# Evaluating Funding Programs through Network Centrality Measures of Co-Author Networks of Technical Papers

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***Abstract*—In this study, we analyze the temporal transition of network centrality of the co-author networks contained in the vast science and technology literature database. We investigated co-author relations of 1.92 million literatures for 15 years (2001-2015) in the literature database of Japan Science and Technology Agency (JST). In addition, as case studies of funding programs conducted by government funding agencies, we analyzed the literatures written by Japan Society for the Promotion of Science (JSPS) Research Fellows and JST PRESTO program researchers. According to the analysis results, network centralities of both JSPS Research Fellows and JST PRESTO program researchers showed significant features, i.e., growing rapidly to much higher rankings than those of all researchers in the database. Using these features, we propose a method to evaluate funding programs through network centrality measures of co-author networks.**

***Keywords-component; academic literature database; co-author network; network centrality; funding program***

## I. INTRODUCTION

Excellent researchers are essential to realizing innovation and developing science and technology, and finding promising young researchers and fostering them is an important concern. Therefore, it is important for funding agencies to select promising young researchers who will be responsible for future academic research and excellent researchers who will promote policy-oriented research, and to provide research funding to such researchers. Furthermore, to implement the funding programs efficiently and effectively, evaluating the programs is very important.

In general, funding programs are evaluated in different ways, such as "assessment" (pre-evaluation) to select research projects or researchers, "monitoring" (intermediate evaluation) to observe efficiency and effectiveness of research activities, and "evaluation" in a narrow sense (post-evaluation) to judge whether each research has academic or socioeconomic effects or influences. To evaluate the funding programs to support research based on researchers' free ideas, pre-evaluation such as peer review and other qualitative measures are often regarded as important. On the other hand, in the funding programs to be tied to policy objectives, intermediate evaluation and post-evaluation, which evaluate the level of research processes or research achievement based on quantitative evidence, are necessary. As for quantitative evaluation indexes, the number of papers or patents and that of cited papers or patents derived from the programs are often used; however, these indexes are not leading indicators for predicting future researchers, but trailing indicators following the professional achievement of researchers, and thus, using these indexes, it is difficult to evaluate young researchers whose research achievements are not yet sufficient.

Based on the above background, we focus on network centralities of co-author networks constructed from scientific and technical literature databases, and then propose to use temporal transition of network centralities as an evaluation index to quantify funding programs, especially programs for promising young researchers expected to grow in the future. This is because network centralities reflect organizational activities as well as intellectual capabilities of researchers. As a result

of our analysis of the Japan Society for the Promotion of Science (JSPS) Research Fellows program, which supports young researchers with free ideas, and Japan Science and Technology Agency (JST) PRESTO program, which supports mainly young researchers to be engaged in policy-oriented research, using JSTPlus, the science and technology literature database provided by JST, we found that network centralities of both JSPS Research Fellows and JST PRESTO researchers grew significantly rapidly to higher rankings from the time of program selection, as compared to all researchers in the database. Based on the results, we propose to use temporal transition of network centrality measures of co-author networks as an evaluation index of funding programs.

## II. RELATED WORK

In this section, we define the terms used in this paper, and then, survey research conducted on the evaluation of funding programs and that conducted on network centrality of co-author networks, which we use as an index to evaluate the programs.

### A. Evaluation of Funding Systems

There are several types of "evaluations" in science and technology policy, including "assessment" (pre-evaluation) to select research areas and researchers to invest public funds in based on scientific and technological development trends and socioeconomic needs, "monitoring" (intermediate evaluation) to observe whether the research is being implemented effectively and efficiently, and "evaluation" in a narrow sense (post-evaluation) to judge whether it has resulted in academic or socio-economic effect or influence. In addition, it is important to link the evaluation results in each phase to

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the decision-making in the next phase in a circular manner. In science and technology policy, "funding" means allocation of public funds to researchers in order to promote research and development (R&D) to realize policies, and "funding agency" refers to an organization that conducts such allocation of public funds. In addition, the "funding program" is a program to embody policies and measures by the funding agency. In order to conduct the funding program efficiently and effectively, the evaluation activities of the program are extremely important.

