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Developing Science and Technology Policies for High Risk-High Reward Research

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Abstract

High Risk-High Reward (HRHR) research refers to scientific research with high risk of failure but characterized by breakthrough, innovation and originality. It truly reflects the original innovation ability of science and technology, is committed to bringing major scientific discoveries and technological breakthroughs, and is conducive to accelerating the improvement of national competitiveness in original science and technology. The theoretical and methodological research in this area will help improve science and technology policies. On the basis of clarifying its development background, conceptual connotation and characteristics, this paper discusses the construction of a "decision-fundingimplementation" model of HRHR research and management system. By taking the HRHR projects of typical international scientific research institutions as case studies, it systematically analyzes, compares and summarizes the basic principles, review processes, advantages and disadvantages of representative academic review mechanisms such as peer-review model, project-manager model, and de-review model. Based on the innovation experience of foreign HRHR research projects, some suggestions are put forward:formulate HRHR research funding policies to promote original innovation; improve the academic review mechanism for selecting HRHR research; and create an excellent academic ecology that stimulates HRHR research development.

Keywords

High Risk-High Reward (HRHR); transformative innovation; original innovation; science funding; science and technology policy; academic review

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Developing Science and Technology Policies for High Risk-High Reward Research

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Abstract: High Risk-High Reward (HRHR) research refers to the scientific research with high risk of failure but characterized by breakthrough, innovation, and originality. It truly reflects the original innovation ability of science and technology, is committed to bringing major scientific discoveries and technological breakthroughs, and is conducive to accelerating the improvement of national competitiveness in science and technology. The theoretical and methodological research in this area will help improve science and technology policies. On the basis of clarifying its development background, conceptual connotation, and characteristics, this paper discusses the construction of a "decision-funding-execution" model of HRHR research management system. By taking the HRHR projects of typical international research institutions as case studies, it systematically analyzes, compares and summarizes the basic principles, review processes, advantages, and disadvantages of representative academic review mechanisms such as peer-review model, project-manager model, and de-review model. Based on the innovation experience of foreign HRHR research projects, some suggestions are put forward: formulating HRHR research funding policies to promote original innovation; improving the academic review mechanism for selecting HRHR research projects; and creating an excellent academic ecology that stimulates HRHR research development. **DOI:** 10.16418/j.issn.1000-3045.20220108001-en

Keywords: High Risk-High Reward (HRHR); transformative innovation; original innovation; science funding; science and technology policy; academic review

The transformation of science and technology (productivity), i.e., the new round of scientific and technological revolution and industrial transformation, is the accelerator and major variable of the profound changes unseen in a century [1]. Interdisciplinary integration and high-tech cluster development, as well as the COVID-19 pandemic, have accelerated scientific and technological innovation, with the speed of scientific and technological transformation far exceeding the expectation [2]. National competition and economic development urgently require major breakthroughs in science and technology, and the funding of research is the basic condition and effective guarantee to promote scientific innovation and technological breakthroughs. In recent years, there have been growing concerns in the scientific community that the funding system is too conservative. Such conservativeness may damage the long-term technological innovation and competitiveness of a country if the funding system does not encourage or support innovative research that risks failure but can bring about major breakthroughs [3]. The reasons for conservative research funding are summarized as follows. (1) Research funds are an important strategic part in a national financial expenditure, so the funding agencies are more willing to fund the research projects that are obviously expected to bring significant research returns in consideration of performance, which leads to a narrow living space for high-risk but potentially high-reward research. (2) The peer-review system in the academic community is dominant. However, due to the limitation of experts' knowledge range and consensus requirements, High Risk-High Reward (HRHR) research is difficult to obtain funding through peer review since its value cannot be accurately predicted [4,5]. (3) Project application is usually closely related to promotion and award of researchers, while this orientation makes researchers inclined to choose safe research projects that are progressive and prudent [6,7].

The transformation of productivity makes science and technology a core content of national comprehensive strength and competitive advantages, and the key to the competition in national science and technology innovation is the competition in science and technology system and policies among countries. To shape the future competitive advantages, major developed countries have sped up the forward-looking layout and exploration of HRHR research projects. For example, the National Institute of Health (NIH) of the United States has established a special HRHR research program to support highly innovative research by creative scientists. The OH Risque program of the French National Research Agency (ANR) aims to support exploratory research projects with high scientific risk and significant scientific, technological, and economic impact. The Transformative Research Technologies program of Tools and Resources Development Fund of the UK Research and Innovation (UKRI) explicitly

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supports pilot HRHR research. These examples reflect that developed countries and their scientific and technological strategies have attached importance to the research and development competition in basic frontier fields with great scientific reward value and high risk.

