



Article

# The Role of Collaboration Breadth Attributes in Research Project and Innovation: The Example of National Funded Projects in China

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**Abstract:** Collaboration is regarded as an effective approach to improve the efficiency of research resources and reduce risks in innovation activities. Collaboration breadth is an important feature of collaborative extent. Therefore, it is necessary to analyse its role between R&D subsidy and innovation and to explore its direct and indirect ties to innovation. The paper is based on government-funded research projects, and the results show that R&D subsidy and collaboration breadth of organizations have positive direct effect on innovation output. Meanwhile, R&D subsidy has positive effect to collaboration breadth. However, the linkage of collaboration breadth of researchers on innovation output is uncertainty. That is, the direct effect is positive, while the indirect effect is negative. It may suggest that collaboration breadth of researchers and innovation output may be affected by other factors, such as knowledge sharing or diffusion. Our contribution is to extend the theory of collaboration breadth and to suggest discussion of the role of knowledge in collaboration breadth.

**Keywords:** collaboration breadth; innovation output; R&D subsidy; research projects



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## 1. Introduction

Innovation is a process of knowledge interaction and aggregation. In the context of global economic competition and technological progress, latecomer countries usually choose government-funded research projects to achieve innovative output [1]. However, mainly participants include universities, institutes and enterprises, and their cooperative relationship plays an important regulating role in the whole research process [2–4]. Their strategy of collaboration aims to acquire external technology, knowledge and human resources. As the knowledge and technology required for innovation become more complex, and as R&D investment increases, extensive external collaboration becomes possible. The collaboration breadth is defined as the number of external resources or research channels, which is based on collaborative participants [5]. The influence of collaboration breadth on resource input and innovation output has been widely attracted [6,7]. The collaboration breadth represents the number and diversity of partners in research project, which enhances the possibility of knowledge interaction between them intentionally or unintentionally [8,9]. Meanwhile, due to the diversity of knowledge stock and the complexity of knowledge transfer [10], it also affects the cost of knowledge integration and transfer in project management. Kobarg, Stumpf-Wollersheim [9] deemed that there is a curvilinear effect between the collaboration breadth and innovation performance under the condition of diminishing marginal revenue. Therefore, we deem that the characteristics of the collaboration breadth in research projects are particularly important for innovation output. As we known, government-funded research projects are regarded as national strategic behaviours in scientific development, talents cultivation and innovation capacity improvement. Obviously, it is a challenging problem for us to explore the influencing factors of innovation output and the attributes of collaboration breadth in research projects.

Innovation is indispensable for latecomer countries to catch up with developed countries in technology and economy. Researchers, enterprises, universities and government policies are all considered as the basic resources for innovation [3,11]. Indeed, innovation is generated through the aggregation of above resources, while research projects provide an approach for the aggregation and a mechanism to guarantee the orderly utilization of resources. At present, literatures on research projects mainly focuses on the government R&D investment, knowledge heterogeneity, innovation performance and policy [1,4,12,13]. However, there is little discussion of the role of collaboration breadth in research projects and innovation.

Collaboration is regarded as an effective way of resource integration and knowledge interaction. In this study, the number of partners involved in collaboration is defined as collaboration breadth, which represents the collaborative range of the project. Collaboration breadth contributes to the specialization, profitability, knowledge stock and innovation in research activities [14–16]. The interaction, absorption, integration and transfer of knowledge in context of collaboration breadth, which improve innovation performance [17], and provide guarantee mechanism for innovation in interorganizational collaboration [18]. The interaction of research resources based on cooperative relationship is increasingly important for small enterprises in developing countries to improve their innovation capacity [19]. In the view of organizational learning theory, the interaction between partners provides an interface for knowledge sharing, transfer and absorption [10,20]. Meanwhile, knowledge dissemination, interaction and integration are all finished base on collaboration relationship, and collaborative network structure also involves organizations or individuals in collaboration [21–23]. In addition, productivity and economic growth are increasingly dependent on innovation performance. Moreover, the stimulation of external R&D subsidy is conducive to the enterprises with rich collaborative experience to expand the collaborative range, so as to obtain diversified knowledge. Scholars demonstrated that R&D subsidy has a significant stimulating effect on collaboration breadth, such as Spain, Japan and South Korea [4,24]. Thus, it is necessary to explore the impact of collaboration breadth at the organizational and individual levels on innovation output in research projects.

The questions to be solved in this paper are as follows: the direct impact of external investment (R&D subsidy) and inner collaboration breadth (organization, researcher) on innovation output in research projects; the intermediary role of collaboration breadth of organizations and researchers between R&D subsidy and innovation output. This paper focuses on research projects supported by National Natural Science Foundation of China (NSFC). It aims to explore the direct on innovation output, and intermediary effect of collaboration breadth (organizations and researchers) between R&D subsidy and innovation output. It is worth noting that the innovation output concerned in this paper refers to the assessment criteria adopted by the National Natural Science Foundation of China (NSFC) in the final evaluation of funded research projects. NSFC classifies innovation outputs into journal papers, conference papers, books, rewards and patents.

The paper has made several contributions to explore the linkage between collaboration breadth and innovation outputs. First, we discuss the role of collaboration breadth attributes in scientific research from organizational and individual perspectives. The study analysed how the collaboration breadth attributes at different levels affect innovation output of research project. Secondly, the empirical model of the study can be extended to specific disciplines, research laboratories, university-industry collaboration and be used to discuss the intermediary role of collaboration in innovation performances.

