# University 3.0: A Portfolio Approach to the Technology R&D Management

**Dmitry Katalevsky**
Associate Professor, Institute of Business Studies [a]; Associate Professor, Director for Industrial Programs [b], d.katalevsky@skoltech.ru

**Natalia Kosmodemianskaya**
Head of R&D Office [b], n.kosmodemianskaya@skoltech.ru

**Arutyun Arutynyan**
Leading Analyst [b], a.arutyunyan@skoltech.ru

**Clement Fortin**
Professor, Associate Provost – International Affairs, Dean of Education [b], c.fortin@skoltech.ru

[a] Russian Presidential Academy of National Economy and Public Administration (RANEPA), 82 Vernadsky ave., Moscow 119571, Russian Federation

[b] Skolkovo Institute of Science and Technology, 30 bld. 1, Bolshoi boulevard, Moscow 121205, Russian Federation

## Abstract

Modern universities play increasingly important role in contemporary society, advancing frontiers of science and transforming regional economies. As funding models of modern universities change, they adopt some features of a business organization. While their ability to attract funding becomes vitally important for universities, especially from private sources (industry), a balance between fundamental and applied research becomes vital. The current research investigates five years of activities of the Skolkovo Institute of Science and Technology (Skoltech) and particularly its research portfolio. It is based on the theory and practice of the Research Domain Portfolio Matrix (RDPM) approach, which considers a university a portfolio of R&D technologies in diverse scientific areas and at various stages of technological maturity. It is of utmost importance for universities to find a balance between basic and applied research while making decisions on launching new projects/programs or modifying the existing projects/programs. The proposed RDPM approach helps to leverage limited resources, establish priorities, monitor risks, and influence outcomes in the short and long term.

**Keywords:** basic and applied research; R&D technology portfolio; technology management; industrial funding; research domain portfolio matrix

**Paper type:** Research Article

**Citation:** Katalevsky D., Kosmodemianskaya N., Arutynyan A., Fortin C. (2022) University 3.0: A Portfolio Approach to the Technology R&D Management. *Foresight and STI Governance*, 16(2), 15–30. DOI: 10.17323/2500-2597.2022.2.15.30

## Changing Roles of Universities in Society

Most universities engage in a combination of basic and applied research. According to the definition of basic research, this is "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable tasks, without any particular application or use in view" (OECD, 2002). Essentially, basic research is research undertaken with the primary purpose of the advancement of knowledge (Bentley et al, 2015). The main difference in the definition of applied research is that it addresses primarily a specific practical aim or objective, usually focusing on solving a particular problem.

There is almost thirty years of debate about the role of universities as the primary source of research. In the late 1990s and early 2000s, the concept of university research turned increasingly toward industrial problem-solving and practical applications emerged. Gibbons et al. (1994) suggested that disinterested and research focused on basic principles by universities could not be considered a primary source of knowledge production (stated as Mode 1 of knowledge production). Increased direct interactions between universities and industry, so-called "Mode 2 knowledge production system," is described by Gibbons et al. (1994) as a new type of social contract. Further, it is said deeper involvement of universities in solving applied problems (Slaughter, Leslie, 1997) is needed. According to the Mode 2 model, universities will not be the only source of knowledge as others, i.e., research institutes, hospitals, think tanks, and so on will contribute as well (Tijssen, Winnink, 2016). Etzkowitz and Leydesdorff suggest a triple helix model of university-industry-state relationships that shape national innovation systems (Etzkowitz, Leydesdorff, 2000). According to this model, university systems are able to play an enhanced role in innovation development contributing to national economic growth. As authors state, this concept was different from earlier approaches of national systems of innovation (Lundvall, 1988; Nelson,1993) under which the industrial company, or the firm, is leading innovation. They stipulate that dynamic relationships between the three elements of the helix indicate the unique role of the universities as core knowledge institutions. Comparing three possible models of the triple helix interaction (state-dominated – Triple Helix I, "laissez-faire" relationship – Triple Helix II), they proclaim it is the third model, that is supposedly the best fit for knowledge-based economics (Triple Helix III). The common objective is to realize an innovative environment consisting of university spin-off firms, trilateral initiatives for knowledge-based economic development, and strategic alliances among firms (large and small, operating in different areas, and with different levels of technology), government laboratories, and academic research groups. These arrangements are often encouraged, but not controlled, by government, whether through new "rules of the game," direct or indirect financial assistance (Etzkowitz, Leydesdorff, 2000).

Responding to the change in roles of universities as "innovation machines" (Xu et al. 2018; Rücker Schaeffer et al., 2018), universities globally underwent a transformation from pure teaching into organizations that combine teaching and research including a strong component of solution-driven research.

Crawley et al. (2020) distinguish between "the curiosity-driven research when scholars are motivated by interesting problems at the frontiers of knowledge, which may or may not be immediately relevant to existing societal or industry issues" (Type 1 research), the "use-inspired research" motivated by the problems of industry or society (Type 2 research), and the research which aims for "directly implementable solutions to larger scale problems of industry, enterprise, government, and society" (Type 3). Curiosity-driven research and use-inspired research are more fundamental by nature, while the solutions-oriented research is usually conducted in the interests of university partners (industry, government).

Considering these trends, academia is increasingly finding itself engaged in solutions-oriented research also known as practical application, industry-funded research (Tijssen, Winnink, 2016), which corresponds to the Triple Helix III model (Etzkowitz, Leydesdorff, 2000). Thus, it is important to find the right balance between basic and applied research in academia.

Bentley et al. (2015) conducted a comprehensive analysis of individuals (more than 10,000 surveyed) from 15 countries mapping differences in focus on basic (fundamental) and applied (practical) research. There were noteworthy country differences in the balance between basic and applied research, i.e., Australian, US and Hong Kong researchers were more likely to specialize in applied research, while Scandinavian (Finnish, Norwegian) and Dutch researchers lean toward basic. The authors note that such differences might be attributed "to specifics of academic governance systems with a stronger academic oligarchy protecting the place of basic research compared to market-driven systems" however noting, that "this was not consistent with results in all countries" (Bentley et al., 2015, p. 704). Another reason for country differences are "institutional norms emphasizing research commercialization" which are, for instance, traditionally weaker for Latin American universities. However, Bentley et al. cautiously note that cross-country results are difficult to explain and "should be treated with caution due to the limitations of the data."

China and Malaysia were identified as unique cases since their research traditions were rapidly evolving. Chinese universities prior to the 1980s were predominantly focused on teaching and later the government encouraged basic research capabilities; at the same time, Chinese researchers are traditionally eager to respond to applied research demands given professional obligation norms to solve society's problems (Mohrman, Baker, 2008). They concluded that "engagement in basic and applied research clearly has strong country-level features" (Bentley et al., 2015). Interestingly, it revealed that most researchers tend to engage in a combination of basic and applied research while researchers specializing in basic research tend to receive *less* external funding. Obviously, the balance between basic and applied research varies from discipline to discipline.

Increasingly universities are not viewed as only centers for teaching and research but also as entities responsible for the economic development of the society (Grover, 2019; Crawley et al., 2020) which has recently sparked their entrepreneurial activity (Schubert, Kroll, 2016). Governments envisage a broader view of the universities playing a key role in modern economies, i.e., contributing to social progress and the common good, enhancing social mobility, and producing talented graduates, discoveries, and creations:

> Government officials… seek stronger engagement of universities with society. They want universities to pay closer attention to society's needs, to become more involved, and better contribute to solutions. They believe that if universities engage with the users of knowledge, the outcomes will be more valuable goods, services, and systems, as well as stable and rewarding jobs (Crawley et al., 2020).

Research shows that the impact of leading universities on the economy can be tremendous. Goldstein and Renault (2004) provided a methodology describing how universities contribute to regional development. Typically, the contribution of a university to a regional economy is provided in a number of ways: i.e., research, technology development and knowledge transfers, and job creation through startups and spin-offs. However, it is still a challenge to quantify the magnitude of such contributions. We can roughly estimate it by calculating the core impacts (direct spending of university itself and its staff) and commercialization effects (startups created, the value of technology transferred to industry through direct contracts and/or technology licensing). For instance, Roberts et al. (2019) conducted a study of MIT's entrepreneurship and innovation impact on the US economy. They estimated that over the period of study (1950-2014), MIT alumni have launched more than 30,000 active companies, employing roughly 4.6 million people, and generating roughly $1.9 trillion in annual revenues, the equivalent of the 10th largest global economy by GDP in 2015.

Thus, "leading universities have an outsized economic impact on their city or region: through spun-off research; as a magnet to attract both students and an educated workforce; and as a direct employer" (EIU, 2020). Long-term contributions of universities to economic development strongly depend on the level of knowledge exchange between the partners, including industry and government (Crawley et al., 2020).