In the past 20 years, China has achieved great progress in science and technology, developing from following to paralleling and leading. We have attached great importance to groundbreaking innovation and transformative technologies, especially the improvement in original innovation capacity. Related concepts frequently appear in academic discussions and governmental documents. For example, the report of the 19th CPC National Congress has pointed out that we should aim for the frontiers of science and technology, strengthen basic research, and make major breakthroughs in pioneering basic research and groundbreaking and original innovations. At the 20th Conference of Academicians of the Chinese Academy of Sciences, the 15th Conference of Academicians of the Chinese Academy of Engineering, and the 10th National Congress of the China Association for Science and Technology, President Xi Jinping emphasized that we should establish the research evaluation system in line with the rules of research activities, the classified evaluation systems for exploratory and task-oriented research projects, and the evaluation mechanism for non-consensus research projects. With the establishment of the strategy of innovation playing a central role in the overall modernization and the policy of self-reliance and self-improvement in science and technology, the scientific and technological management and the research funding should and must pay more attention to original innovative research. This study first introduces the development background, conceptual connotation, and characteristics of HRHR research, then clarifies roles and relationship of relevant responsibility subjects in HRHR research, and finally summarizes typical funding policies and evaluation mechanisms of international research institutions for such research projects. These results are helpful for obtaining beneficial research management experience to promote HRHR research, which may provide a basis for the formulation and improvement of science and technology policies supporting high-risk exploratory projects in China.

1 Development background, conceptual connotation, and management system of HRHR research

1.1 Development background

1.1.1 Essential attributes of scientific development revealed by paradigm theory

Thomas Kuhn's paradigm theory is regarded as the theoretical origin of transformative research. Thomas Kuhn believes that science is constantly progressing during the alternations of conventional science and revolutionary science. Conventional science is the dominant paradigm under scientific consensus, while revolutionary science is the scientific breakthrough caused by the accumulation of too many abnormal phenomena in the traditional scientific paradigm, which usually happens beyond the focus of the paradigm [8]. For example, when researchers make errors in judgments and predictions on some scientific questions and social phenomena based on the existing scientific paradigms, they will break through the limitations of existing paradigms and seek new theoretical explanations and solutions, which thus lead to scientific revolution. HRHR research has the characteristics of revolutionary science. It has the courage to challenge the traditional scientific paradigm and break through the shackles of conservatism. Although having a high risk of failure, it will form a major scientific breakthrough, promote scientific development, and even trigger scientific revolution once successful. Currently, research has entered a new era of scientific breakthroughs driven by big data, and the paradigm theory has well explained the principles of major scientific breakthroughs and laid a theoretical foundation for the development of HRHR research.

1.1.2 Competition for scientific and technological leadership under fierce scientific and technological competition

Nowadays, scientific and technological strength is the core competitiveness and the strategic support of a country. As the new round of scientific and technological revolution and industrial transformation is accelerating in recent years, many developed countries have strengthened their strategic planning and layout of science and technology [9]. In the wake of the COVID-19 pandemic in 2020, international competition in science and technology has become increasingly intensive. Governments are adjusting their development strategies to focus more on scientific and technological progress and innovation-driven development, so as to accelerate economic recovery and win scientific and technological competitive advantages [10]. For example, the United States released the National Strategy for Critical & Emerging Technologies [11] in October 2020 and an updated version in 2022 [12]. The US Congress officially passed the America COMPETES Act of 2022 [13] in March 2022, aiming to promote scientific and technological breakthroughs and support basic research, thus maintaining the leading position and competitive advantage in core scientific and technological fields. The UK Government released the UK Research and Development Roadmap [14] in July 2020, expressing support for transformative research to achieve scientific breakthroughs. The Ministry of National Defence of the UK released the MOD Science and Technology Strategy in October 2020 [15] to further strengthen research and technological innovation layout. Other developed countries also actively plan their national development strategies in science and technology. The realization of national strategic goals and the breakthroughs of science and technology bottlenecks often rely on original innovation research with high risk and high reward.

1.1.3 Consensus demands of the scientific community for research breakthroughs

After World War II, the United States formed a research funding system dominated by the thought in the *Science: the Endless Frontier* [16], and peer review has become the mainstream review mechanism for research funding. However, peer review is essentially the consensus judgment of experts based on the current knowledge scope. Limited by existing knowledge boundary and discipline classification, it is difficult to make an accurate judgment on groundbreaking and original HRHR research, thereby inevitably leading to doubts about the funding system dominated by peer review mechanism. For example, Braben [17] argued that the current system was in favor of safe and conservative research while ignoring high-risk research. Gong [18] revealed that there was a fundamental conflict between the consensus and disciplinary nature of peer review and the non-consensus and interdisciplinary nature of transformative research. Moreover, Lee [19] and Gillies [20] believed that the broad consensus in peer review would lead to homogenous and conservative development of research. Therefore, some international research funding agencies have accelerated the adjustment in science and technology policies, optimized the layout and improved the mechanism of research funding, and paid special attention to HRHR research that may be easily overlooked by peer review.