The rest of the paper is as follows. Section 2 presents relevant innovative resources in research projects and some literatures review about collaboration breadth. Section 3 introduces sample and data. Section 4 shows the empirical analysis results on the influencing factors of innovation outputs in research projects and tests the robustness of above results. Section 5 reports the discussions including conclusions, theoretical contributions, limitations, implications and further directions

## 2. Literature Review and Hypothesis

### 2.1. R&D Subsidy and Innovation

The impact of R&D subsidy on innovation has been widely discussed in academic theory and governmental policy. Scholars generally believe that R&D subsidy positively affects innovation output or performance [25,26]. Innovation capability is a weakness of small and medium sized enterprises (SMEs), which is due to the lack of technical capital, human capital, knowledge capital and social capital [27,28]. Specifically, R&D investment is considered a key factor. Kang and Park [4] indicated that the increased research expenditure of firms stimulate innovation performance. As a type of external resource, government subsidies are conducive to university-industry collaboration [29]. In this sense, although innovation derives from knowledge accumulation, it is also inseparable from the role of R&D subsidy. The current studies pay little attention to the type of funding, especially the national funded basic research projects. The main attributes of government in innovation systems include facilitating knowledge dissemination and providing research funding [30]. With other words, governmental R&D subsidy can be considered public investment to stimulate innovation activities [31,32].

R&D subsidy in different countries and industries present heterogeneous, but the positive effect on innovation remains widespread [29,33,34]. On the one hand, R&D subsidy from government can indirectly promote the motivation of innovation activities. Resource integration, on the other hand, relies on collaboration breadth in research projects, which represent the number or diversity of collaborative partners. After all, innovation cannot be separated from intellectual and human capital. It depends on the combination of social capital, human capital and knowledge capital can produce innovation [11]. R&D and collaborative network as a supplementary driving force of innovation output [35], and innovation is inseparable from resource integration among heterogeneous entities (e.g., companies, enterprises, universities) in collaboration [2,36].

Taken together, our cognition of R&D subsidy and innovation in research projects is as follows. First, governmental R&D subsidy is an important source of research expenditure for research projects. Secondly, collaboration breadth provides effective approaches for researchers to utilize external ideas, knowledge and resources in research projects. Moreover, the use of external resources through collaboration breadth helps to expand the knowledge and technology boundaries of enterprises, so as to gain benefits [37]. Therefore, we propose the following hypothesis.

**Hypothesis 1 (H1).** *R&D subsidy has a positive effect on innovation output.*

### 2.2. R&D Subsidy and Collaboration Breadth

Collaboration provides an important approach to integrate skills and knowledge. Collaboration breadth is a key feature to measure collaborative range [3]. Fritsch and Franke [38] presented that knowledge dissemination promoted collaborative efficiency. As for universities, the interaction of scholars in research collaboration contributes to search new insights and practices [39]. Cooperative relationship, strategy and pattern have different moderating effects on knowledge benefit in academic research [7]. Besides, the R&D investment affects innovation performance and collaborative partnerships in research projects. That is, governmental R&D subsidy not only improves innovation performance but also affects the number and diversity of partners. After all, the support of social capital is regarded as an important motivation for collaborative participants to expand research projects [40]. Thus, we deem that the investment of research resources has a direct impact on collaboration breadth in research projects.

Innovative elements (e.g., funding, human, knowledge) can have a clustering effect in research projects [3,41]. Scholars argued that the moderating effect between internal R&D and innovation from government incentives [4,42]. The government's policies have a significant guiding effect on the collaboration breadth and collaborative relationship [43,44].

Therefore, government-subsidized funds as external social capital have an impact on collaboration breadth in research projects.

As for the cognitive process of collaboration, scholars usually conduct research at the interorganization and human capital levels [3,45–47]. Human capital in collaboration refers to the number of researchers, educational background, titles, disciplines and other factors [48,49]. In this sense, in order to identify the organizational and human resource dimensions of collaboration breadth, whether there is an influence between external social capital and innovation. Thus, we propose the following hypotheses.

**Hypothesis 2 (H2).** *R&D subsidy has a positive effect on collaboration breadth of organizations.*

**Hypothesis 3 (H3).** *R&D subsidy has a positive effect collaboration breadth of researchers.*

### 2.3. Collaboration Breadth and Innovation

The management of research projects is also influenced by collaborative partnership [50]. A series of literatures pointed that collaborative feature has a significant positive influence on the utilization of external network and resource complementarity, such as increasing the stability, output and efficiency of collaboration [50–52]. As for the output measurement of collaboration, there are some differences among participants but mainly the weight of papers and patents. At the macro level, academic institutions (universities, public institutes, etc.) usually regard it as research output, and the weight of papers is higher [53]. However, firms usually use innovation output for business reasons, and patents have a high weight [6]. For example, in university-industry collaborations, universities focus on papers, and industries focus on patents. In order to unify the measurement path, scholars generally use innovation output as the variable in collaboration research of the coexistence of papers and patents. After all, the research projects of both universities and firms belong to innovation activities. At the national level, universities, public institutes and private enterprises are regarded as the main participants in innovation activities. Due to the differences of their own knowledge stock, R&D capability and social mission, they have different contributions to the agglomeration of innovation elements in research projects with common goals. As for university-industry collaboration, universities and industries are complementary to each other in knowledge capital, human capital and social capital. Universities have strong research capabilities and relatively sufficient knowledge base, so they have an advantage in innovation resources. Therefore, we propose the following hypothesis.