Because traditional funding programs are rarely related to specific policy objectives but are in line with a seed-driven linear model, the assessment (pre-evaluation) of R&D projects is the most important. This assessment is often conducted by peer reviewers who can judge the research topics in their specialized research field. On the other hand, recent funding programs are clearly tied to policy objectives and are often in line with need-driven innovation model. Consequently, it becomes more important to not only assess project selection but also to evaluate its contribution to the achievement of the objectives and the steering of the research activities leading to the objectives; thus, the evaluation in a narrow sense (post-evaluation) of outcomes (achievement of the programs) and impact (influence beyond the achievement of the program or effect of policy intervention), and the monitoring (intermediate evaluation) of research activities, as well as the evaluation of the overall program, become matters of interest. Therefore, as R&D activities become required to contribute to the realization of policy objectives, the use of multifaceted evaluation methods not limited to peer review is an issue to be addressed.

In this paper, based on the above background, we propose a new index focusing on quantitative post-evaluation of funding programs, especially programs for young researchers.

### B. Evaluation of Funding Programs

As an evaluation of the funding programs, Yoshida et al. (2007) stated that the numbers of papers and patents are insufficient for evaluating funding programs because they are not direct indexes but indirect ones generated from R&D. They conducted a case study on JST's CREST and other funding projects with respect to their success factors, and found "collaboration" to be an important success factor [1]. Conducting a quantitative evaluation of the funding programs, Kurosawa et al. (2015) stated that it is difficult to evaluate research results only with quantitative numbers of papers and citations. They built a database (FMDB) on JST and JSPS funding program information and indicated the direction of quantitative analysis and evaluation of results and effects of the funding programs [2].

However, regarding the indexes for evaluating funding programs, there are not sufficient concrete indexes other than numbers of papers and patents or numbers of cited papers and patents. Thus, in this paper, we propose temporal transition of centralities of co-author networks as a concrete evaluation index.

### C. Network Centrality of Co-Author Networks

As examples of social networks contained in scientific and technical literature databases, there are two typical networks: citation networks, which are constructed from citation relations between science and technology fields in academic papers or patents, and co-author networks, which are constructed from co-author relations of the literatures.

In the citation networks, the number of citations of literature such as papers and patents shows the strength of interest in the fields and categories of science and technology. Science and patent maps are examples of applications of citation networks. Impact factor and h-index are indicators based on citation relations of papers, though they are difficult to be used for evaluating young researchers who have not had sufficient and accumulated achievement, since they are not leading indicators for predicting future researchers but trailing indicators following the professional achievement of research and publication and citation of papers in leading journals [3].

On the other hand, co-author networks are proxy variables of collaborative relations in R&D activities. In addition, network centrality of co-author networks shows strength of researchers' intellectual capability proved through published literatures and researchers' organizational capabilities such as leadership and teamwork in research organizations.

Melin (1996) used the co-author relation of science and technology papers to clarify the characteristics of researchers' collaboration within a research institute, domestic institutions, and international institutions, and concluded that the results of analysis of co-author relations are useful for science and technology policy [4]. In addition, Barabasi et al. (2002) analyzed the structure and features of growth of networks by constructing co-author networks of papers in the fields of mathematics and brain science [5]. Furthermore, Newman (2004) analyzed co-author networks of articles in the fields of biology, physics, and mathematics, and clarified the difference in collaboration pattern by each field [6]. While research on co-author networks has been progressing, the relation between network centricity and researcher performance has been discussed. For example, Abbasi et al. (2012) constructed co-author networks of literatures published in the Information Science and Library Science magazine, and showed that researchers with higher network centralities have higher research performances [7].

In this paper, we evaluate funding programs, focusing on the network centralities of co-author networks considering both intellectual capabilities of researchers and their organizational capabilities, such as leadership and teamwork, and propose to use temporal transition of network centralities as an index to evaluate the programs.

## III. Data and Method of Analysis

While evaluating the funding programs, we focus on network centralities of co-author networks in these papers. In this section, we present an outline of the literature database to be analyzed, the features of the co-author networks constructed by this database, and characteristics of JSPS Research Fellow and JST PRESTO researchers who were analyzed as samples for case studies.

### A. *Data of Analysis*

In this study, we analyzed the academic literature database provided by JST (JSTPlus). This database comprehensively contains more than 25 million literatures of about 50 countries around the world and domestic scientific literature including conference presentation papers. By using this database, activities of young researchers who have not sufficiently accumulated research results are likely to be captured. We extracted and analyzed about 1.92 million literatures in the biology field from JSTPlus for 15 years (from 2001 to 2015), as shown in Table 1.