1.2 Conceptual connotation and characteristics

1.2.1 Conceptual connotation

HRHR research is a concept that is widely used in science and technology policies and funding plans in other countries in recent years. America COMPETES Act of 2007 pointed out that scientific institutions should support HRHR basic research projects to promote the innovation in the United States and defined HRHR research as the research projects that meet fundamental technological or scientific challenges; 2) involve multidisciplinary work; and 3) involve a high degree of novelty [21]. The HRHR Research Program established by the NIH is designed to support scientists in conducting highly innovative research. These research projects may be risky or too novel to be recognized at the early stage, but have the potential to exert a broad impact on biomedicine, behavior or social sciences. The Organisation for Economic Co-operation and Development (OECD) released the Effective Policies to Foster High-Risk/High-Reward Research in May 2021 [22], which defines HRHR research as the research that strives to understand or support solutions to ambitious scientific, technological, or societal challenges; strives to cross scientific, technological, or societal paradigms in a revolutionary way; involves a high degree of novelty; and carries a high risk of not realizing its full ambition as well as the potential for high, transformational impact on a scientific, technological, or societal challenge. This is the most comprehensive conceptual interpretation of HRHR research so far.

HRHR research is also known as transformative research, non-consensus research, and original research. The National Science Foundation (NSF) of the United States defined the concept of transformative research in the Enhancing Support of Transformative Research at the National Science Foundation in 2007 [23]: the research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. NSF further consummated and defined transformative research as follows: transformative research involves ideas, discoveries, or tools that radically change our understanding of an important existing scientific or engineering concept or educational practice or lead to the creation of a new paradigm or field of science, engineering, or education. Such research challenges current understanding or provides pathways to new frontiers ①. Non-consensus research and original research are similar concepts that are commonly used in China. For example, the National Natural Science Foundation of China defined original research as the research that puts forward original academic thought, carries out exploratory and high-risk research, aims at cultivating or producing leading original work from scratch, solving scientific questions, leading research direction or expanding research field, thereby providing source supply to promote high-quality development of basic research ②. Therefore, these concepts are basically similar to the definition of HRHR research, while the difference lies in that these concepts lay more emphasis on the potential impact and reward of research in semantics, without indicating the risk of failure. However, HRHR research highlights the risks of failing to achieve the initial goals of studies while focusing on potential reward and impact.

Although the concept of HRHR research has not been completely unified, its connotation is clear. That is, HRHR research challenges the existing research paradigm and may not be favored or recognized at the initial stage with a high risk of failure, while it is the original research with the potential to bring about major scientific discoveries or great technological breakthroughs, mostly in the field of basic research. The high reward of HRHR research mainly refers to the scientific impact caused by knowledge innovation to achieve research breakthroughs; the social impact to handle major social challenges through new knowledge or technology;

① National Science Foundation. Transformative Research: Definition. [2022-04-20]. https://www.nsf.gov/about/transformative_research/definition.jsp.
② National Natural Science Foundation of China. Guidance for Application of Original Exploration Program of 2021 National Natural Science Foundation of China. (2021-02-22)[2021-10-30]. https://www.nsfc.gov.cn/publish/portal0/tab948/info79908.htm.

and the economic impact of new goods and services involving the key scientific breakthroughs.

1.2.2 Characteristics

The OECD proposes that HRHR research have knowledge features, including higher levels of basicness (experimental or theoretical discovery without any concrete application or use in view), generality (a general discovery is applicable to a wide number of scientific fields), and novelty (a potential leap forward) [24]. NSF summarizes the characteristics of transformative research as: challenging the existing research paradigms or results; generating new methods or technologies that cannot be foreseen; and expanding the scopes of science, engineering, and education [23]. As a matter of fact, all the contents discussed above are pre-research characteristics that cannot fully reveal the characteristics of HRHR research.

Combining the conceptual connotation and the whole life cycle of HRHR research, this study proposes that HRHR research has the following three features. (1) Novelty, a pre-evaluation feature, refers to a new scientific theory or technological approach that challenges people's widespread understanding and is a non-consensus idea or concept. (2) Uncertainty, an evaluation characteristic during the process of research, means that the research ideas and methods may be changed during the process of research. It is difficult to predict whether the results will be successful or not, with a high risk of failure, but it may also achieve great success. (3) Breakthrough, the post-evaluation feature, which means that the research results can overturn or innovate the existing scientific thinking and research paradigm, and promote the understanding and solution of scientific questions.