**Hypothesis 4 (H4).** *Collaboration breadth of organizations has a positive effect on innovation output.*

Kang and Park [4]’s study presented that the multiple organizational network in cooperation is considered to affect the innovation performance. In line with De Man and Duysters [46]’s conclusion that the interorganizational relationship stimulates innovation. The establishment of interorganizational cooperative networks has increased the sources, quality and technicality of information. In particular, in the context of specialization and scarcity of resources, the reciprocal information exchange path is the key to guarantee the innovation achievements [46]. Collaboration breadth clearly extends different knowledge bases, which helps to quickly seek new technologies and grasp the trend of future technology development among organizations [54].

Although interorganizational collaboration expands the R&D resources of innovation output in research projects. However, the national scientific research activities have a strategic mission of talent training and advances in technology. The excessive pursuit of cutting-edge knowledge in the innovation activities of universities and public research institutes leads to insufficient attention to the economic effect of the industrialization of their innovation results, which is too far away from the market. Yet, firms are usually market-oriented and pursue economic benefits. However, due to the lack of R&D capacity, they need to obtain research support from universities, institutes and public laboratories. Thus, the increase of organizations in cooperation not only complements research resources,

but also brings about conflicts of communication and benefits. Shi, Wu [55]’s empirical study shows that the initial stage of university-industry collaboration has a restraining effect on the company’s innovation efficiency. After all, in the different stages of research and commercialization, scholars believe that different organizations have differences in benefit cognition and the cost of knowledge integration [7,56]. Therefore, we propose the following hypotheses

**Hypothesis 5 (H5).** *Collaboration breadth of organizations acts as a mediator between R&D subsidy and innovation output.*

In addition to the increase in the number of organizations, the expansion of collaboration breadth has been accompanied by an increase in the number of researchers. Zhou, Hong [57] showed that technical human resources affected the knowledge flow in collaborative network between Australia and China. Moreover, researchers promote R&D capabilities, patents and knowledge flow in collaboration activities [4,58]. The advantage of human capital in innovation process is closely related to the experience, skills and abilities of researchers [59]. As for knowledge sharing or mutual learning among researchers, it improves the team’s ability to innovate and provides a continuous complement of the resources to sustain R&D and innovation. Typically, high-tech companies rely heavily on researchers’ intellectual capital for innovation [60]. Nevertheless, the trust, interaction, motivation, cohesion and creativity among researchers play an important coordinating role in innovation of SEMs [3]. Specifically, managers should not hesitate to focus on the sustainable investment of human resource advantage for the radical innovation [44]. Obviously, human capital advantage in collaborative research will facilitate innovation. Therefore, we propose the following hypothesis

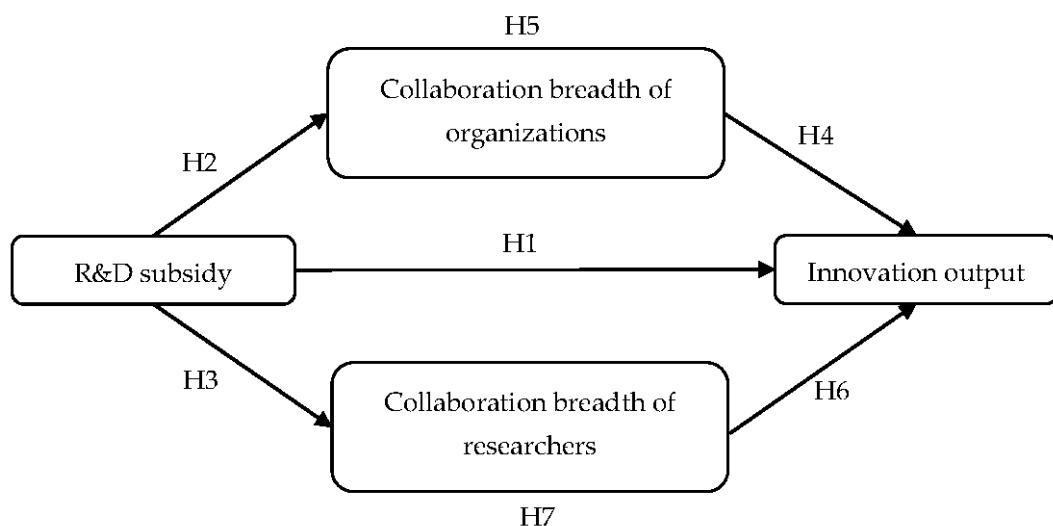
**Hypothesis 6 (H6).** *Collaboration breadth of researchers has a positive effect on innovation output.*

The increase in the number of researchers is the most intuitive embodiment of human resource advantages in research projects. Researchers are the direct objects in the process of knowledge integration, dissemination and sharing. The differences of individual characteristics (e.g., knowledge field, cultural background, experience, ability) increase the complexity of communication interface [13]. On the one hand, the interaction mechanism and practice formed in collaboration provide channels for promoting knowledge transfer and increasing opportunities for organizational learning among researchers. The cooperative experience and organizational practice communication of internal staff is contributing to knowledge integration of enterprises [61], thus expanding the influence of collaboration breadth on innovation performance.

