essential for the full commercialisation of the various research directions and applications (Tab. 2).

Table 2

Research and development difficulty levels

Scale	Description
1	2
1	Very low expected level of difficulty. The need for individual studies to ensure high success probability in areas of further applications. 99% probability of success.
2	Moderate expected level of difficulty, probably limited to individual trials. Possible need to carry out certain attempts to find an alternative solution to ensure high success probability in areas of further applications. 90% probability of success.

Table 2 (contd)

1	2
3	High expected level of difficulty that requires carrying out work on the creation and testing of at least two technological solutions at an early stage in order to prepare alternatives for subsequent systemic solutions to ensure high success probability in areas of further applications. 80% probability of success.
4	Very high expected level of difficulty that requires carrying out work on the creation and testing of many various technological solutions at an early stage in order to prepare alternatives for subsequent systemic solutions to ensure high success probability in areas of further applications. 50% probability of success.
5	Particularly high expected level of difficulty connected to the necessity to carry out certain basic research in order to define possible systemic solutions. 20% probability of success.

Source: J. C. Mankins, *Research and Development Degree of Difficulty (R&D3)*. A white paper [1998], <http://www.hq.nasadiff.gov/office/codeq/trl/r&d3.pdf>, 2.10.2009.

The latter (technology readiness) is related to assessment of the possibility to implement research findings into production (Table 3).

Table 3

Technology readiness level

	Scale	TRL definition	Description
1	2	3	4
Research (basic and applied)	1	Basic principles observed and reported	The lowest readiness level. Scientific research findings are just beginning to be translated into applied research and development.
	2	Technology concept and/or application formulated	The beginning of the invention process. The discovery of basic principles/rules leads to the first concepts of future applications.
Early stage commercialisation (models/tests)	3	Analytical and experimental critical function and/or characteristic proof of concept	The beginning of implementation research and development work. Analytical and lab work is used to confirm analytical assumptions (defined at earlier stages) concerning individual technology components, e.g.: experiments, models and a simulations confirmation of the potential of the technology, its feasibility, efficiency, etc.
	4	Component and/or breadboard validation in laboratory environment	Integration of basic technological components in order to determine the possibilities and principles of operation (first models).

Table 3 (contd)

1	2	3	4
Full commercialisation (prototypes/ tests/demonstrations)	5	Component and/or breadboard validation in relevant environment	A combination of technological and supporting components (initial technological project) and the first simulations.
	6	System/subsystem model or prototype demonstration in a relevant environment	Systemic solutions/the technological project tested in real conditions.
	7	System prototype demonstration in an operational environment	Preparation and testing of a prototype in actual operating conditions (a plane, a car, a drilling machine, <i>etc.</i>)
	8	Actual system completed and qualified through test and demonstration	Completion of development work, preparation of design documentation, prototype testing and acceptance, preparation for commercial implementation.
Diffusion	9	Actual system proven through successful mission operations	First implementations (return on technological novelty)
	10	Market acceptance of technology	Technology dissemination (economies of scale) and emergence of new areas of application.

Source: H. Armbruster *et al.*, *ManVis Report No. 3. Manufacturing Visions – Integrating Diverse Perspectives into Pan-European Foresight (ManVis). Delphi Interpretation Report* [2005], http://www.forera.jrc.ec.europa.eu/documents/Final_Report_final.pdf, 12.10.2007; Homeland Security Institute, *Department of Homeland Security Science and Technology Readiness Level Calculator. Final report and user's manual* [2009], http://www.homelandsecurity.org/hshireports/DHS_ST_RL_Calculator_report20091020.pdf, 21.11.2009; J. C. Mankins, *Research and Development Degree of Difficulty (R&D³). A white paper* [1998], <http://www.hq.nasadiiff.gov/office/codeq/tr/r&d3.pdf>, 2.10.2009; J. Wonglimpiyarat, N. Yuberk, *In support of innovation management and Roger's Innovation Diffusion theory*, "Government Information Quarterly" 2005, Vol. 22.

Moreover, the concept of technology life cycle provides an opportunity for a new perspective⁶ on product/service innovativeness as a derivative of various knowledge deficits (Table 4).