## University Funding: A Change in the Funding Paradigm

However, the transition of universities' role and mission from teaching and research toward a more developmental role in society presupposes an inevitable shift in funding paradigms. Although public funding is still the predominant source of funding for university research, some recent studies suggest that public funding of universities is declining while industrial funding and other forms of public-private funding are growing. According to a Council on Foreign Relations report (USA), "despite its importance to the nation's innovation base, federal spending on research and development as a percentage of the overall economy has declined since the mid-1980s, from 1.2 percent of GDP in 1985 to 0.66 percent in 2016" (Manyika et al., 2019). In 2015, for the first time in US history, private sector R&D spending prevailed over the public funding (Mervis, 2017). In Russia, by contrast, government spending on scientific research has been modestly growing in absolute funding in 2015-2019 reaching 1,134 trillion rubles. However, R&D spending in terms of it as a percentage of GDP has not been able to exceed 1.11% over the last ten years, and even slightly declined in 2018-2019 ranging between 0.98% and1.03%. Contrary to the US and Western European countries which boast the dominance of private funding in R&D, in Russia the government's share of R&D funding is estimated in the range of 60% to 70%. Continuous tightening of funding conditions put pressure on the universities to engage more in international collaborations to become more cost-effective as well as to seek more non-governmental sources of funding.

Funding models for universities are typically classified by source of funding into internal (government core funding) and external (public or private funding not part of the core funds – i.e., project-based funding or grants by public funding agencies) (Irvine et al, 1990). It is recognized that core funding may increase stability in the university system by covering the salaries of permanent faculty members for research and teaching and basic infrastructure. University systems relying more on external funding are typically prone to more volatility compared with systems based on core funding. However, externally funded universities have more flexibility for new initiatives while universities with predominantly government core funding are potentially less dynamic (Geuna, Martin, 2003).

There is still no clear evidence whether a mixed funding model for a university accounts for more productivity within the university system. For instance, Auranen and Nieminen (2010) studied whether there is a connection between funding models and established financial incentives on the one hand and the efficiency of university systems on the other. They compared funding systems in seven European countries (Denmark, Finland, Germany, the Netherlands, Norway, Sweden, and the UK) and Australia concluding that although there are significant differences in the competitiveness of funding systems in these countries, there is no straightforward connection between financial incentives and a boost in publication productivity. However, Gulbrandsen and Smeby (2005) claimed that there is a significant relationship between industry funding and research performance. By questioning all tenured faculty in Norway, they found that faculty with industrial funding are involved in applied projects to a greater extent, tend to be more collaborative ("a highly collaborative mode of research") with other research institutions and international partners, produce more scientific publications, and, interestingly, generate more entrepreneurial output (consulting work, creation of spin-off companies, patent production, etc.) (Gulbrandsen, Smeby, 2005).

Over time, expenses in operating budgets have increased at a more rapid rate than sources of funding at many colleges and universities all over the world and these institutions are finding themselves in a difficult financial situation (Drucker, 1997; Selingo, 2013; Lyken-Segosebe, Shepherd, 2013). As a response to these financial issues, colleges and universities are investing significantly in market-driven academic programs (Seers, 2007; Altbach, Knight, 2007; McDonald, 2007; Hemsley-Brown, Oplatka, 2010). These programs leverage academic research in a variety of disciplines as well as leading practices from industry to prepare students to address opportunities and challenges that exist in these areas of focus. Market-driven academic programs that address market gaps and needs for employee development of specialized skills, knowledge, and capabilities have the potential to not only impact society in a positive way, they can also play a key role in addressing the financial challenges of the colleges and universities who effectively address these market needs.

## Hypothesis: Universities with a Balanced Portfolio of Research Projects are Able to Leverage Funding

University funding is typically a scarce resource and the question of the allocation of resources is a vital one. The question of scarce resource allocation between various research domains becomes particularly important.

There have been numerous studies in resource allocation in the academic environment (Kotler, Fox, 1985; Dolence, Norris, 1994; Wells, Wells, 2011). Some research projects tried to assess academic educational programs via a business toolkit using product portfolio models. The most recognized product portfolio models are probably the General Electric (GE) McKinsey model and the Growth Share Matrix by the Boston Consulting Group, BCG. Although product portfolio models have been successfully used as tools for strategic analysis for many decades already, their application is not quite widespread in the academic context.

One of such applications is an approach by Wells and Wells (2011) who proposed an Academic Program Portfolio model (APPM) essentially based on a customized GE McKinsey Product Portfolio model. The application of this model is widely used by industrial consultants and extensively described, for instance, in (Yip, 1981). The APPM approach has a number of advantages since it has only two dimensions (educational program attractiveness, institution competitive capabilities) which is easy to understand and measure. The researchers suggest that academic administrators should integrate APPM into the university strategic analysis and planning mechanism. As the authors claim, a potentially fruitful idea might be to build a university product portfolio based on APPM.

In a recent study Burgher and Hamers (Burgher, Hamers, 2020) proposed a quantitative model that can be used for decision support for planning and optimizing the composition of academic program portfolios in higher education. The model provides five-year horizon planning and was tested on the data of a leading US private university (not disclosed). A portfolio of six master programs was evaluated over the period of 2011-2015 with some 800 students involved. The objective of the model was to maximize cumulative financial surplus for the planning period. The application of the model suggested modifying three original programs, canceling one program, and adding three programs each consecutive year over the next three years of the planning cycle. The authors concluded that a portfolio approach might be useful for achieving enhanced financial returns on academic products (in particular, market-oriented educational programs). Overall, this research is useful in providing not only a qualitative but also a quantitative approach to decision-making for the management of a university striving to create additional capacity and impact.

The research conducted by Arman (2019) introduced a case study of the Kuwait Institute of Scientific Research (KISR), describing the concept of the Portfolio Evaluation Matrix (PEM) to allocate limited resources across a set of strategic research initiatives of KISR. The PEM represents a bubble chart with "a two-dimensional matrix consisting of two criteria: a potential impact that the solution may have in the next five years and the ability of the current program team to deliver what is being promised" (Arman 2019, p.154). The axes on a scale from 1 to 10 reflect an internal assessment of each project by the staff of KISR. The size of bubbles represents the anticipated revenue stream from the R&D projects. He argues that introduction of this tool has helped the research center at KISR become more focused on aligning its R&D portfolio with long-term goals. However, this model is mainly a forward-looking approach based on a subjective evaluation of R&D outcomes.

We find the idea of viewing a university through the lens of a **portfolio** theory a worthy approach to explore. Crawley et al. (2020) insist that "research groups and universities would do well to have a balanced portfolio of these approaches. This balance will create knowledge outcomes that will influence economic development in the near-, mid-, and long term." This is an important implication for viewing a university from an R&D portfolio perspective.

The practice of R&D portfolio management has been extensively practiced by leading technology businesses over the last 30 years already. As Cooper states, "portfolio management is a critical topic because it integrates a number of key decision areas, all of which are problematic: project selection and prioritization, resource allocation across projects, and implementation of the … strategy" (Cooper et al., 1998). We hypothesize that *a university can be viewed from the perspective of a portfolio of R&D projects ofvarying maturity and timelines*. The management of a university has to make decisions for allocating scarce funding to a limited number of R&D programs in various technology areas and with varying levels of maturity. The goal of our research is to test this hypothesis using the Skolkovo Institute of Science and Technology (Skoltech) as a case study.

We draw from the modern investment portfolio theory founded by American economist Harry Markovitz. Markovitz laid the groundwork of investment portfolio selection theory. Markovitz was awarded a Nobel Prize for his contribution to economic sciences in 1990. His valuable addition to the investment field was the introduction of the portfolio diversification concept, which allows for the lowering of overall investment portfolio risk when properly selecting non-correlating individual investment assets (Mangram, 2013).

We suggest applying a similar approach to the research management of a university, assuming that it can viewed as a portfolio of R&D technologies in diverse scientific areas and at various stages of technological maturity. Therefore, the *goal* of our research is to develop a simple and useful methodology to assess the R&D portfolio of a modern technology university to lower R&D risks while maximizing its potential.

In order to achieve this goal, we have to provide:

1) An assessment of the of R&D technology portfolio balance in terms of fundamental (basic) and applied research in diverse scientific areas and at various stages of technological maturity;

2) A performance assessment of each research area (Target Domain) by differentiating between the leading performers, average performers, and laggards (low performers);

3) Regular monitoring of progress in each research area over time in terms of both scientific impact (i.e., publications) and value generation (i.e., external funds attracted).