On the other hand, knowledge integration is usually accompanied by accidental knowledge leakage in an open organizational environment [62]. Besides, considering the possibility of the above risks, it leads to a sense of unfairness in the distribution of benefits. Therefore, opportunistic behaviour may breed in the cooperation of researchers [63], such as cooperation break down, negative and slack cooperation. Especially in research projects with long R&D cycles, innovation resources (R&D subsidy, equipment, knowledge integration) are often heavily invested, and the opportunism of researchers is a serious threat to the stability of cooperative relationships. Consequently, we propose the following hypotheses.

**Hypothesis 7 (H7).** *Collaboration breadth of researchers acts as a mediator between R&D subsidy and innovation output.*

Figure 1 provides the research model and our hypotheses.

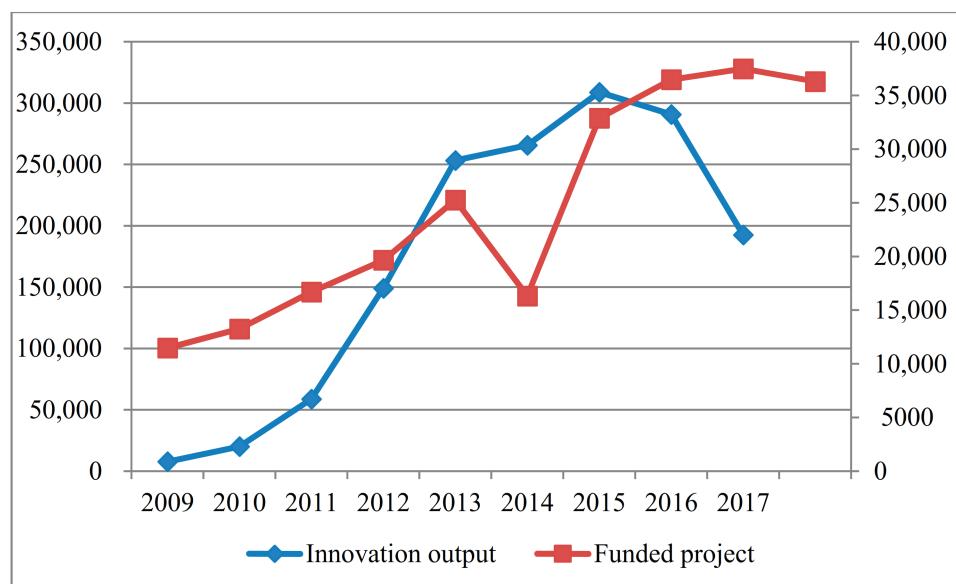


**Figure 1.** Theoretical model.

### 3. Data and Method

#### 3.1. Sample and Data

In this section, we selected our samples from the national natural foundation basic research knowledge base (<http://ir.nsfc.gov.cn/search>). This database is a part of the big data knowledge management service platform of national natural fund. The purpose of this service platform is to comprehensively display the current situation of NSFC research funding and promote the opening of basic research information resources, including basic research knowledge data, big data knowledge management and network services. This platform provides supported fund information, completed projects, project results retrieval and statistical information. Based on the summary of historical data, we found that NSFC funded projects and innovation outputs were present in Figure 2.

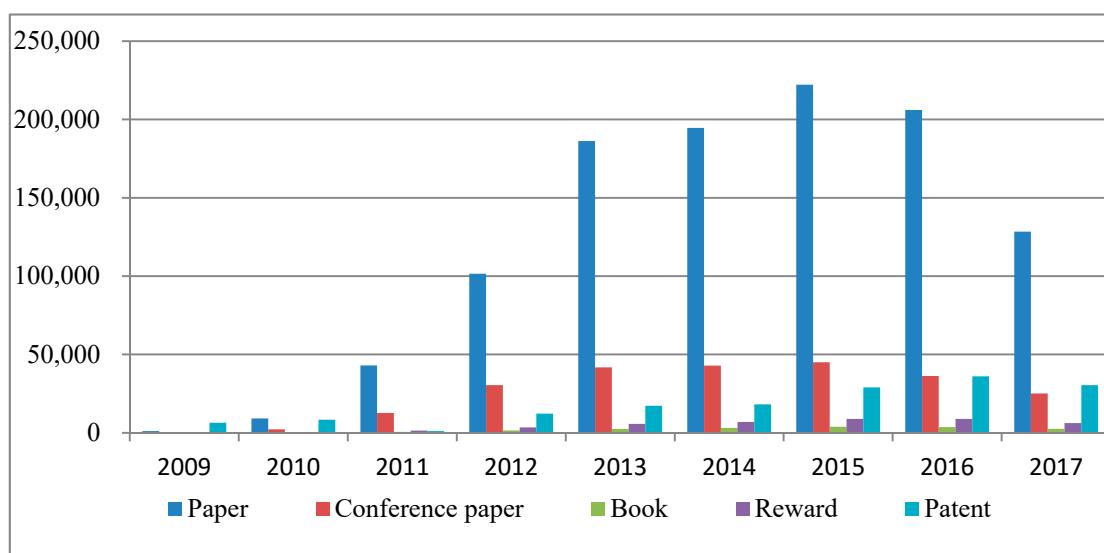


**Figure 2.** The number of research project and innovation output, 2009–2017.

As shown in Figure 2, an increase in the number of research projects does not necessarily facilitate innovation outputs, although two indications were generally consistent. However, after 2015, they showed the opposite trend, that is, as the number of projects

increased, the innovation outputs decreased. Notably, this phenomenon has appeared for two consecutive years, and the subsequent years are still unknown due to the limitations of the database. Therefore, we find that the innovation performance of research project is not completely affected by the number of funded projects. It must be restricted by other influencing factors.