1.3 Management system

Breakthrough in scientific and technological innovation is a systematic problem involving multiple actors and multiple decision-making processes. Clarifying the roles and relationships of the responsibility subjects is conducive to formulating targeted governmental funding strategies and strengthening the exploration and support of HRHR research. With reference to the review of OECD on the collaboration among stakeholders in HRHR research [22], it can be found that governmental decision-making agencies, research funding agencies, and research execution agencies are the main responsibility subjects for promoting HRHR research. They promote and influence each other, playing positive, neutral or negative roles in HRHR research (Figure 1). The governmental decision-making agencies, as the organizers of scientific and technological innovation, provide long-term policy and project support to promote strategic research with strong innovation, high risk, great difficulty, long cycle, and good prospect, and expect short-term performance (early results, great achievements). As funding providers, research funding agencies tend to pursue value maximization and avoid the failure of investment in research and development. They usually adopt funding combination to avoid the risk of failure, and formulate reasonable funding mechanism and evaluation criteria to ensure the fairness and justice of research funding. Research execution agencies provide conditions for the development of research. However, to encourage researchers to rapidly produce great achievements, they often associated research achievements with awards and career promotion, which is not conducive to the development of innovative research with higher risks. In general, all the responsibility subjects play important roles in promoting HRHR research, while there are negative effects, such as the expectation of short-term results, aversion to failure, and solidified evaluation channels, which are the main reasons for the increasing conservatism of the existing research. In the future, the responsible subjects should try to overcome or avoid the negative effects in the process of funding to promote scientific progress and technological innovation.

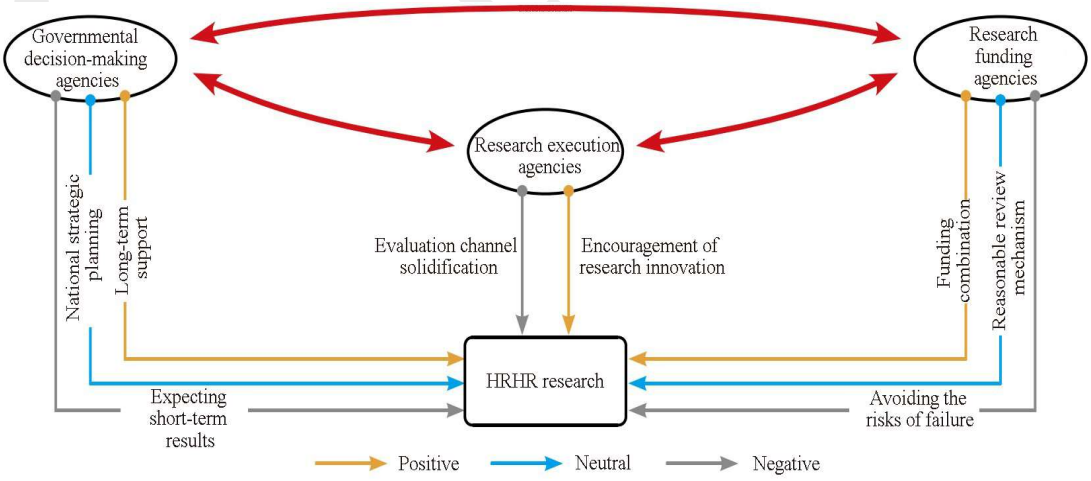

Figure 1 HRHR research management (decision-funding- execution) system

Modified and compiled from OECD report *Effective Policies to Foster High-Risk/High-Reward Research*

2 Funding mechanisms for HRHR research

HRHR research is an important part of scientific and technological innovation and research funding activities. Some international research funding agencies have realized the limitations of peer review in the assessment of HRHR research and other free exploratory research. They have actively explored funding mechanisms to promote HRHR research and generated some successful cases and new theories. The HRHR research funding mechanisms can be classified into three models: improved peer-review model, project manager model, and de-review model, the typical representative agencies of which are the US NIH, the US Defense Advanced Research Projects Agency (DARPA), and the Health Research Council (HRC) of New Zealand.

2.1 Improved peer-review model

Peer review is a common review approach of research funding. Due to the inherent caution and conservatism, peer review is not conducive to the identification and cultivation of HRHR research. Therefore, it must be improved in the specific review process. The NIH HRHR program is a typical example of the improved peer review model, which funds innovative research of highly creative scientists through a multi-level review approach aimed at addressing key challenges in biomedical, behavioral, and social sciences. This program funds four awards (Table 1): pioneer award, new innovator award, transformative research award, and early independence award. All of them emphasize that applications should be as short as possible, which to some extent avoids spending much time in preparing applications. Meanwhile, due to the high degree of uncertainty in HRHR research, the application only needs to focus on the creativity of the ideas and questions, with no need for a detailed research strategy or budget.