Thus, we claim that a modern university needs to:

1) diversify its research technology portfolio by having both *basic* (fundamental) and *applied* research;
2) diversify its technology portfolio across *various fields of science* that are not correlated with one another;
3) develop a balanced technology portfolio consisting of technological projects and competencies at *different stages of market maturity* (some of them might be benchmarked by a famous "technology hype curve" used by Gartner[1]);
4) find the right *balance along the R&D project horizon* (i.e., short and long-term projects);
5) carry out *regular audits of its technology portfolio* (at least once in 2-3 years) in order to reassess and optimize the R&D portfolio
6) balance its research portfolio with educational programs aiming to optimize its benefits for society.

We test our hypothesis by analyzing the case of the Skolkovo Institute of Science and Technology (Skoltech), a newly established technological university.

## Skolkovo Institute of Science and Technology: A Brief Overview

It was decided to test the proposed hypothesis using the Skolkovo Institute of Science and Technology (Skoltech) and its five years of activity as a case study. The Skolkovo Institute of Science and Technology (Skoltech) was founded in 2011 by the Russian government in partnership with the Massachusetts Institute of Technology with the vision of creating a world-leading academic institute of science and technology. Skoltech is performing cutting-edge basic and applied research in priority areas, promoting innovation and entrepreneurial activity while educating future specialists in science, technology, and business. In 2019, Skoltech was included in the top-100 Nature Index Young Universities ranking[2].

The total grants and contracts portfolio for 2016–2020 exceeds RUB 5.72b or USD 7.74m (at the rate of the Central Bank on December 31, 2020) corresponding to approximately RUB 13m or USD 0.17m (at the rate

[1] https://www.gartner.com/en/research/methodologies/gartner-hype-cycle, accessed 19.05.2022.
[2] https://www.natureindex.com/supplements/nature-index-2019-young-universities, accessed 19.05.2022.

of the Central Bank on December 31, 2020) *per faculty member* in 2020. More than 116 startups have been founded by Skoltech faculty, students, and alumni between 2011 and 2021.

An interesting question remains about the potential effects of Skoltech on regional economic development. According to some internal assessments conducted recently, such contribution might be tow to three times the amount of state funding of Skoltech, reaching as much as RUR 15-18 billion in 2020.

Skoltech research is closely linked with its educational and innovation activities. The combination of these activities contribute to Skoltech's Target Domains, which are broad scientific areas in which research, education, and innovation activities are concentrated. For now, there are seven key Target Domains contributing to Skoltech's mission by implementing long-term programs on academic and technology excellence in priority areas of science and technology development:

- Data Science & Artificial intelligence
- Life Sciences & Health
- Cutting-edge Engineering & Advanced Materials
- Energy Efficiency
- Photonics & Quantum Technologies
- Oil & Gas
- Advanced Studies (theoretical mathematics & physics)

A Target Domain is a lever for academic and technology excellence. Target Domain Programs are subject to a regular international expert review to assess achieved results, their relevance to strategic goals, and elaborate recommendations on improving activities.

Each Domain represents a combination of basic and applied research. However, some of Domains are more focused on applied research and collaboration with industry, i.e., Data Science & Artificial intelligence, Oil & Gas, and Cutting-edge Engineering & Advanced Materials. Meanwhile Life Sciences & Health, Energy Efficiency, and Photonics & Quantum Technologies represent a combination of applied and basic research with fundamental research prevailing. Domain Advanced Studies (theoretical math & physics), perform purely basic research.

As per our estimations, Skoltech's "curiosity-driven research" (Type 1 research) accounts for 50%-55% of total research funding (internal and external) while the "use-inspired research" (Type 2 research) has a share of 12%-15%, and the rest (30%-40%) should be attributed to "directly implementable research" (Type 3 research).

Considering the university as a portfolio of Target Domains, there is an opportunity to update the research priorities in a flexible manner, to conduct cutting-age research as well as to move into new emerging research areas.

## Methodology

In the study, we examine the distribution of research publication output and attracted external funding output across the Institute's Target Domains.

Both publications and funding can be classified as basic (fundamental) or applied, although in some cases such classification can be rather tricky. Therefore, in this study for simplicity reasons we assume that the applied research is

(1) *research which is either supported by an industrial company* or

(2) *the results of the research that are likely to be commercialized within the two to three years.*

If research does not match any of these criteria, it is considered fundamental (basic) research.

There are certain exceptions to this rule, i.e., companies with long-term research timelines that are eager to fund even basic research in some areas of high interest and priority to them (i.e., quantum technology, new math methods, etc.), however such cases represent exceptions of the rule. Thus, our study revealed less than ten projects with industrial partners out of more than 850 projects analyzed that can be classified as fundamental research (with results that are potentially applicable for industrial use on a horizon of more than five years).

Research publications include faculty publications affiliated with Skoltech. The analyzed publications are indexed in Web of Science (WoS) and Scopus and published in high impact factor journals (mostly Q1 and Q2). The indicator "Research Publications" is used as a measure of academic excellence in cutting-edge basic and applied research.

The indicator "External attracted funding" defines funds attracted from different external funding sources in the form of R&D funding from governmental, non-governmental and industrial sources, professional education, advisory services, services of shared facilities, and technology licensing. The indicator "External attracted funding" consists of two types of funding - basic and applied attracted funding. Basic attracted funding is funding supporting fundamental R&D activities. It is typically provided by either Skoltech's internal sources or national and international funding agencies and foundations (i.e., the Russian Science Foundation) to support curiosity-driven research and use-inspired research.

Applied research funding is based on directly implementable industry-oriented research funded by national and international industrial players (large corporates or midsized high-tech companies) as well as research and innovation agencies (i..e., Foundation for Assistance to Small Innovative Enterprises, FASIE in Russia), the Russian National Technology Initiative, the Ministry of Education, or the Ministry of Industry and Trade of Russia through specially designed mechanisms to support applied R&D.

The analyzed projects vary from short-term (1-2 years projects) to large-scale, long-terms projects (3-4 years) including joint laboratories with industrial partners for multi-year research programs.

The quantitative and qualitative methods as well as comparative analysis were used in the study to make the analytical process more profound and broader. Our analytical framework is based on data from 2016 through 2020 for the Skoltech's Target Domains. We assume that the information from this subset is fairly representative for an in-depth analysis.

In order to analyze the research publication output of each Target Domain, we grouped publication data for 2016-2020 by each Target Domain per year. We used the same approach for analyzing external funding output for each target Domain. To make the study more accurate, we analyzed the funding output for each type of funding separately, in particular, for basic and applied.

The qualitative analysis has been made to identify the progress and achievements in each Target Domain. The following data have been analyzed and classified:

1) More than 2,500 papers in WoS and Scopus in 2016–2020 cited more than 32,000 times. A substantial part of papers were written in partnership with international and national universities and centers. Top international collaborators include CNRS (163), MIT (140 papers), papers), Aalto University (88 papers), Harvard University (66 papers), RIKEN (55 papers), Chinese Academy of Sciences (53 papers), NWPU Xian (50 papers), Stony Brook (46 papers).

2) More than 850 projects with funding totaling RUB 5.7 billion (USD 88.5m dollars) for 2016-2020 were analyzed including projects supported by national and international funding agencies and foundations (Russian Foundation of Basic Research, Russian Science Foundation, Horizon2020), national research and innovation agencies (Ministry of Science and Higher Education of the Russian Federation, Russian Government Programs, e.g., the National Technology Initiative and the Digital Economy), and leading national and international companies (Sberbank, Huawei, Gazprom Neft, Philips, Lukoil, Bayer, Alibaba, etc).

In summary, we introduce sboth quantitative and qualitative models that should provide support in selecting the composition of project portfolios with a goal to achieve the planned financial and non-financial objectives of the institute or university.

## Results

In this section we present the results of our approach. We analyzed the previous four years of Skoltech development (2016-2020) by comparing achievements of Skoltech's key Target Domains in terms of

1) publications in quality scientific journals (Q1-Q2);

2) attracted external funding (both grants and industrial funding);

We further decompose investments and results by top areas of Skoltech expertise: i.e., Data Science & Artificial Intelligence, Life Sciences & Health, Cutting-edge Engineering & Advanced Materials, Energy Efficiency, Photonics & Quantum Technologies, Oil & Gas, and Advanced Studies (theoretical math & physics). Mapping the results against investments in these areas provides a clear picture of the university portfolio structure (see *Figure 1*) and insights into optimal strategy for future development.