TABLE I. NUMBER OF PAPERS IN THE PUBLICATION YEAR

| Year | No. of Literatures | Year | No. of Literatures | Year | No. of Literatures |
|---|---|---|---|---|---|
| 2001 | 115,627 | 2006 | 122,191 | 2011 | 138,405 |
| 2002 | 110,113 | 2007 | 132,722 | 2012 | 131,785 |
| 2003 | 115,032 | 2008 | 130,656 | 2013 | 147,125 |
| 2004 | 118,545 | 2009 | 138,432 | 2014 | 136,272 |
| 2005 | 119,051 | 2010 | 137,717 | 2015 | 126,518 |
| Total (2001 – 2015) | | | | | 1,920,191 |

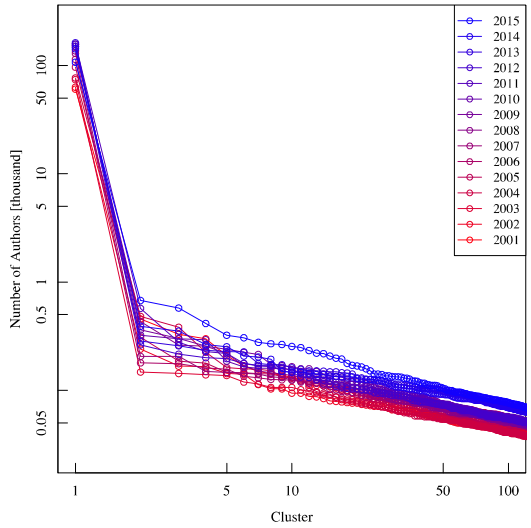



Figure 1. Distribution diagram of cluster size (horizontal axis: logarithm of cluster number, vertical axis: logarithm of cluster size)

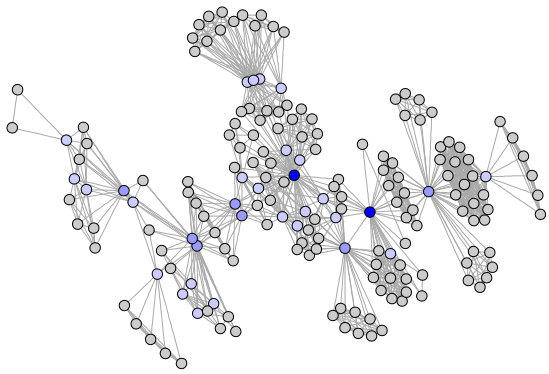


Figure 2. Example of a cluster in the co-author network in 2006

### B. *Construction of Co-Author Networks*

We divided the 1.92 million literatures extracted in the biology field into 15 segments by issue year, and constructed co-author networks with authors as nodes and papers as edges based on the co-author relation.

Fig. 1 shows the distribution of clusters of the co-author networks constructed in each year from 2001 to 2015; the horizontal axis indicates the logarithm of cluster number and the vertical axis indicates the logarithm of the cluster size. It can be seen that the co-author networks are composed of one big cluster located on the left end and many other small clusters.

Fig. 2 shows an example of one cluster configuration in the author network in the case of the second largest cluster in 2006. The network consists of 179 authors (researchers) as nodes, and the dark blue nodes in the network indicate authors with high network centrality.

### C. *Temporal Transition of Network Centrality*

Then, we calculated the value of network centrality for each author of co-author networks for each issue year, and ranked the centrality based on the calculated centrality value. In this study, considering the connection of a researcher with other researchers, we selected betweenness centrality as the network centrality of co-author networks, because betweenness centrality indicates the degree to which a researcher is located on the shortest path between other researchers and represents researchers who work to connect other researchers. In addition, we analyzed the temporal transition of ranking of the network centrality of each author.

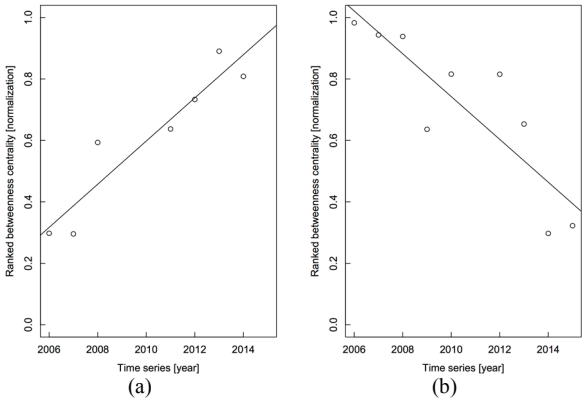



Figure 3. Samples of transitions of network centrality rankings of researchers by linear regression (A researcher whose network centrality has increased (a) and decreased (b))

Fig. 3 shows examples of the results of linear regression analysis for individual authors (from 2006 to 2015, number of occurrences of centrality ≥ 4, p-value < 0.05). Fig. 3(a) shows a researcher whose centrality has increased, and Fig. 3(b) shows a researcher whose centrality has declined.