⁶ In contrast to the traditional one where products new to a given company and/or to a given market are considered innovative (*Foresight technologiczny...*).

Table 4

Determinants of the level of product/service innovativeness

Category of knowledge deficit	Description	Proposed assessment scale
Technological uncertainty	The degree to which the development of products/production processes requires the creation of new knowledge, which constitutes a real challenge (the necessity to trigger the “learning through exploration” process). The greater the need for the creation of new knowledge, the higher the level of radical innovation.	1 to 5 scale (where 1 means a very low level of uncertainty and 5 a very high level)
Technical inexperience	The degree to which the development of products/production processes requires the necessity to have qualifications/competences (also for operating new machines/equipment) that the company lacks (the necessity to trigger “learning through education, further education, retraining”). The greater the need to acquire new knowledge (education, further education, retraining and purchase of new machines and equipment), the higher the level of radical innovation.	1 to 5 scale (where 1 means slight inexperience and 5 great inexperience)
Business inexperience	The degree to which the development of products/production processes requires the creation of new knowledge necessary for the development and implementation of new business practices (the development of organisational innovation). The greater the need to create such knowledge, the higher the level of radical innovation.	1 to 5 scale (where 1 means slight inexperience and 5 great inexperience)
Technology costs	The degree to which the development of products/production processes requires investments to purchase new machines/equipment (the necessity to trigger “learning through use” processes). The greater the costs of acquiring the knowledge embodied in new machines/equipment, the higher the level of radical innovation.	1 to 5 scale (where 1 means very low costs and 5 very high costs)

Source: N. Amara *et al.*, *Radical innovations in traditional manufacturing industries* [2004], <http://www.2.druid.dk/conferences/viewpaper.php?id=2359&cf=16>, 23.11.2009.

4. TECHNOLOGY ROADMAPPING

Technology roadmapping is an instrument complementary to technology life cycle that combines two areas⁷:

⁷ M. L. Garcia, O. H. Bray, *Fundamentals of technology roadmapping* [1997], <http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=0FAE363C58A3941BD8ABF5A3E524F62C?pu rl=/471364-PDo152/webviewable>, 11.02.2007; S. Lee, Y. Park, *Customization of technology roadmaps according to roadmapping purposes: Overall process and detailed modules*, “Technological Forecasting & Social Change” 2005, Vol. 72; R. Phaal, C. J. P. Farrukh, D. R. Probert,

- the area of technology change management (identification, selection, acquisition, implementation and technology protection) and
- the area of technological transformation, i.e., the transformation of emerging technologies into mature and very mature technologies,

Hence, technology roadmapping is widely used in designing measures to accelerate more radical innovations (Fig. 3).

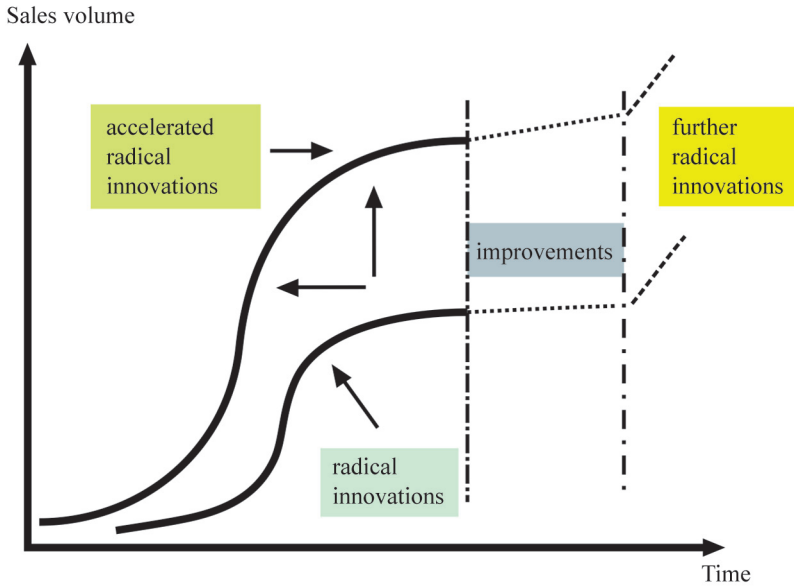


Fig. 3. Accelerated radical innovation model

Source: J. Bers *et al.*, *Accelerated radical innovation: Theory and application*, “Technology Forecasting & Social Change” 2009, Vol. 76.