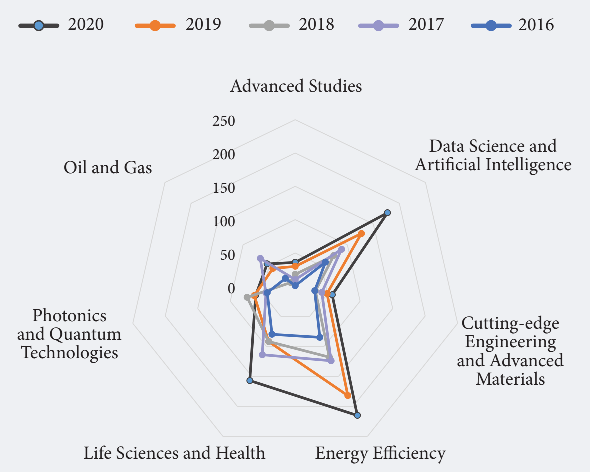
Skoltech's scientists have published mostly in the spheres of Data Science & Artificial Intelligence and Energy Efficiency, which prevail over other fields. The least amount of publications were noted in the Domain of Advanced Studies (theoretical math & physics) and amounted to 36, this field was established only recently (2017). Three Target Domains - Data Science & Artificial Intelligence, Energy Efficiency as well as Life Sciences account for most of the publications. Taking into consideration that Skoltech is a relatively young university starting its operations in 2011, this steady increase demonstrates the growing research activity of Skoltech faculty.

At Skoltech, applied research plays an important role in the university's everyday activities. Figure 2 shows that there has been a considerable increase in attracted applied research funding from 2016 to 2020. The most industry-oriented spheres in Skoltech are Data Science& Artificial Intelligence and Oil & Gas. The Domain of Advanced Studies (theoretical math & physics) has attracted zero industrial funding due to the nature of the Domain. Also, the least applied research funding was attracted by Life Sciences. The same phenomenon is detected in the sphere of Photonics and Quantum Material, where the most successful year from that point of view was 2019. In general, the diagram shows that each year there is steady increase in attracted external applied research funding almost in all spheres.

As shown in Figure 3, attracted basic research funding grows annually. Most grants in 2020 were received by Data Science & AI and Energy Efficiency. The Domain of Advanced Studies (theoretical math & physics ) at Skoltech is exclusively grant-oriented, since it performs only basic research. The other Domains – i.e., Oil & Gas and Cutting edge Engineering – are predictably more focused on applied research and less on basic research.

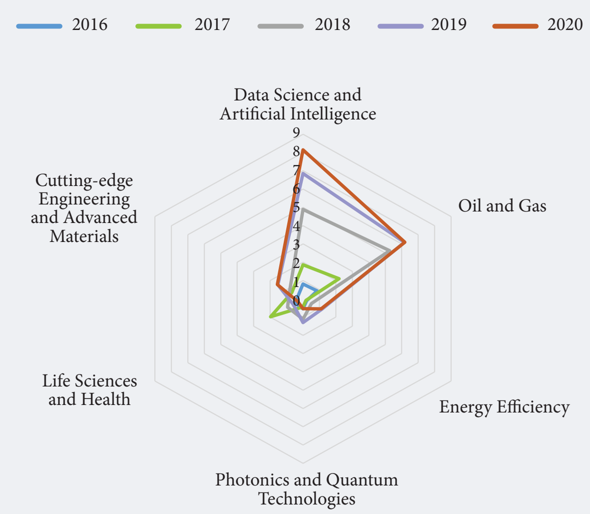
From the point of view of publications and attracted external funding, the most balanced sphere is Data Science & AI with a good quantity of publications and attracted external funding (Figures 4 and 5). The Oil & Gas Target Domain is definitely the most industry-oriented sphere, with rather few publications. Energy Efficiency has a considerable number of publications but less external funding. External funding for Data Science & AI as well as Oil & Gas has grown drastically over the period of 2016-2020.

Figure 1. **Publications of Skoltech 2016-2020 according to Target Domains**




*Source:* Composed by the authors on the basis of Skoltech Annual Reports. https://www.skoltech.ru/en/about/annual-reports/, accessed 14.11.2021.

Figure 2. **Attracted Funding – Applied Research 2016-2020 as per Target Domains, USD mln**




*Source:* Composed by the authors on the basis of Skoltech Annual Reports.

From 2016 to 2020, these two areas have become much more industry-oriented. The changes that took place from 2019-2020 are shown in the Figure 5. Energy Efficiency clearly grew in both directions – publications and external funding, becoming comparably more balanced. Oil & Gas increased its publications. Life Sciences and Photonics and Quantum Materials slightly decreased their publication activities but augmented attracted funding. Data Science &AI and Engineering & Advanced Materials show similar pattern dynamics, but on a much different scale.

## Discussion

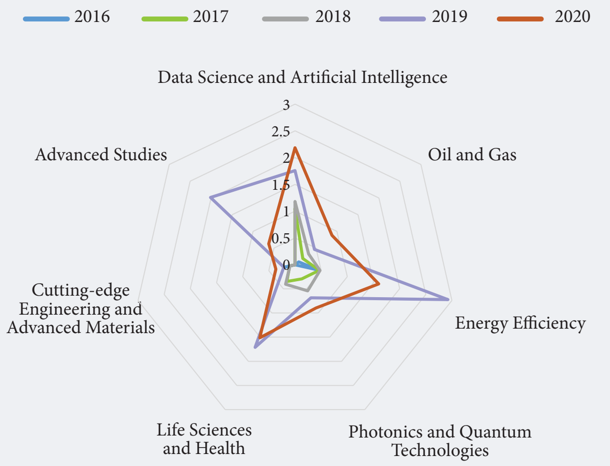
Some early research in the Academic Portfolio Model includes (Kotler, Fox, 1985) who proposed the Academic Portfolio Model for the strategic analysis of a university's academic programs. They mapped three dimensions for assessment of an academic portfolio strategy: (1) how central is the academic program to the university's mission; (2) academic quality of the program (program depth, rigor and faculty quality); (3) the market demand for the program.

Wells and Wells (2011) proposed the Academic Program Portfolio Model (APPM) for the strategic evaluation of university's academic programs adapted from the GE McKinsey Product Portfolio Model. The GE McKinsey Product Portfolio Model is based on the assessment of a company's products on two dimensions – industry attractiveness and competitive capabilities. The APPM approach proposes assessing university academic programs based on the following dimensions – Program Marketplace Attractiveness (industry attractiveness) and Program and Institution Capabilities (similar to competitive capabilities). The assessment criteria are selected and measured by a 1-5 score metric to be later mapped on the portfolio matrix. The analysis can be performed at the level of either interfaculty (comparison of faculty members of the university or its science domains) or within academic programs of a particular faculty (i.e., within Medical School programs). As Wells and Wells conclude, "the APPM, offers the opportunity to assess the strategic direction of specific academic programs relative to one another and relative to the institution… administrators simultaneously consider multiple academic programs relative to strategic direction, resource allocation, financial returns, and importance to the institution…" (2011, p. 11).

The research of (Wells, Wells, 2011) is mainly based on qualitative methods. However, a quantitative approach is of particular interest since it leads to a fact-based judgement when designing and promoting academic programs. (Labib et al, 2014) proposed a framework for the formulation of a higher education institutional (HEI) strategy based on an operational research (OR) methodology. Recently (Burgher, Hamers 2020) proposed a decision support tool based on a quantitative approach aimed at optimizing the composition of portfolios of market-driven academic programs.

Both the approach proposed in this paper and the approach introduced by (Burgher, Hamers, 2020) are focused on optimizing financial and non-financial dimensions of portfolios, i.e., the R&D Technology Portfolio and the Portfolio of Market-Driven Aca-

Figure 3. **Attracted Funding – Basic Research 2016-2020 as per Target Domains, USD mln**




*Source:* Composed by the authors on the basis of Skoltech Annual Reports.