### D. Extraction of Selected Researchers for Funding Programs

Finally, as case studies of the funding programs to be evaluated, we extracted researchers selected by the JSPS Research Fellow program and JST PRESTO program. The JSPS Research Fellow program is a program for young researchers who are in the early stages of their doctoral course or post-doctoral status, and supports their research based on each researcher's free idea. JSPS requests JSPS Research Fellows to mention "JSPS Research Fellow" or "NIHONGAKUJYUTSUSHINKOUKAITOKUBETSUKE NKYUIN," which means "JSPS Research Fellow" in Japanese, in the column of organization in their papers supported by JSPS. In our analysis, we extracted authors of papers including the above words in the column of organization in the database as researchers with a background of JSPS Research Fellow project. The number of authors extracted from biology during the 15 years from 2001 to 2015 was 1,656.

The JST PRESTO program is a policy-oriented basic research program, in which research is mainly conducted by young researchers in their 30s. The program aims to promote independent research by individual researchers and to provide a platform for them to grow with researchers with various backgrounds involved in the same research area. As researchers with a background of JST PRESTO projects, we extracted authors of papers including words "PRESTO" or "SAKIGASE," which means "PRESTO" in Japanese, in the column of organization in the database. The number of authors extracted from biology during the 15 years was 1,575.

## IV. Results of Analysis

In this section, we compared the network centrality of the co-author networks of JSPS Research Fellows with that of all researchers in the database, and conducted similar comparison for JST PRESTO researchers. The results are shown as follows.

### A. Comparison of Network Centralities between JSPS Research Fellows and General Researchers

The blue part in Fig. 4 shows the histogram of 10 years (from 2006 to 2015) of researchers who published their first paper as JSPS Research Fellows in 2008, from left to right in the horizontal direction from 2006 to 2015 in the order of year of publishing. The red part in Fig. 4 shows the histograms of all researchers who published their first paper in 2008 in the same manner, and shows them overlapping with the blue part. In each histogram of publishing year, 10-quantile (decile) of network centralities is shown from top to bottom in the vertical direction from top 10%, 10 to 20%, ..., 90 to 100% in the order of decile.

In general, researchers, as well as their network centralities, grow with experience. This can be seen in the red part in Fig. 4. On the other hand, Fig. 4 also shows that the network centralities of researchers selected as JSPS Research Fellows grow more rapidly with time than those of all researchers.

### B. Features of Network Centralities of JSPS Research Fellows and JST PRESTO Researchers

Fig. 5(a) shows the features shown in Fig. 4 from another viewpoint. In each graph of Fig. 5(a), the horizontal axis indicates the year in which the paper was detected as JSPS Research Fellow for the first time, in the middle of the axis with year of "0," and shows the terms for both eight years before and eight years after the year of "0." The upper-side graph shows the trends of the number of JSPS Research Fellows detected in each year, while the lower-side graph shows the ratio of the number of JSPS Research Fellows with

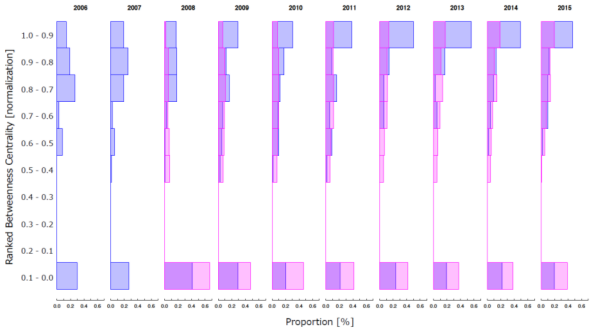
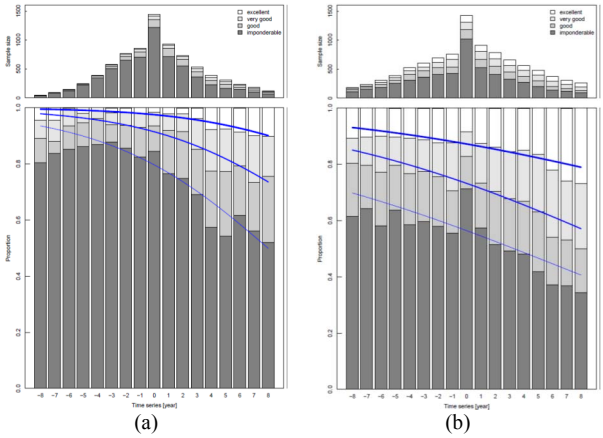