As shown in Figure 3, the innovation output of research projects was mainly presented in the form of papers, conference papers, books, patents and rewards. Additionally, papers and patents were account for more than half of innovation output. As we know, the phenomenon of collaboration widely exists in the publication of papers and the grant of patents. As the important factors influencing the innovation activities, the different types of collaboration breadth or network structure significantly influence innovation performance.



**Figure 3.** The distribution of innovation output in research projects, 2009–2017.

With the support of shared service network of NSFC, we chose research projects were limited to produce academic papers, conference papers books, patents in 2019. The specific project information collection steps are as follows: in the first step, using 2019 as a label to retrieve 667 journal articles. Then, we received the number of research project from paper information. Thirdly, the project number is used as the keyword to retrieve the corresponding finished project information. Finally, we collected 230 items with complete information. We obtained datasets including project name, project type, subject application code, project leader, the title of researchers, number of participating organizations (e.g., universities, institutes, enterprises, public hospitals), project duration, supported funds and the number of research results (e.g., papers, patents, monographs, conference papers).

### 3.2. Dependent Variable

Innovation output (IO). Papers and patents have been widely used as proxy to innovation performance [12,64]. Books and rewards are also viewed as important indicators of innovation performance in NSFC. In this study,  $n$  denotes the number of types of innovation output in each research project, and  $P_i$  represents the number of innovation outputs of type  $i$ . Therefore, all types of outcomes of each research project will be examined as the measure of innovation performance, which can be calculated as follows:

$$\text{Innovation output} = \sum_{i=1}^n P_i$$

### 3.3. Independent Variables

R&D subsidy. As an important resource to maintain innovation activities, R&D subsidy can stimulate innovation [29,33]. Firstly, governmental subsidies are the main source for supporting universities and institutes to engage in innovation activities [65]. Secondly, papers, patents, rewards and other knowledge outputs provide explicit indicators for the performance of research projects. Thus, NSFC funded expenditure is selected as a proxy of R&D subsidy in each research project.

Collaboration breadth. The types of collaborative networks in innovation activities have been discussed in previous literatures [6]. Coauthored articles and patent co-ownership can be measured as an interorganizational collaboration [4], and the average number of partners can represent the extent of collaboration breadth [6]. Consequently, we proposed that collaboration breadth of each research project should be divided into two aspects: organization and researcher. Two levels of collaboration breadth measures as follows are as follows.

Collaboration breadth of organizations (CO). This variable measures the number of collaborative organizations in each research project. It is considered to be the average ties of each organization in collaborative network.

Collaboration breadth of researchers (CR). This variable measures the number of collaborative researchers in each research project. It is considered to be the average ties of each researcher in collaborative network.

### 3.4. Control Variables

We chose project duration, fund type and university involvement as control variables. The measures of these variables are as follows.

Project duration. Bae and Lee [1] deemed research project duration exists as a time limit on patent output, thus project duration should be controlled for innovation performance in research project.

Fund type. In previous studies, the development type of innovative activities was also considered to be associated with the acquisition, utilization and allocation of external resources [1,66]. That is, the dependence of research activities on external resources determines the innovative performance, so the fund type is controlled.

University involvement. Academic papers and patents are the main evaluation indicators of innovation output in universities. As the main participants of innovation activities, universities also play the role of talent training mission. The advantages of universities in R&D resources and human capital are closely related to innovation output. Thus, we adopted the number of universities involved in each research activity to be controlled in innovation performance.

### 3.5. Descriptive Statistics

Table 1 provides a statistical description of all variables in this study is provided, including mean, correlation coefficient, and significance. In this paper, the dependent variable (innovation output) and two intermediary variables (collaboration breadth of organizations, collaboration breadth of researchers) belong to the count variable, inappropriate use least-squares regression. Meanwhile, their average value and standard deviation are close to each other, and the distribution is not excessively dispersed. Thus, we adopted Poisson regression analysis to test the hypothesis in the previous section.

**Table 1.** Descriptive statistics and correlations.

Variable	1	2	3	4	5	6	7
1. Innovation output	1						
2. R&D subsidy	0.7995 ***	1					
3. Collaboration breadth of organizations	0.3129 ***	0.2764 ***	1				
4. Collaboration breadth of researchers	0.1493 **	0.1491 **	0.3086 ***	1			
5. Project duration	0.3038 ***	0.4142 ***	0.3309 ***	0.4429	1		
6. Fund type	−0.0045	−0.1588 **	0.0117	0.0956	−0.1098 *	1	
7. University involvement	0.0687	−0.0081	−0.0594	−0.3007	−0.4398 ***	0.0101	1
Mean	20.9000	77.4609	1.3304	7.4739	3.5391	0.7261	0.5478
S.D.	28.6081	147.4804	0.6832	2.0296	0.7152	0.4469	0.4988
VIF		2.2109	1.3400	1.6118	2.1725	1.3465	1.2217

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

The results of variable correlation show that independent variable (R&D subsidy) is significantly positively related to innovation output. Two intermediary variables, namely collaboration breadth of organizations, collaboration breadth of researchers, are significantly positively related to innovation output. The correlation coefficients between independent variables and intermediate variables are both significantly positive. There is a significant positive coefficient between the two intermediate variables.