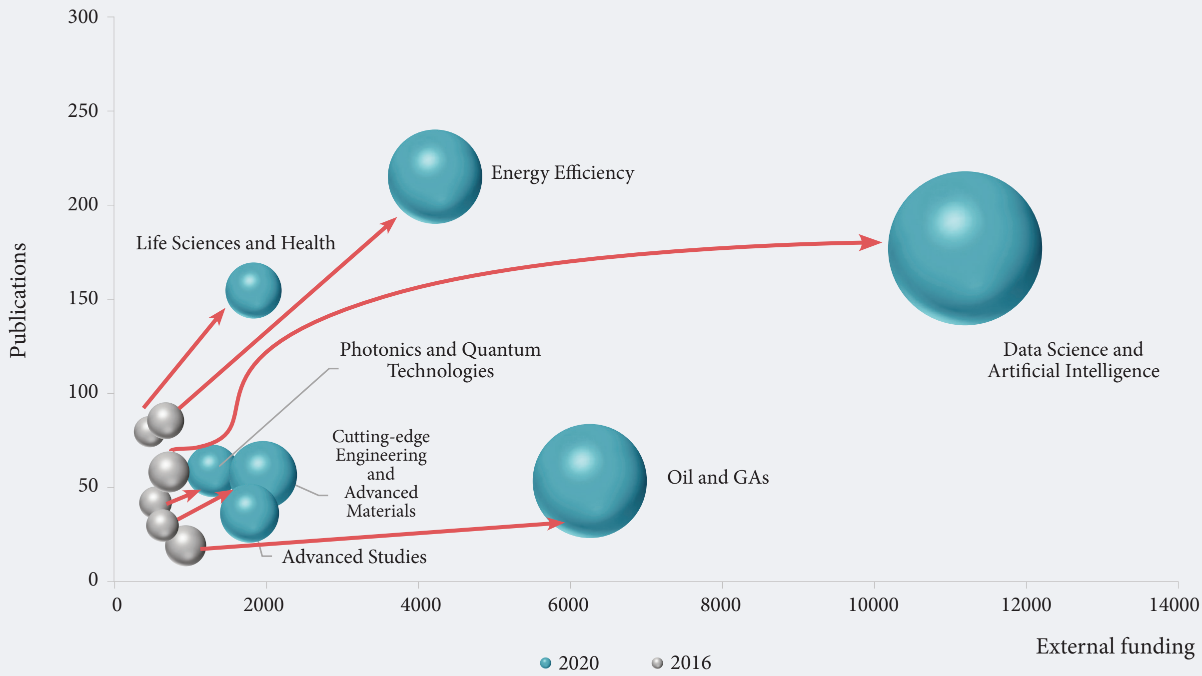
demic Programs. The main idea of both approaches is balancing financial and non-financial dimensions to achieve the desired impact of portfolios upon universities' strategic goals and their financial stability as well as market needs.

In their research (Burgher, Hamers, 2020) introduce methods of quantifying qualitative information related to market-driven program dimensions and developing the quantitative model for strategic planning in higher education for a portfolio's optimization. The output of the model is a program management schedule and development plan for the portfolio optimization process for the planning period.

Our approach – the Research Domain Portfolio Matrix (RDPM) - is different from the previous research in the following:

1) We incorporate both qualitative and quantitative approaches in our research. The quantitative angle is very useful in terms of fact-checking and benchmarking the university's strategy against financial return on allocated resources (as the trend for market-driven academic programs is growing due to financial constrains experienced by academia).

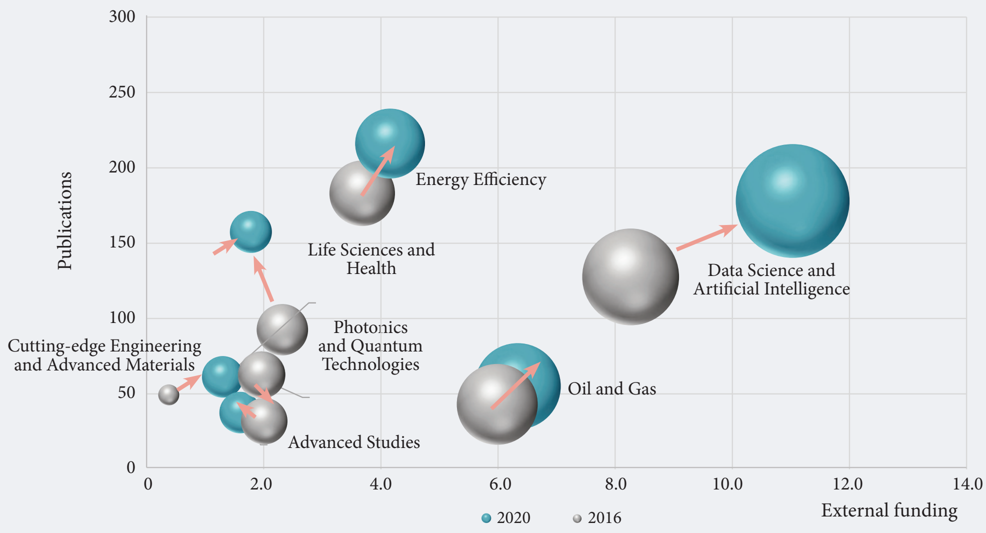
Figure 4. **The Evolution of Publications Activity and Research in 2016–2020 (USD mln)**




*Note:* Scientific impact is measured by publications in Q1-Q2 scientific journals (Y-axes, number of publications); external funding application is measured by attracted funding for both basic and applied research (X-axes, USD m).

*Source:* Composed by the authors on the basis of Skoltech Annual Reports.

Figure 5. **The Progress in Publication Activity and External Funding from 2018 to 20209 (USD mln)**




*Note:* Scientific impact is measured by publications in Q1-Q2 scientific journals (Y-axes; number of publications); external funding is measured by attracted funding for both basic and applied research (X-axes; USD mln); size of the bubble reflects amount of the total external funding. Yellow arrows indicate progress dynamics (change in positions from 2019 till 2020).

*Source:* Composed by the authors on the basis of Skoltech Annual Reports.

2) Our focus is on the finding a *right balance between the basic and applied research* since both dimensions are important and neither should be neglected.

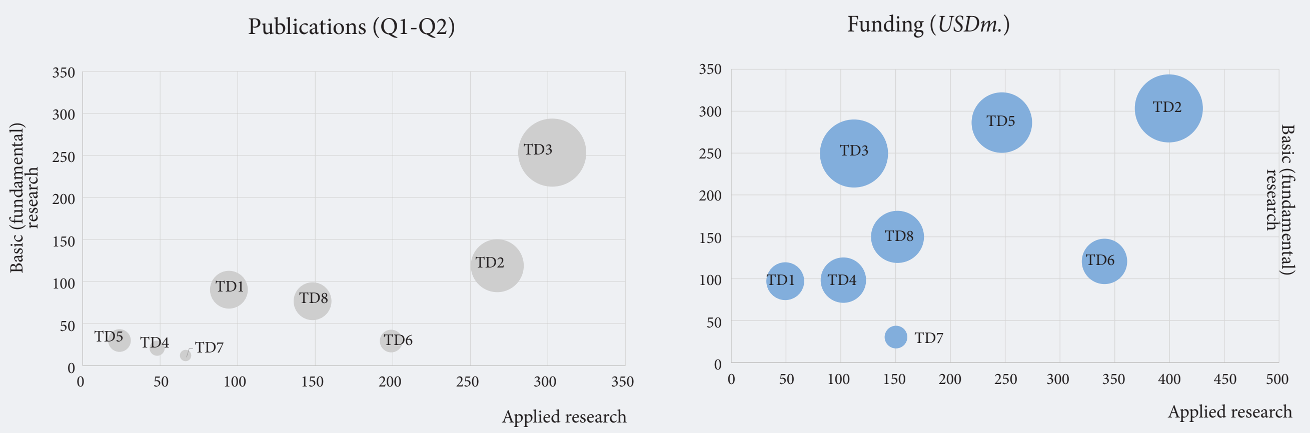
3) We suggest focusing more on the dynamics of research achievements (changes over time, i.e., Figures 4-5) rather than static measurements that are usually common for product portfolio matrixes (i.e., the approach by (Wells, Wells, 2011).

The RDPM approach maps key research areas (Target Domains) of a university according to their fundamental or applied nature. A university is treated as a portfolio of research projects. The X and Y axes of the matrix represent the level of fundamental and applied research measured by either produced publications or attracted funding (a hypothetical university research portfolio provided on Figures 6-7 for illustrative purposes). The proposed approach has been successfully used to classify more than 850 projects implemented by Skoltech over the period of 2016-2020.

The RDPM approach helps to provide a holistic view of the state of university research. Like a company balance sheet, it gives a snapshot of the current state of the research portfolio (its composition). It provides a good visualization of the top contributors across research domains to the university's scientific visibility and impact on the one hand, as well as its usefulness to industry and real-life applications. Additionally, RDPM viewed dynamically (i.e., across several years) is useful in tracking the progress of Target Domains and, therefore, providing more or less reliable estimates of 1) scientific return on investment (i.e., in the form of quality publications in Q1-Q2 journals) or 2) financial return on investment (funding from either government sponsored grants or industry sponsored research). The management of the university can "praise the winners" and "punish the laggards" by allocating the excess of internal funding to the areas with the highest scientific or industrial returns in the short- to mid-term (Figure 7). Thus, RPDM might be used as a simple and powerful tool to *rebalance research portfolio* by setting and modifying the priorities of current and future university research, which is naturally a topic of hot debate for university management given resource allocation constraints.