Table 1 Comparison of various awards for NIH HRHR program in the United States

Item	Pioneer award	New innovator award	Transformative research award	Early independence award
Year of launching	2004	2007	2009	2011
Target group	Individuals of exceptional creativity proposing pioneering approaches	Individual early stage investigators of exceptional creativity proposing research with uncommonly high impact potential	Individuals or teams proposing transformative research that may require very large budgets	Outstanding junior scientists wishing to "skip the postdoc" and immediately begin independent research
Research strategy	● 5-page limit; ● respond to questions about the challenge, potential impact, suitability for the award, investigator's innovativeness, and how the research qualifies as new research direction; ● no detailed research strategy or budget information	●10-page limit; ● respond to questions about significance and potential impact , innovativeness of approach, how risks and challenges will be addressed, suitability for the award, and investigator qualifications; ●no detailed research strategy or budget information	● 12-page limit; ● respond to questions about the challenge, innovativeness of approach, potential impact, and appropriateness for the award; ● no detailed research strategy or budget information	● 12-page limit; ● respond to questions about the challenge, innovativeness of approach, investigator's qualifications, and plans for development; in addition, host institution must provide details of commitment; ● no detailed research strategy or budget information
Reference letters	3 letters required	None accepted	None accepted	3–5 letters required
Review format	Multi-phased, "editorial board," interview of finalists	Multi-phased, "editorial board"	Multi-phased, "editorial board," anonymized review being piloted	Multi-phased, "editorial board"

Note: Modified and compiled from NIH HRHR program comparison (https://commonfund.nih.gov/highrisk/table)

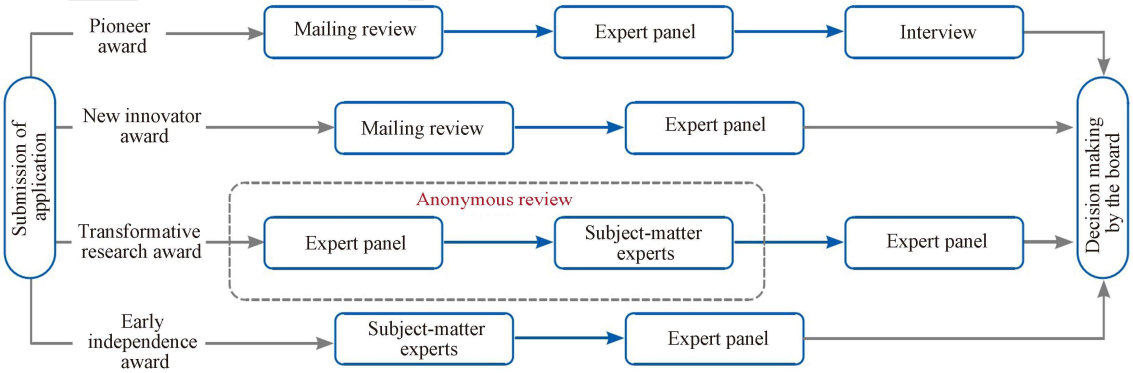

Figure 2 Multi-level review process of various awards for NIH HRHR program in the United States

The multi-level peer review process varies among the four awards of NIH HRHR program (Figure 2). The expert panel is composed of scientists with different academic backgrounds, including scholars with professional scientific knowledge, experience, and opinions as far as possible. The review experts form consensus judgment through group discussion, questioning, and debate. Subject-matter experts (also known as mail reviewers) are scholars who closely match the subject matter of the application and evaluate the application based on their expertise. In the pioneer award, the interview is a face-to-face meeting with the applicant to gain insight into the impact potential of the proposed project. In the first two stages, experts can only access the specific research proposal anonymously, but not the applicant's identity information and other application materials. The final results of these four awards must be approved by the board ③ before they can be funded. However, the board does not involve scientific or technical review, but only evaluates the fairness and uniformity of the entire review process.

The Sinergia program of the Swiss National Science Foundation (SNSF) has been restructured since 2016 to step up high-risk transformative research, requiring applications that demonstrate collaborative, interdisciplinary and breakthrough characteristics. SNSF set up special review groups for HRHR research ④. ENERGIX ⑤, a large energy project of the Research Council of Norway (RCN), and the MAESTRO Project ⑥, a pioneering research project of the National Science Centre of Poland (NCN), both use a two-level system (panel review and interview) to identify high-quality research. After analyzing the relevant international models, we summarized the improvement measures for peer review in Table 2.

Expert recommendation, as a form of peer review, has been used for a long time in the review of the Nobel Prize. It has been introduced into other scientific awards in recent years and may also be used for funding research projects in the future. However, it should be noted that expert recommendation here is a kind of passive recommendation, which requires applicants to seek experts by themselves. If the passive recommendation can be changed into active recommendation, and experts take the initiative to nominate high-quality research to participate in the application with their own academic reputation, it will better reflect the judgment of authoritative experts on the frontier of the field and help to explore the research projects with potential impact.