Figure 4. Comparison of network centralities between JSPS Research Fellows and all researchers ((blue decile: researchers who published their first paper as JSPS Research Fellows in 2008, red decile: all researchers who published their first paper in 2008)




(a) (b)

Figure 5. the transition of the numbers (the upper graphs) and the proportions (the lower graphs) of researchers whose centralities are certain rankings; white band: higher than 1.0%, thin gray band: 1.0%-2.5%, the gray band: 2.5%-5.0% and dark gray band: 5.0%-100.0% ((a) shows the case of JSPS Research Fellows and (b) shows the case of JST PRESTO researchers.)

rankings of network centrality of co-author networks. In the lower-side graph, the white band shows the proportion of fellows with centrality rankings higher than 1.0%. In addition, the thin gray band below it, the gray band below it, and the remaining dark gray band at the bottom show the proportions with, respectively, centrality rankings of 2.5% or more and less than 1.0%, 5.0% or more and less than 2.5%, and less than 5.0%, which is the lower 95.0%. In the lower-side graph, the three curves show the results of logistic regression analysis of the transition of the proportion of fellows whose centralities are certain rankings. The upper curve shows the transition of proportion of fellows whose centralities are higher than 1.0%, the middle and lower curves show the transitions of proportions of fellows whose centralities are, respectively, 2.5% or more and 5.0% or more. The figure shows that the centralities start to grow more rapidly from around the time "0" when the literatures are detected as JSPS Research Fellows for the first time.

Fig. 5(b) shows the result of performing the same operation as that in Fig. 5(a) for the researchers selected as JST PRESTO researchers. The figure also shows that, besides the case of JSPS Research Fellows in Fig. 5(a), the centralities of the JST PRESTO researcher start to grow rapidly from around the time "0" when the literatures are detected as JST PRESTO researchers for the first time. On the other hand, compared to JSPS Research Fellows, the centralities of JST PRESTO researchers have already been much higher before the time when they were selected as JST PRESTO researchers (from "-8" to "-1" in Fig. 5(b)).

## V. Discussion

Based on the results in the previous section, we propose evaluating the funding programs based on network centralities of the co-author networks, and discuss its effectiveness and future issues.

### A. Evaluation of Funding programs utilizing Network Centralities

Based on the results shown above, centralities of co-author networks of JSPS Research Fellows (doctoral students or post-doctoral young researchers who conduct research with free ideas) or JST PRESTO researchers (young researchers in their 30s who conduct research with political mission) are remarkably growing with time as compared to those of general researchers. Therefore, we can search for promising young researchers by searching for researchers with features similar to those of network centralities of JSPS Research Fellows and JST PRESTO researchers.

In addition, the features of centralities of co-author networks of JSPS Research Fellows and JST PRESTO researchers who were analyzed are summarized as follows.

(1) In both cases, centrality grows markedly.
(2) In the case of JSPS Research Fellows, compared to JST PRESTO researchers, centralities are lower until the time of selection by the program, while in the case of PRESTO researchers, centralities have already been higher before the time of selection by the program.
(3) In both cases, the starting points when centralities start to grow remarkably are around the point when the researchers were selected as the program researchers.

In addition, these features are considered to be consistent with the following general conscience of JSPS Research Fellows and JST PRESTO researchers.

- As for JSPS Research Fellows, promising researchers who have just started their research will grow significantly as a result of being selected by the program.
- On the other hand, as for JST PRESTO researchers, young researchers who have already been recognized as excellent researchers will further grow through selection by the program.

Therefore, we propose to use temporal transition of centralities of co-author networks as an index to quantitatively evaluate funding programs for young researchers.