Overall, Skoltech maintained a good balance between basic and applied research. The judgement of whether the balance is "good" or "bad" is largely *at the discretion of the university's management*. Skoltech governance is based on the principles of collegiality. The strategy issues are overseen by the Board of Trustees. The Board of Trustees monitors Skoltech results on a regular basis (quarterly or semi-annually), reviews proposals for new initiatives of strategic importance, and approves the changes to Skoltech's overall strategy. However, Target Domains are managed by the respective centers where faculty are largely responsible for setting up directions for research. Periodically (no less than once in three years), the programs of the centers are audited by the International Advisory Committee providing valuable input on Skoltech's international scientific agenda. Most of the Target Domains also have Industrial Councils, comprised of representatives of the top management of leading Russian and international companies. Industrial

Figure 6. **Research Domain Portfolio Matrix Approach Maps Key Research Areas (Target Domains) of the Hypothetical University according to theirFundamental or Applied Nature**




*Note*: Considering University as a portfolio of research projects the X and Y axes of the matrix represent the level of fundamental and applied research measured by either produced publications or attracted funding.

*Source*: Composed by the authors on the basis of Skoltech Annual Reports.

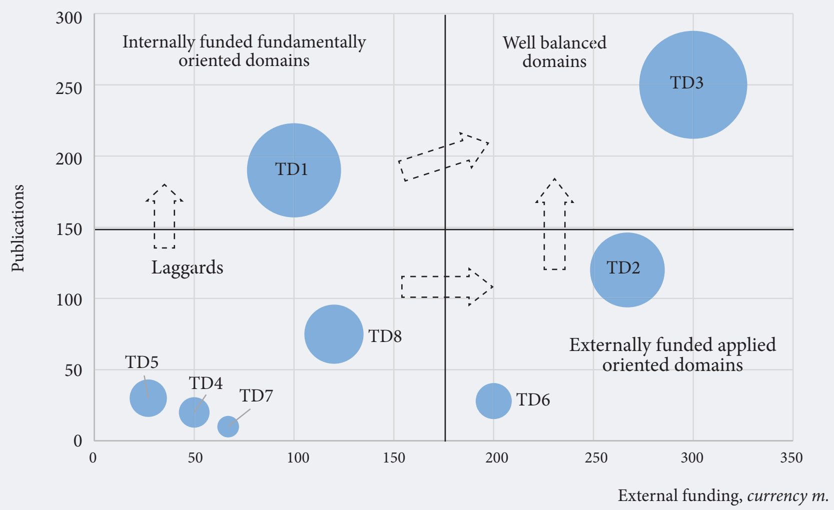
Councils together with the Industrial Programs Department under the Vice-President of Industrial Cooperation help set the direction of applied technology research.

In 2011, when the Skoltech was established, the Board of Trustees set up a rather ambitious target to get at least 30% of university funding from external sources (i.e., industrial funding or grants and subsidies from domestic or international science funding agencies) by 2020. This was included in the KPIs of Skoltech (in 2020, the share of external funding reached 29.6%[3]).

The effective allocation of resources to several Target Domains in the early years (2013-2016) – in particular, to applied areas such as Oil & Gas, Data Science & Artificial Intelligence helped to attract industrial funding and bring cutting-edge technologies to the market, while investments in Life Sciences & Health, Cutting-edge Engineering & Advanced Materials, Energy Efficiency, and Photonics & Quantum Technologies helped to gain early scientific visibility.

Some of the successful examples of Skoltech's basic research include, for instance, new methods of gene

Figure 7. **Research Domain Portfolio Matrix**




*Note*. Dashed arrows indicate a desired improvement trajectory for Target Domains

*Source*: Composed by the authors on the basis of Skoltech Annual Reports.

[3] https://www.skoltech.ru/app/data/uploads/2019/10/Skoltech-Annual-Report-2020.pdf, accessed 19.05.2022.

editing, a next generation of telecom technology (6G), prospective cathode materials with high energy density, research in photonics, new math methods, etc. Among the recent applied research projects are telecom software development (5G Open RAN), AI technology applications for various industrial and medical purposes, lightweight perforated honeycomb technology production from aluminum foil, and new technologies for exploration and production of hard-to-recover hydrocarbons. Some of these projects have been commercialized recently for the leading Russian companies, i.e., SberMed.AI (medical software), a space industry manufacturer (honeycomb technology), leading oil & gas companies, and others.

Taking into account these considerations and based on the conducted analysis of Skoltech performance in 2016-2020, we conclude that:

1. Successful applied research projects help to generate more external funding year-on-year, they attract new industrial partners, and bring cutting-edge technologies to the market. There is a positive feedback reinforcement loop when successful results of applied research are used to bring in even more partnerships and funding resulting in more future successes. We believe this positive feedback loop is an important engine of growth for academic universities especially in times of shrinking government support and limited funding for basic research.

2. Some Target Domains have made remarkable progress in both basic and applied research within the last several years while others have not shown rapid growth. We believe that the performance dynamics of each Target Domain over the past three to four years is a reliable indicator to consider some strategic decisions for administrators involving resource reallocation choices that are difficult in a resource-constrained environment.

3. A further investigation is needed to define whether there are any barriers for growth for Target Domains that have not demonstrated the expected progress.

Therefore, our RDPM approach suggests that portfolio analysis is quite helpful in facilitating a strategic discussion for the management of the university. It is a useful tool for seeing the "helicopter view" of university's achievements. Also, it can be helpful in facilitating a discussion about the strategic vision for research directions and resource allocation choices.

Figures 8-9 provide some insights into the potential strategic moves for each of Skoltech's Target Domains in the future (based on 2020 data).

A systemic representation of the typical self-reinforcing loops behind the university engine of growth is provided on Figure 10. Top international scientists attracted to the university generate high quality research that results in publications (Q1-Q2 journals) and advanced scientific projects. As the scientific reputation of the university improves, making it visible within the domestic and international arenas, it becomes easier for the university to attract industrial funding for applied projects. Industrial funding also contributes to quality publications and advanced projects that drive reputation further. Thus, strong self-reinforcing loops begin serving as growth accelerators for the university as it is the case with rapidly growing companies (i.e., Achi et al., 1995; Katalevsky, 2007).

## Conclusions

This paper adds to current theory and practice by developing the Research Domain Portfolio Matrix (RDPM) approach, which considers the university portfolio of R&D technologies in diverse scientific areas and at various stages of technological maturity. We claim that it is important for universities to find a balance between basic and applied research when making decisions on launching new projects and programs or when modifying existing projects and programs.

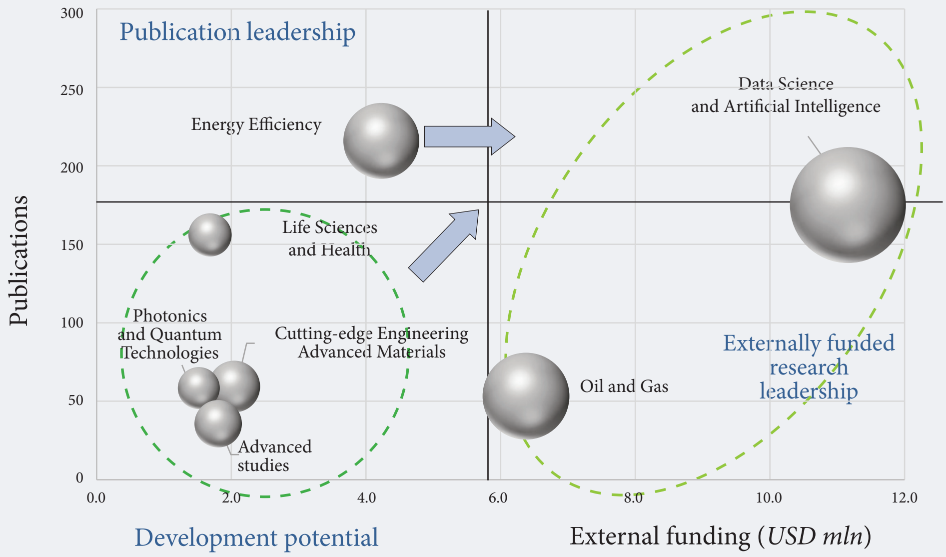
Proposing the RDPM approach to study a university's research portfolio, we conclude that an analysis of research indicators (publications in scientific journals, attracted external funding for basic and applied research) further decomposed by the specific areas of Target Domains helps to provide a clear picture of the university portfolio structure and insights into the optimal strategy for future development and investments. Unlike other approaches to R&D portfolio matrixes mentioned above, our approach is based on the assessment of real results achieved by each Target Domain whether in terms of academic excellence (publications) or industrial impact (proceeds from external funding, either basic or applied).

We analyzed key Target Domains of Skoltech research by publication activity and attracted external funding. Furthermore, we provided an assessment of Target Domains' progress in 2016-2020. This research helped us to arrive to several important conclusions.