The procedure of roadmapping is carried out in several stages that usually cover⁸:

- initial/preparatory measures: i) securing favourable conditions; ii) leadership definition and iii) scope and boundaries definition;
- preparation of technology map(s): i) identification of the “product” which is the central point of the map; ii) identification of the most important system requirements and their target values; iii) specification of the most important areas of technology; iv) specification of “technology driving forces” and their target

Technology roadmapping – A planning framework for evolution and revolution, “Technological Forecasting & Social Change” 2004, Vol. 71, p. 5–26; *Applying science and technology roadmapping in environmental management, Draft*, [in:] U.S. Department of Energy [2000], <http://emi-web.inel.gov/roadmap/guide.pdf>, 11.02.2007.

⁸ *Applying science...*

characteristics; v) identification of alternative technologies and their time sequence; vi) selection of the target technologies and vii) preparation of a report presenting the technology roadmap;

- implementation: i) criticism and approval of the technology roadmap; ii) preparation of an implementation plan and iii) systematic evaluation and update.

This results in a multi-layered scheme presenting the scope of measures that should be taken in each of the analysed areas in order to realise this vision (Fig. 4).

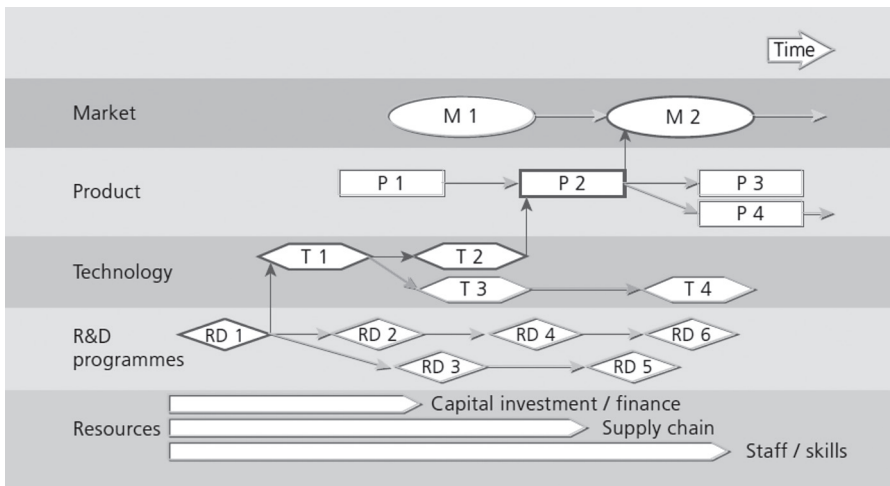


Fig. 4. Technology roadmapping scheme

Source: *Foresight technologiczny. Organizacja i metody. Textbook*, vol. 1, Polska Agencja Rozwoju Przedsiębiorczości, Warszawa 2005, Polish translation.

5. SUMMARY

The low level of the innovativeness of Poland's economy⁹ confirms the previous assessments of the European Commission¹⁰ which conclude that the process of closing the technology gap between the "old" (EU 15) and new (EU 10)

⁹ *Diagnoza na potrzeby Strategii Rozwoju Kraju 2020*, [in:] *Ministerstwo Rozwoju Regionalnego* [2011], www.mrr.gov.pl/rozwoj_regionalny/Polityka_rozwoju/SRK_2020/Documents/Zal_1_Diagnoza_do_SRK_09112011.pdf, 12.03.2012; A. Rogut, B. Piasecki, *Główne kierunki polskiej innowacyjności. Podstawowe czynniki warunkujące kreowanie i powstawanie innowacji* [2010], http://www.mrr.gov.pl/rozwoj_regionalny/Polityka_rozwoju/SRK/Ekspertyzy_aktualizacja_SRK_1010/Documents/glowne_kierunki_polskiej_innowacyjnosci_2010.pdf, 10.03.2011.