Table 2 Improvement measures of peer review

Improvement measures	Fundamental principles	Advantages	Disadvantages
Limitation for applications	The application should provide clear strategy of HRHR research	The application is easy to prepare and allowed to focus on HRHR research	Difficult to accurately define and predict HRHR research in advance
Anonymous review	Double-blind. Neither the reviewer nor the applicant knows the identity of the other	Avoid peer bias against certain categories of applicants	Reduce the amount of information reviewers can refer to and weakens the responsibility of reviewers and review results
Expanding peers	Multi-disciplinary, multi-identity, multi-age experts will be included in the review expert panel	Avoid the limitations of peers within a close field to some extent	Increase the review time and cost
Multi-phased review	Comprehensive use of email review, expert panel review, interview, and other review methods	Improve the judgment accuracy of HRHR research value	Complex and interdependent review procedures, high cost
Classified review	Develop separate funding programs for researchers at different stages and have different review criteria	Eliminate the concerns of early stage investigators about the impact of innovative research on their career	The classification is not directly related to the HRHR research
Expert recommendation	Applicants are required to find a number of peer experts to write letters of recommendation for their research	Provide useful reference for project review, which is relatively objective and fair	Worldly recommendation cannot be ruled out

2.2 Project-manager model

The project-manager model is a review mechanism that bypasses peer review and directly allocates funds based on the judgment of project managers. The core of this model is outsourcing of project responsibility, which endows project managers with greater autonomy and decision-making power. DARPA is considered an accelerator of innovation, which is a typical agency that employs project-manager model to

③ The Scientific Advisory Committee to the Director of the NIH Office is called the Board of Scientific Counselors.
④ SNSF. Sinergia–interdisciplinary, collaborative and breakthrough. [2021-11-20]. https://www.snf.ch/en/HzVMPWm96mz69ZJ8/funding/programmes/sinergia.
⑤ The Research Council of Norway. Work programme in effect from 2018: Large-scale programme Energy Research-ENERGIX. [2022-04-20]. https://www.forskningsradet.no/en/about-the-research-council/publications/2019/work-programme-and-energix/.
⑥ National Science Centre of Poland. Announcement of the MAESTRO 12 call. [2022-04-24]. https://www.ncn.gov.pl/en/ogloszenia/konkursy/maestro12.

support HRHR research. It is a flat organization with only three levels: director, office director, and project manager. Among them, the project managers are mainly recruited from the most outstanding scientists and engineers in academia, industry, and government laboratories on secondment for a short period of time. They are required to have a keen sense of science, a certain research background and technical depth, as well as rich experience in project management and investment [25]. Their tenure is typically 3–5 years, with a maximum of 6 years. Such mobility facilitates research execution.

The specific project-manager model of DARPA is illustrated in Figure 3. When a project is initiated, the project manager has full autonomy to identify and fund relevant innovative research projects in their field, without extensive peer review, as long as the director of DARPA and the office director agree to the project. In the process of project implementation, the project manager is fully responsible for the recruitment of team members, the determination of technical routes, and the independent allocation of project funds. The administrative office and other agencies can provide expert support in confidentiality, law, finance, and other aspects. Meanwhile, as HRHR research is often difficult to predict, project managers adopt the research management strategy of easy to apply and hard to be approved and follow the workflow of implementation, assessment, and funding at the same time. Parallel competition is encouraged at the early stage of research to promote the research projects with different technical routes to enter the implementation stage and phased assessment [26]. Additional funding is provided to promising projects, while timely suspension of losses is given to the projects with poor performance, thus avoiding potential failure risks to a large extent.

The success of DARPA model has led to a scramble for imitation by relevant institutions in various countries, and "ARPA-everything" has begun to thrive [27]. The most obvious cases were in the United States. The Obama administration established the Advanced Research Projects Agency- Energy (ARPA-E) to promote low-carbon technologies. In the first budget proposal, the Biden administration proposed the creation of the Advanced Research Projects Agency-Health (ARPA-H) [28] and the Advanced Research Projects Agency-Climate (ARPA-C) [29] to accelerate innovative breakthroughs in biomedical and climatic research. In 2018, Japan launched a Moonshot program ⑦ inspired by the DARPA model to address major national challenges that require high-risk research and technological breakthroughs. In 2019, Germany established the Federal Agency for Disruptive Innovation (SPRIN-D), which aimed to identify highly innovative research projects with disruptive potential and provided substantial funding support for ideas that disrupted traditional knowledge ⑧. The United Kingdom announced in 2021 the establishment of a new independent research agency, the Advanced Research and Inventions Agency (ARIA), to focus on high-risk projects that have the potential to produce technological change or scientific paradigm shifts ⑨. Therefore, the project-manager model has exerted a great impact on strategic planning and organizational setting in some countries, providing valuable experience for the funding management of HRHR research.