First, the initial investments of Skoltech in relevant infrastructure and the hiring of internationally recognized faculty for the Oil & Gas and Data Science & Artificial Intelligence Domains have led to the development of strong industrial collaborations and the attraction of significant funding (2016-2020). These Target Domains currently have the greatest amount of support from industrial partners and continue to thrive even as internal funding from Skoltech is gradually diminishing due to new research areas being prioritized. Domestic and international businesses will likely support some future promising research in these Domains (i.e., various applications for Artificial Intelligence, 5G/6G technology, hydrocarbon recovery and modeling of fracking technologies for oil and gas extraction, the reduction of the carbon footprint, etc.) through long-term collaboration programs.

Second, some Target Domains (primarily Energy Efficiency, Life Sciences & Health, and Photonics &

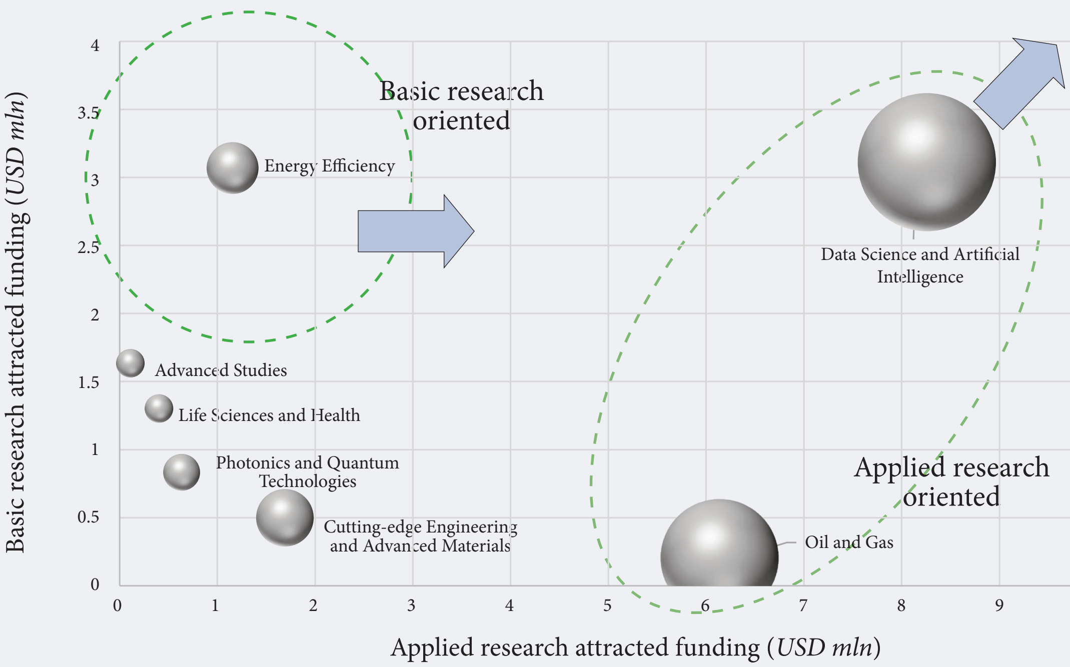
Figure 8. **Skoltech Target Domains: Strategic Future Directions (2020)**




*Note:* Scientific impact is measured by publications in Q1-Q2 scientific journals (Y-axes; number of publications); total external funding is measured by attracted funding for both basic and applied research (X-axes, USD mln); size of the bubble reflects amount of the total external funding; yellow arrows indicate potential strategic development directions.

*Source:* Composed by authors on the basis of Skoltech Annual Reports.

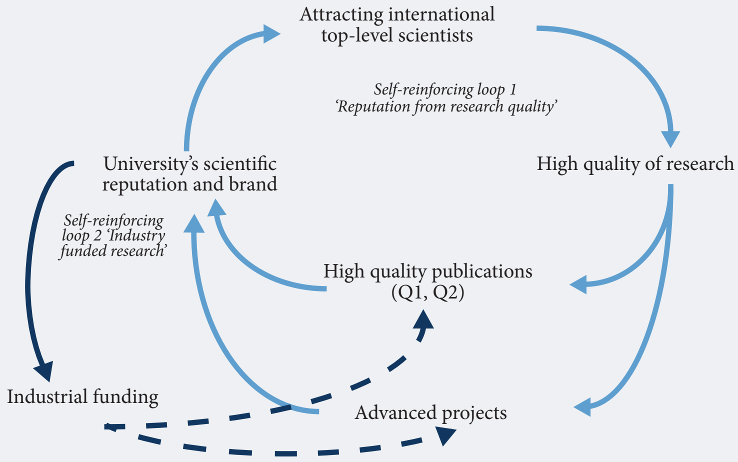
Figure 9. **Skoltech Target Domains: Basic vs Applied Research (2020)**




*Note:* Basic research attracted external funding (Y-axes; USD mln); applied research attracted funding X-axes, USD mln); size of the bubble reflects amount of the total external funding; yellow arrows indicate potential strategic development directions.

*Source:* Composed by authors on the basis of Skoltech Annual Reports.

Figure 10. **A Systemic Representation of the Self-reinforcing Loop of High Quality Research Driving Reputation and Helping to Attract Industrial Funding of the University**




*Source:* Composed by authors.

Quantum Technologies), represent a mixture of applied and basic research, with fundamental research prevailing. Although applied research funding levels achieved by Oil & Gas and Data Science have not been reached, these Domains were instrumental in generating a stream of quality publications. Their contributions have helped to gain valuable scientific visibility for Skoltech by 2020. Thus, in less than ten years since Skoltech was established, it was included in the top-100 Nature Index Young Universities ranking in 2019. Meanwhile, next steps should be aimed at including more industry oriented research on the agenda, i.e., quantum algorithms, THz and RF photonics, nanomaterials in the Photonics & Quantum Technology Domain, cathode materials, Li-ion batteries, conversion, and diversified energy systems in the Energy Efficiency Domain.

Third, some domains, i.e., Cutting-edge Engineering and Advanced Materials, still have to realize their potential. The same is true for the Advanced Studies Domain (theoretical math & physics), which will continue to be focused on basic research. Interestingly, Engineering can have a great impact on Skoltech since it can influence the innovation cycle of all technological domains. As shown in Figures 6 and 7, it is still in its infancy because it has been so far difficult to attract a critical mass of top engineering researchers in the fields of Product Development, Systems Engineering, and Digital Engineering, which are the key areas in Design and Systems Science, the core competency required for Cutting-edge Engineering.

Fourth, Skoltech is currently well positioned among peer technological universities in Russia being recognized as a leader in several research domains, i.e., artificial intelligence, energy storage materials, hydrocarbon extraction, and other areas. However, to sustain its position as the technology leader, it must continue attracting top international scientists to support new promising areas of basic and applied research. In addition, more efforts should be put into the early discovery of promising intellectual property from idea disclosure to active patenting of curiosity-driven research results. Thus, the RDPM portfolio matrix can be updated by using "IP/Patent application" as a vertical axis indicating the amount of IP generated over a certain period of time. When conducted, such an analysis will be able to suggest new ways for improvement.

Finally, we conclude that the proposed approach allows us to clearly formulate priorities in research development, support leaders, and decide which research directions need to be adjusted (Figure 9). The periodic adjustments to a Domain's development strategy is cause to audit a Domain's technology portfolio. We believe that the audit of a university R&D portfolio should happen at least once every three years.

To optimize funding allocation, it is important to consider the scientific area, market maturity of the technology, and the potential return for the university, economy, and society in the short- and long-term while balancing the impact of its educational programs. Investment portfolio theory provides valuable insights into how to optimize the allocation of funding (a scarce resource) in areas with the most promising risk-return profile. Further research is needed to identify the best risk-return strategies and produce mathematical models to be able to quantify the risk and payoffs of funding a particular scientific area.

It is planned that the next step should be the development of a general model for university R&D technology portfolios based on the RDPM approach. The current research is based on five years of activity at

Skoltech and we assume that the information from this subset is representative for an in-depth analysis. Meanwhile, the model should be further developed based on the analysis of case studies of different universities (both national and international) and their approaches to selecting and funding different types of R&D projects and programs. The mathematical model should include the decision alternatives, scientific domain specifics, constraints, among other elements.

It would be reasonable to investigate in further research the opportunity to rework Harry Markowitz's investment portfolio theory to apply to the area of university R&D technology portfolio management that will enable one to lower the R&D portfolio risk while maximizing its potential. A new toolbox needs to be created by further research referencing key terms suggested by investment portfolio theory.