¹⁰ *Bureau of European Policy Advisers, Directorate-General for Economic and Financial Affairs Enlargement*, [in:] *Two Years After: An Economic Evaluation*, "European Economy, Occasional Papers" 2006, No. 24, (European Commission, Brussels).

EU member states may be a two-speed process. One speed is the speed at which the Baltic countries will be closing the gap to the EU average and the other speed is the speed with which the other new member states, including Poland, will be moving. Moreover, according to this scenario, it will take decades to completely close the gap. Poland, however, has certain possibilities to develop modern technologies, including the ones that are currently in the first stages of their life cycle (e.g. nanotechnology, spintronics, physical chemistry of surface phenomena, robotics, *etc.*) and have a high potential for generating profits at relatively low (i.e., not related to the production costs) investment expenditures and lower requirements concerning previously acquired experience (Fig. 5).

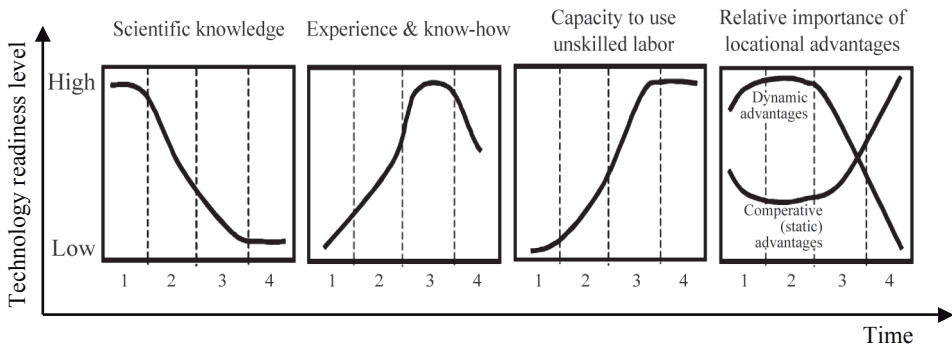


Fig. 5. Determinants of the development of technologies in the early stages of the life cycle

Source: C. Pérez, *Technological change and opportunities for development as a moving target*, "Cepal Review" 2001, Vol. 75.

Making use of these opportunities requires widening the traditional instrumentation, based mostly on the output of the rational expectations theory. Among the new approaches, particular emphasis should be placed on foresight and the related issues: technology life cycle and roadmapping, which enable: i) a systemic approach to evaluating and understanding new science and technology trends and their (future) development trajectories¹¹; ii) the development of the available assets in order to discern technological opportunities as soon as possible and to use them to the best advantage¹².

¹¹ S. Kaplana, M. Tripsas, *Thinking about technology: Applying a cognitive lens to technical change*, "Research Policy" 2008, Vol. 37, p. 790–805; P. Nightingale, *Technological capabilities, invisible infrastructure and the un-social construction of predictability: The overlooked fixed costs of useful research*, "Research Policy" 2004, Vol. 33, p. 1259–1284.

¹² S. Brown, F. Fai, *Strategic resonance between technological and organisational capabilities in the innovation process within firms*, "Technovation" 2006, Vol. 26, p. 60–75; R. Dekkers,

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WYBRANE INSTRUMENTY ZARZĄDZANIA ROZWOJEM TECHNOLOGICZNYM

Polska dysponuje pewnymi możliwościami rozwijania nowoczesnych technologii, także tych, które aktualnie znajdują się w pierwszych fazach cyklu życia (np. nanotechnologii, spintroniki, fizykochemii zjawisk powierzchniowych, robotyki itd.), i mają wysoki potencjał generowania zysku przy relatywnie niskich (bo niezwiązanych z samymi kosztami produkcji) nakładach inwestycyjnych i niższych wymaganiach, jeśli chodzi o wcześniej zdobyte doświadczenie. Wykorzystanie tych możliwości wymaga rozszerzenia o nowe podejścia tradycyjnego instrumentarium zarządzania technologią, opartego głównie na dorobku teorii racjonalnych oczekiwań. Wśród tych nowych podejść na szczególną uwagę zasługuje *foresight* i towarzyszące mu: cykl życia technologii i mapowanie, które są przedmiotem niniejszego artykułu.