In addition, to evaluate multicollinearity in the constructed model, we measure variance inflation factors (VIFs) for variables. Obviously, all VIFs are well below the alert value of 10. The maximum value is 2.2109. Such results indicate that there is no obvious multicollinearity in this model [67].

### 3.6. Method Specification

The dependent variable belongs to non-negative count characteristic data in this paper, so we do not choose the commonly used least squares regression to analyse the sample data. Poisson regression model or negative binomial regression model is usually suitable for the type data. As shown in Table 1, the distribution of dependent variables does not show a more discrete trend, and their mean and variance are relatively close. It implies that negative binomial regression model is not suitable [7]. That is, Poisson regression model should be selected in this study. In a similar vein, the same way is used to explore the mediating effect of collaboration breadth. Moreover, we evaluate the multicollinearity of variables by the measure of VIFs. In order to avoid reverse causality, we add geographic location tool variables to the model when testing the robustness of regression results. Our models can be divided into three parts. Firstly, we evaluate the direct effect of R&D subsidy, collaboration breadth of organizations and collaboration breadth of researchers on innovation output, respectively. Secondly, we evaluate the direct effect of R&D subsidy on collaboration breadth (organizations and researchers), respectively. Finally, combined with the results of the above two parts, we evaluate the indirect tie between collaboration breadth of organizations and innovation output.

## 4. Empirical Analysis

Table 2 displays Poisson regression analysis results of our samples, including the direct and indirect effects on the dependent variables. Model 1–7 tested the above five assumptions about direct and indirect effects. Model 1 included independent variable (R&D subsidy) and control variables (Project duration, Fund type and University Involvement). In model 2 and 3, intermediary variables were respectively entered to determine the direct effect of collaboration breadth. Model 4 and 5 are used to examine the direct effects

between independent variable and two intermediary variables, respectively. Then, to check the two intermediary effects, collaboration breadth of organizations and researchers were added in model 6 and 7. Model 8 is used to examine the effect of R&D subsidy on innovation output holding collaboration breadth of organizations and collaboration breadth of researchers' constant.

**Table 2.** Poisson regression analysis results of collaboration breadth on innovation (standard errors in parentheses).

Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Variables		IO		CO	CR		IO	
Control variables								
Project duration	0.0110 (0.0276)	0.5531 (0.0219) ***	0.6743 (0.0239) ***	0.0445 (0.1245)	0.0584 (0.0548)	-0.0127 (0.0281)	0.0303 (0.0287)	0.0080 (0.0292)
Fund type	0.4780 (0.0302) ***	0.4219 (0.0307) ***	0.5102 (0.0300) ***	0.1313 (0.1219)	-0.0432 (0.0533)	0.4480 (0.0309) ***	0.4747 (0.0302) ***	0.4394 (0.0311)
University involvement	0.3311 (0.0341) ***	0.1674 (0.0337) ***	0.2119 (0.0344) ***	0.1116 (0.1319)	0.1065 (0.0559) +	0.3067 (0.0345) ***	0.3597 (0.0354) ***	0.3377 (0.0355) ***
Independent variables								
R&D subsidies	0.6334 (0.0190) ***			0.2388 (0.0960) *	0.1106 (0.0447) *	0.6143 (0.0197) ***	0.6418 (0.0192) ***	0.6222 (0.0199) ***
Collaboration breadth of organizations		0.2236 (0.0165) ***				0.0766 (0.0175) ***		0.0878 (0.0177) ***
Collaboration breadth of researchers			0.0005 (0.0089)				-0.0255 (0.0079) **	-0.0316 (0.0080) ***
Constant	-0.1179 (0.0890)	0.3144 (0.0923) ***	0.1122 (0.0920)	-0.9741 (0.3740) **	1.3118 (0.1663) ***	-0.0295 (0.0907)	-0.0463 (0.0919)	0.0721 (0.0944)
Number of observations	230	230	230	230	230	230	230	

+  $p < 0.1$ , \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

#### 4.1. Direct Effects

As for the direct effect on innovation output, the paper defines it as increasing or decreasing innovation output without any intermediary. As shown in Table 2, the results of model 1 show that R&D subsidy have a positive and significant impact on innovation output, supporting H1. In model 2 and 6, collaboration breadth of organizations significantly significant positive effect on innovation output, supporting H4. In model 4, the coefficient of R&D subsidy is positive and significant on collaboration breadth of organizations, supporting H2. Meanwhile, the result of model 5 shows that the relationship between R&D subsidy and collaboration breadth of researchers is positive and statistically significant. Consequently, H3 is supported. Unfortunately, the result of model 7 is also not consist with it, which indicates that the collaboration breadth of researchers significantly negative affect innovation output. Thus, H6 is not supported.