2.3 De-review model: lottery system

Lottery system is an important attempt for de-review mechanism. It applies a random selection of opportunity as the main determinant to the project funding process and gives applicants great fairness and freedom to promote and encourage non-consensus HRHR research. The HRC of New Zealand used the lottery system for the first time in the review of the explorer grant ⑩ in 2013. This grant aimed to attract and fund transformative research projects that had the potential to significantly impact health. Applications were required to be short and anonymous for initial quality judgments by reviewers, and all the applications assessed as transformative and feasible were equally eligible for funding.

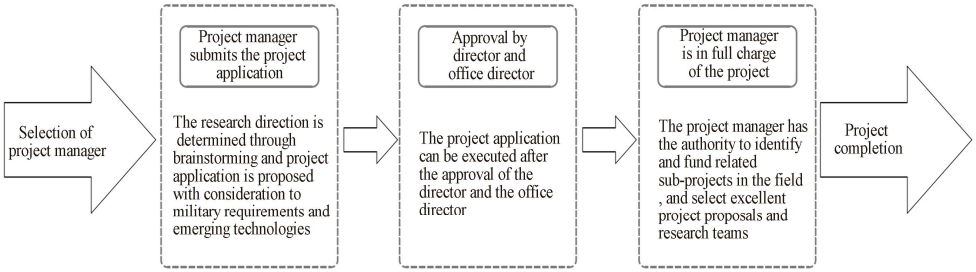

Figure 3 Implementation process of DARPA project-manager system in the United States

⑦ JST's Moonshot. Moonshot R&D. [2022-04-24]. https://www.jst.go.jp/moonshot/en/about.html.

⑧ Research in Germany. Federal Agency for Disruptive Innovation. [2022-04-24]. https://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/agency-to-promote-breakthrough-innovations-%E2%80%93-sprind.html.

⑨ GOV.UK. UK to launch new research agency to support high risk, high reward science. [2022-04-24]. https://www.gov.uk/ government/news/uk-to-launch-new-research-agency-to-support-high-risk-high-reward-science.

⑩ Health Research Council of New Zealand. HHRC explorer grant applications open 1 October 2015. [2022-04-24]. https://www.hrc.govt.nz/news-and-events/hrc-explorer-grant-applications-open-1-october-2015.

The lottery system of the HRC mainly includes three steps: qualification assessment, quality assessment, and random selection (Figure 4). The lottery system is the simplification and complement rather than the replacement of peer review. The quality assessment relies on the knowledge and judgment of peer experts for preliminary quality screening, with the purpose of identifying and eliminating the poor projects. Peer experts do not directly participate in the decision of funding or not, and the ultimate result is determined by random selection without difference, which weakens the artificial influence on the decision-making process and is more transparent and fairer. In addition, the HRC tracked the implementation performance and the researchers' acceptance of the lottery system. It was found that 63% of respondents agreed with random allocation of funds and they believed that this method did not affect the quality of research [30].

Pilot trials of lottery have sprung up in several countries in recent years. The seed project of the Science for Technological Innovation National Science Challenge (SfTI) in New Zealand also employed a lottery to fund small innovative projects with high risk and technical complexity ⑪. Experiments! funded by the VolkswagenStiftung supported novel and bold research ideas in science, engineering, and life sciences by introducing a lottery in the 2017 project review ⑫. In the pilot stage of the postdoc-mobility grants of the Swiss National Science Foundation (SNSF) in 2018–2020, the reviewer panel was asked to draw lots to determine the applications receiving postdoctoral fellowships [31]. In general, lottery avoids all kinds of biases and conflicts of interest in peer review and simplifies the review process, which is friendly to high-risk research of free exploration. Currently, the lottery system is still in trial in a few countries, and its applicability and scientificity need to be verified by enough data and facts. It has not yet reached a broad consensus in the international scientific community, but undoubtedly provides an alternative funding idea for the assessment of HRHR research.

2.4 Comparison of the three funding models for HRHR research

The three funding models mentioned above all aim to promote the identification and cultivation of HRHR research and overcome the uncertainties and potential failure risks of HRHR research from different perspectives. When applied to HRHR research, the improved peer-review model focuses on the ideas and concepts proposed by applicants, weakens the specific research strategy and budget request, and adopts anonymous and multi-phased review to eliminate review bias and reduce uncertainty. The project-manager model trains and selects appropriate project managers, gives project managers full autonomy, and adopts staged review of the research results in real time to dynamically adjust the funding plan, thereby timely stopping losses and reducing risks. The lottery system ignores research details and only excludes obviously unqualified studies, thereby randomly selecting funding objects in an undifferentiated manner and avoiding the artificial bias and preference in project selection. These funding models provide useful references for the formulation of relevant policies for HRHR research projects in China. In the practice, we can select, plan, and design the funding review mechanisms and strategies for specific projects based on the actual situation.