### B. Validity of Network Centrality Measures for R&D Evaluation

Here, we will discuss the effectiveness of centralities of co-author networks for R&D evaluation from two viewpoints: contribution to issues of R&D evaluation and features of co-author networks.

First, as for contribution to issues of R&D evaluation, "Evaluation guidelines on R&D of the Ministry of Education, Culture, Sports, Science and Technology" revised in April 2017 point out four important research issues of R&D evaluation to be resolved, and further points out the following concrete issues.

(1) Not to simply aim at raising the number of papers published or cited, but to reflect the ability of top management and their efforts considering organization building and practical implementation in the evaluation.
(2) To establish an evaluation system that leads to the promotion of interdisciplinary areas, fusion areas, and interdisciplinary collaborative research so as to explore challenging and new research areas.
(3) To evaluate so as to promote training and support for young researchers.
(4) To improve the evaluation method toward rational and effective evaluation by resolving the burden of increased frequency of evaluation.

For these issues, the evaluation method using the temporal transition of centralities of co-author networks proposed in this paper has the following features, so it contributes to solving the issues of government's R&D evaluation and is considered highly effective.

(1) An index reflecting the research system without relying solely on the number of papers published or cited
(2) Highly correlated with collaborative relations for the promotion of interdisciplinary areas, fusion areas, and interdisciplinary collaborative research
(3) Possible to evaluate young researchers who have not accumulated sufficient research results

(4) An objective index automatically obtained using the academic literature database so as to reduce the burden of evaluation

Second, we will discuss the features of co-author networks. In Fig. 1, there was one large research group including about 20% of the authors and many small research groups. This large research group shows the existence of one core research community in the biology field, where knowledge flows and exchanges are active, and many small research groups are considered to represent specialized research communities in this field. A large research group such as that shown in Fig. 1 has also been shown in related studies. For example, Newman (2004) showed that when a co-author network is constructed from literature in the fields of biology and physics for 5 years, about 90% of authors form one group in each field [6]. Also, Wagner et al. (2005) showed that international co-author networks are growing and international collaboration of research is self-organizing [8].Similarly, the size and structure of co-author networks show the importance of collaboration in research activities. It is worthwhile to measure the central researchers who intermediate knowledge in research communities, that is, to measure betweenness centrality in co-author networks, as interdisciplinary research that integrates two or more academic fields is being required more.

### C. *Factors to Grow Network Centralities of Co-Author Networks*

In this study, we analyzed biology field, where collaborative research is relatively frequent, as a case study. In this field, there are many types of collaborative research due to the necessity of experimental facilities. Exchange of information in academic communities is effective even in fields such as mathematics, where the theoretical research method is adopted and the number of cooperative researchers is relatively few. Furthermore, in interdisciplinary fields such as biotechnology and bioinformatics, it is considerably effective to research not only within a specific research field but also across multiple research fields. Therefore, it is presumed that the features of the temporal transition of the co-author network are not related to the research fields, and that extension of the research fields influences centralities of co-author networks.

In addition, in this study, JSPS Research Fellows and JST PRESTO researchers were analyzed as promising or excellent researchers. Both these programs are programs to support individual researchers; the JSPS Research Fellows program basically obliges the movement of research institutes when a researcher is selected as a fellow, and the JST PRESTO program expects selected researchers to interact with other researchers from various organizations gathered in the same research area. Therefore, movement of the organizations and exchange with other researchers may influence the growth of centralities of co-author networks.

As described above, if the causal relation between expansion of the research fields or movement of organizations and temporal transition of centralities of co-author networks and the relation between those and R&D performance becomes clear, it would be useful for improving R&D activities through feedback of R&D evaluation. Therefore, further research on these causal relations is strongly desired.

## VI. CONCLUSION

We analyzed the JSPS Research Fellow program, which supports young researchers with free ideas, and the JST PRESTO program, which is a policy-oriented research program mainly for young researchers, using JST's academic literature database. As a result, features such as remarkable growth of centralities of co-author networks of researchers selected for these programs were confirmed. Based on this result, we proposed to use the temporal transition of centralities of co-author networks contained in the science and technology literature database as a quantitative evaluation index of the programs for young researchers. This index is considered to be effective for resolving R&D evaluation issues raised by the government.

There is a possibility that expansion of researcher's research field and movement of their organization influences the temporal transition of centralities of co-author networks, and further research on these causal relations is thus desired.

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