The RDPM approach will help one leverage limited resources, establish priorities, monitor risks, and influence outcomes in the short- and long-term. Our approach might be useful for universities' leadership to facilitate strategic analysis and guide choices aimed at ensuring the desired impact of the R&D technology portfolio aligned with the universities' strategic goals, their financial stability, market needs, and potential impact on society.

*Dmitry Katalevsky supervised the work, designed the study and together with Natalia Kosmodemyanskaya developed the original idea, wrote the manuscript, performed analytical calculations and derived conclusions. Arut Arutyunyan assisted with preparation of data sets and graphic representation of information. Clement Fortin reviewed the paper and provided some useful insights.*

## References

Achi Z., Doman A., Sibony O., Sinha J., Witt S. (1995) The paradox of fast growth tigers. *The McKinsey Quarterly*, 3, 4–17.

Altbach P.G., Knight J. (2007) The Internationalization of Higher Education: Motivations and Realities. *Journal of Studies in International Education*, 11 (3–4), 290–305. https://doi.org/10.1177%2F1028315307303542

Arman H. (2019) A Practical Strategic Planning Approach for R&D Organisations. In: *R&D Management in the Knowledge Era. Innovation, Technology, and Knowledge Management* (eds. T. Daim, M. Dabić, N. Başoğlu, J. Lavoie, B. Galli), Cham: Springer, pp. 145–159. https://doi.org/10.1007/978-3-030-15409-7_5

Auranen O., Nieminen M. (2010) University research funding and publication performance — An international comparison. *Research Policy,* 39(6), 822–834. https://doi.org/10.1016/j.respol.2010.03.003

Bentley P., Gulbrandsen M., Kyvik S. (2015) The relationship between basic and applied research in universities. *Higher Education,* 70(4), 689–709. https://doi.org/10.1007/s10734-015-9861-2

Burgher J., Hamers H. (2020) A quantitative optimization framework for market-driven academic program portfolios. *International Journal of Educational Management*, 34(1), 1–17. https://doi.org/10.1108/IJEM-03-2018-0099

Cooper R.G., Edgett S.J., Kleinschmidt E.J. (1998) Best practices for managing R&D portfolios. *Research Technology Management*, 41(4), 20–33. https://www.jstor.org/stable/24131706

Crawley E., Hegarty J., Edström K., Garcia Sanchez J.C. (2020) *Universities as Engines of Economic Development*, Cham: Springer.

Dolence M.G., Norris D.M. (1994) Using Key Performance Indicators to Drive Strategic Decision Making. *New Directions for Institutional Research*, 82, 63–80. https://doi.org/10.3991/ijim.v13i04.10547

Drucker P. (1997) *Seeing things as they really are* (Interview with R. Lenzner & S.S. Johnson). *Forbes,* 03.10.1997. http://www.forbes.com/forbes/1997/0310/5905122a.html, accessed 15.02.2022.

EIU (2020) *New Schools of Thought. Innovative Models for Delivering Higher Education,* London, New York, Hong Kong: Economist Intelligence Unit.

Etzkowitz H., Leydesdorff L. (2000) The Dynamics of Innovation: From National Systems and "Mode 2" To a Triple Helix of University–Industry–Government Relations. *Research Policy,* 29(2), 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4

Geuna A., Martin B.R. (2003) University research evaluation and funding: An international comparison. *Minerva,* 41(4), 277–304. https://doi.org/10.1023/B:MINE.0000005155.70870.bd

Gibbons M., Limoges C., Nowotny H., Schwartzman S., Scott P., Trow M. (1994) *The new production of knowledge: The dynamics of science and research in contemporary societies,* London: Sage.

Goldstein H., Renault C. (2004) Contributions of universities to regional economic development: A quasi-experimental approach. *Regional Studies*, 38(7), 733–746. https://doi.org/10.1080/0034340042000265232

Grover R. (2019) The Relationship between Science and Technology and Evolution in Methods of Knowledge Production. *Indian Journal of History of Science,* 54(1). http://dx.doi.org/10.16943/ijhs/2019/v54i1/49597

Gulbrandsen M., Smeby J.-C. (2005) Industry funding and university professors' research performance. *Research Policy,* 34(6), 932–950. https://doi.org/10.1016/j.respol.2005.05.004

Hemsley-Brown J., Oplatka I. (2010) Market orientation in universities. *The International Journal of Educational Management*, 24(3), 204–220. https://doi.org/10.1108/09513541011031565

Irvine J., Martin B.R., Isard P.A. (1990) *Investing in the Future,* Cheltenham, UK: Edward Elgar.

Katalevsky D.Y. (2007) Management of organization growth based on a system-dynamic approach. *Moscow University Bulletin*, Series 21, 4, 64–79 (in Russian).

Kotler P., Fox K.F. (1985) *Strategic Marketing for Educational Institutions,* Englewood Cliffs, NJ: Prentice-Hall, Inc.

Labib A., Read M., Gladstone-Millar C., Tonge R., Smith D. (2014) Formulation of higher education institutional strategy using operational research approaches. *Studies in Higher Education,* 39(5), 885– 904. http://doi.org/10.1080/03075079.2012.754868

Lundvall B-Å. (1988) Innovation as an Interactive Process: From User-producer Interaction to the National System of Innovation. In: *Technical Change and Economic Theory* (eds. G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete), London, New York: Pinter, pp. 61–83.

Lyken-Segosebe D., Shepherd J.C. (2013) *Higher Education Leadership and Policy Studies Peabody College Of Education and Human Development*, Nashville, TN: Vanderbilt University.

Mangram M.E. (2013) A simplified perspective of the Markowitz portfolio theory. *Global Journal of Business Research*, 7(1), 59–70.

Manyika J., McRaven W.H., Segal A. (2019) *Innovation and National Security: Keeping Our Edge,* New York: Council on Foreign Relations.

McDonald R.E. (2007) An Investigation of Innovation in Nonprofit Organizations: The Role of Organizational Mission. *Nonprofit and Voluntary Sector Quarterly*, 36(2), 256–281. https://doi.org/10.1177%2F0899764006295996

Mervis J. (2017) Data Check: U.S. Government Share of Basic Research Funding Falls Below 50%. *Science*, March 9. DOI: 10.1126/science.aal0890

Mohrman K., Ma W., Baker D. (2008) The research university in transition: The emerging global model. *Higher Education Policy*, 21(1), 5–27. https://doi.org/10.1057/palgrave.hep.8300175

Nelson R.R. (1993) *National Innovation Systems: A Comparative Analysis,* New York, Oxford: Oxford University Press.

OECD (2002) *Frascati Manual Proposed Standard Practice for Surveys on Research and Experimental Development,* Paris: OECD.

Roberts E.B., Murray F., Kim J.D. (2019) Entrepreneurship and Innovation at MIT: Continuing Global Growth and Impact — An Updated Report. *Foundations and Trends in Entrepreneurship*, 15(1), 1–55. DOI: 10.1561/0300000093.

Rücker Schaeffer P., Fischer B., Queiroz S. (2018) Beyond Education: The Role of Research Universities in Innovation Ecosystems. *Foresight and STI Governance*, 12(2), 50–61. DOI: 10.17323/2500-2597.2018.2.50.61

Schubert T., Kroll H. (2016) Universities' effects on regional GDP and unemployment: The case of Germany. *Papers in Regional Science,* 95(3), 467–489. DOI: 10.1111/pirs.12150

Seers A. (2007) Management education in the emerging knowledge economy: Going beyond "those who can, do; those who can't, teach. *Academy of Management Learning and Education*, 6(4), 558–567. https://doi.org/10.5465/amle.2007.27694955

Selingo J. (2013) *College (Un)Bound: The Future of Higher Education and What It Means for Students,* Las Vegas, NV: Amazon Publishing.

Slaughter S., Leslie L.L. (1997) *Academic capitalism: Politics, policies, and the entrepreneurial university,* Baltimore: The Johns Hopkins University Press.

Tijssen R.J.W., Winnink J. (2016) Twenty-first century macro-trends in the institutional fabric of science: bibliometric monitoring and analysis. *Scientometrics*, 109, 2181–2194. https://doi.org/10.1007/s11192-016-2041-z

Wells R., Wells C. (2011) Academic program portfolio model for universities: Guiding strategic decisions and resource allocations. *Research in Higher Education Journal*, 11(1). https://www.aabri.com/manuscripts/11745.pdf, accessed 18.01.2021.

Xu G., Wu Y., Minshall T., Zhou Y. (2018) Exploring innovation ecosystems across science, technology, and business: A case of 3D printing in China. *Technological Forecasting and Social Change*, 136, 208–221. https://doi.org/10.1016/j.techfore.2017.06.030

Yip G.S. (1981) *Market Selection and Direction: Role of Product Portfolio Planning,* Boston: Harvard Business School Publishing.