3 Enlightenment and suggestions

3.1 Formulating HRHR research funding policies to promote original innovation

HRHR research is a highly exploratory research activity, with high uncertainty and potential failure risk, which leads to limited resource allocation and less participation of researchers. The government should bring the roles of macroscopic control and forward-looking layout into full play. While continuing to fund conventional research, the government

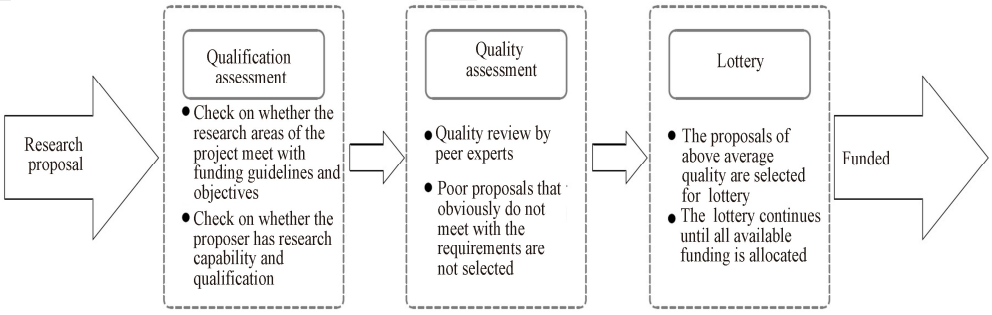

Figure 4 Implementation process of HRC lottery system in New Zealand

⑪ Science for Technological Innovation. Seed project development process. [2022-04-24]. https://www.sftichallenge.govt.nz/for-researchers/funding-and-get-involved/seed-project-development-process/.
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should attach great importance to HRHR research that transforms the conventional paradigm, and formulate tangible research funding policies, development strategies,and project planning. Particularly, the public nature of science of basic HRHR research projects determines that the research input should be mainly provided by the government, while the establishment of special fund for HRHR research is a common method employed by some national research agencies. For example, large research funding agencies, such as NSF and NIH in the United States, have set up special funds for HRHR research. In 2019, the National Natural Science Foundation of China has launched a pilot program for classified applications. The fund are classified into four categories of scientific problem attributes, among which the first category is encouraging exploration and highlighting originality, and the original exploratory projects have been launched. In the future, in the management of HRHR research, it is necessary to formulate relevant national policies and strategic plans based on national strategic requirements and international competitive landscape of science and technology, and establish more funds for HRHR research projects centering on key common science and technology issues.

3.2 Improving the academic review mechanism for selecting HRHR research projects

Research management departments should face up to disciplinary knowledge limitation and conservative preference in the existing review system, learn from successful experience of improved peer-review model, project-manager model, and lottery system, and explore a new funding mechanism suitable for the HRHR research in China. In terms of project design and review orientation, the traditional thinking pattern in the review process should be changed, and the support should emphasize the high-risk research that has the potential to produce important scientific and technological breakthroughs and academic impact, especially those can serve the national strategic goals. In terms of project discovery and review criteria, emphasis should be placed on the novelty of scientific questions and research ideas, as well as innovative and groundbreaking discussions of research, while specific normative requirements, such as expected goals, technical paths, implementation methods, and capital budgets, should be weakened. In terms of project selection and review methods, the phenomenon of relying only on the expert review should be changed, and expert opinions should be taken as reference to establish a sound, fair, and transparent review process. Questioning and defense should be allowed to eliminate bias and preference dependence in the process of continuous interaction, thereby making funding decisions fair and transparent. In terms of project review and review process, we should draw lessons from the practice of easy to apply but hard to approved of the project-manager model, attach importance to the phased-review of projects. Additional funding and extension of time limit should be provided for the research projects with broad prospects, while a flexible exit mechanism should be employed for the projects that have been proved to be not feasible.

3.3 Creating an excellent academic ecology that stimulates HRHR research development

The advancement of science and technology is a transformative knowledge creation activity that challenges the existing paradigm. Science and technology policies should be oriented to fully stimulate scientific innovation, avoid scientific conservatism or mediocre behavior, give scientists more research freedom, and promote the widespread development of free exploratory research. (1) It is necessary to weaken the rigid requirements on the output of expected results, fundamentally solve the research concerns of researchers, and provide them with a favorable environment for HRHR research. For example, for basic frontier exploratory projects, we should not put forward rigid requirement for expected results at the time of project application, truly establishing a culture that tolerates failure. (2) We should develop funding policies that help choosing research capability over professional title to motivate and guide researchers to conduct forward-looking exploration. For example, opening competition for selection of the best candidates is a non-periodic reward system for collecting innovative scientific and technological achievements aiming to solve specific questions and key technologies [32]. (3) We should implement the science and technology policy of researchers being dominant in the research process. HRHR research is characterized by long research cycle and high uncertainty. Relevant management agencies should grant researchers the right to make project implementation decisions and choose the technical route, and allow them to flexibly change the research route in the implementation of projects to cope with the new research problems and ideas in the research practice.

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