#### 4.2. Indirect Effects

As for the indirect effect on innovation output, the paper defines it as a variable that can act as a mediator between direct effect and innovation output. In terms of the indirect tie of collaboration breadth on innovation output. Model 4 shows that R&D subsidy has a significant positive impact on collaboration breadth of organizations. Meanwhile, collaboration breadth of organizations has significant positive effects on innovation output

in model 6, which is partly mediating effect. Thus, H5 is supported. This indicates that collaboration breadth of organizations positively moderates the relation between R&D subsidy and innovation output. In other words, it can increase the benefits of R&D subsidy to innovation. Model 5 presents that R&D subsidy has a significant positive effect on collaboration breadth of researchers. In model 7, collaboration breadth of researchers has a significantly negative effect on innovation output. Thus, H7 is supported. However, it shows that collaboration breadth of researchers has a negative moderating effect between R&D subsidy and innovation output. That is to say, the increase of the collaboration breadth of researchers will reduce the benefit of R&D subsidy to innovation output. Finally, the total effect of R&D subsidy on innovation output is also supported in this section. Specifically, the results of model 8 are consistent with the results of model 1 in Section 4.1. Thus, H1 is supported again.

#### 4.3. Robustness Check

In order to ensure the robustness of the empirical analysis results in this paper, we have made two adjustments to our model. Firstly, different measure of innovation output is accepted, that is, other types of knowledge benefits are deleted, and only academic papers are used as innovative achievements of research projects. Secondly, geographical location is added into the model as a control variable. The location of project has a significant impact on the knowledge spillover effect of innovation activities. Developed region has strong absorption capacity in collaboration [12]. Qiu, Liu [12] divided Chinese provinces into three clusters based on GDP and innovation performance (the number of university paper university coauthored paper (Cluster 1: Shanghai, Guangdong, Jiangsu, Zhejiang, Shandong, Hubei, Liaoning, Shaanxi; Cluster 2: Anhui, Hebei, Heilongjiang, Hunan, Jilin, Sichuan, Tianjin, Chongqing; Cluster 3: Fujian, Guangxi, Guizhou, Henan, Jiangxi, Shanxi, Yunnan). Therefore, location in this study was classified as two types: developed and developing regions. Location variable is set as a dummy variable in the robustness test model. Developed region (cluster 1 and 2) included Beijing, the default value is developing region.

As shown in Table 3. In terms of direct effects, model 1 is to examine the direct tie between R&D subsidy and innovation output. Models 2 and 6 are to verify the direct tie between collaboration breadth of organizations and innovation output. Models 3 and 7 aim to test the direct tie between collaboration breadth of researchers and innovation output. Models 4 and 5 are used to verify the direct effects of R&D subsidy and collaboration breadth, respectively. Meanwhile, models 1, 4 and 6 provide the indirectly positive effect of collaboration breadth of organizations between R&D subsidy and innovation output. In a similar vein, models 1, 5 and 7 present the indirect effects collaboration breadth of researchers between R&D subsidy and innovation output, and their results are inconsistent. Finally, H1, H2, H3, H4, H5, H7 are all supported; H6 are not supported. The results of the robustness test in this section are consistent with Sections 4.1 and 4.2. Therefore, we deem that the results of this study are generally robust.

**Table 3.** The results of robustness check (excluding conference papers, awards and books).

Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Variables		IO		CO	CR		IO	
Control variables								
Project duration	−0.0158 (0.0306)	0.6028 (0.0245) ***	0.7498 (0.0271) ***	0.0450 (0.1248)	0.0573 (0.0545)	−0.0301 (0.0312)	0.0217 (0.0325)	0.0053 (0.0330)
Fund type	0.3603 (0.0340) ***	0.3678 (0.0347) ***	0.4432 (0.0338) ***	0.1340 (0.1226)	−0.0487 (0.0535) +	−0.0301 (0.0350)	0.3533 (0.0389) ***	0.3265 (0.0352) ***

**Table 3.** Cont.

<b>Model</b>	<b>Model 1</b>	<b>Model 2</b>	<b>Model 3</b>	<b>Model 4</b>	<b>Model 5</b>	<b>Model 6</b>	<b>Model 7</b>	<b>Model 8</b>
University involvement	0.1822 (0.0372) ***	0.005 (0.0368)	0.0667 (0.0375) +	0.1111 (0.1319)	0.1078 (0.0559)	0.1684 (0.0376) ***	0.2337 (0.0341) ***	0.2182 (0.0390) ***
Location	−0.1819 (0.0378) ***	0.0379 (0.0367)	0.0958 (0.0360) **	0.0275 (0.1277)	−0.0559 (0.0528)	−0.1858 (0.0378) ***	−0.1929 (0.0379) ***	−0.2008 (0.0380) ***
Independent variables								
R&D subsidies	0.7184 (0.0214) ***			0.2353 (0.0975) *	0.1177 (0.0451) **	0.7091 (0.0219) ***	0.7281 (0.0215) ***	0.7157 (0.0221) ***
Collaboration breadth of organizations		0.1958 (0.0194) ***				0.0451 (0.0203) *		0.0664 (0.0206) **
Collaboration breadth of researchers			−0.0304 (0.0100) **				−0.1929 (0.0087) ***	−0.0506 (0.0089) ***
Constant	−0.3305 (0.0994) ***	0.0562 (0.1038)	−0.0969 (0.1037)	−0.9813 (0.3757) **	1.3262 (0.1667) ***	−0.2831 (0.1013) **	−0.1837 (0.1037) +	−0.0984 (0.1066)
Number of observations	230	230	230	230	230	230	230	230

+  $p < 0.1$ , \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

## 5. Conclusions and Limitations

Innovation capacity is often regarded as the driving force for sustainable economic growth. Under the macro perspective of national economic competition, various research projects are an important choice for technology catch-up countries to improve their innovation capacity, aiming to catch up with developed countries in the economic and technological gap. The national natural science foundation of China, as one of the largest official channels for basic research in China, and part of the national innovation system, aims to enhance the innovation capacity of organizations (universities, institutes, enterprises) and researchers (professors, engineers, PHDS and masters). Thus, this paper discusses the characteristics of collaboration breadth in NSFC funded research projects and examines how collaboration breadth affects innovation output from the perspective of organization and researcher.

The main purpose of this study is to explore the direct influence of two types of collaboration breadth (organizations and researchers) on innovation output. At the same time, we also confirm the intermediary role of collaboration breadth of organizations between R&D subsidy and innovation output. Specifically, R&D subsidy in research projects has a positive direct tie on innovation output. It stimulates the growing of innovation achievements, which is line with previous studies [29,33]. Collaboration breadth has direct and indirect influence in this process, but only the positive effect of collaboration breadth of organizations is supported. Firstly, collaboration breadth of organizations has a positive tie to innovation output; secondly, collaboration breadth of organizations has a significant positive intermediary effect between R&D subsidy and innovation output. Thirdly, collaboration breadth of researchers has a significant negative intermediary effect between R&D subsidy and innovation output. Meanwhile, the direct relationship between collaboration breadth of researchers and innovation output is not supported. It suggests that the integration of human resources in collaboration breadth has certain complexity [6]. In other words, the relationship between the number of researchers and innovation output is still uncertain in collaboration, so we should further explore the other influencing factors in collaboration. As we know, innovation output includes papers, patents, monographs and awards, which are regarded as new knowledge. New knowledge creation is closely related to heterogeneous knowledge integration and intellectual property right [1,68,69]. However,

collaboration provides an open climate to balance the relationship, and knowledge diffusion is a tie to maintain collaboration. Obviously, compared with the knowledge diffusion and integration among organizations, there are higher fortuity, uncertainty and informality among researchers [21,63]. Therefore, interorganizational collaboration in research projects can improve innovation output, but the integration of human resources needs to be further explored in collaboration.

### 5.1. Theoretical Contributions

The contribution of this study is to provide a new perspective for the cognition of collaboration breadth. We expand the existing research on the relationship between collaboration breadth and innovation. In addition, we analyse the direct and indirect effects of collaboration breadth (organizations and researchers) on innovation output, which has not been paid attention to by some existing literatures [7,70]. This study can be used as an exploratory test of collaboration breadth and influences in the innovation output of research projects funded by NSFC. Based on resource-based view [71], this paper confirms the impact of R&D subsidy and collaboration breadth of organizations on innovation output. The results show that the increase of the number of organizations in collaboration can improve the efficiency of research resources (R&D subsidy) in innovation activities and thus improve the innovation output. On the other hand, based on organizational learning view, the communication and interaction among researchers create innovative opportunities [20,72]. This study explores the impact of collaboration breadth of researchers on innovation output in innovation activities. The results show that the linkage between the number of researchers and innovation output, which may be complexity and uncertainty. It implies that, compared with the knowledge transfer across organizations, the communication through research is more likely to be affected by accidental factors. After all, knowledge transfer paths across organizations are more standardized. Combined with knowledge sharing, flow, dissemination and disclosure of relevant literature [62,67,73], this paper suggests that the above factors may exist between the collaboration breadth of researchers and knowledge transfer. Finally, the results confirm the role of R&D subsidy and collaboration breadth in innovation activities and emphasize the differences of collaboration breadth at the organizations and researcher. The empirical results show the stimulating effect of R&D subsidy on innovation output, which can be further amplified by collaboration breadth of organizations. However, the role of collaboration breadth of researchers on innovation output still needs to be further explored from other perspectives. Our conclusion deepens the cognition of collaboration breadth in innovation activities and has theoretical and practical significance for the future research in the field of collaboration innovation.

### 5.2. Practical Implications

This study provides some important policy applications. Firstly, this paper expands the cognition of collaboration breadth and focuses on the difference of it at two different levels: organization and researcher. The organization has more influence on the integration of innovation resources than the researcher. The management of the collaboration project should pay attention to organizations, which provides direct and indirect positive effects to innovation output. Secondly, the uncertainty of opportunism among researchers may be the key factor restricting the output of collaboration research and innovation. As the direct implementers of knowledge and resource integration, the role of researchers in research projects is worth empirical analysis from many aspects. This conclusion may provide a new perspective on the impact mechanism of collaborative research and innovation performance.

### 5.3. Limitations and Future

There are still some limitations in this study. First, the background of collaboration relationship is lack of discussion in research projects. Whether our results can extend to other types of research projects, industries and knowledge backgrounds remains to be

tested. Secondly, sample size and data acquisition are also a limitation of this study. These factors lead to potential problems in our conclusions. After all, this study only focuses on these research projects funded by NSFC and only take these finished research projects in 2019 as samples. Besides, our dataset is limited to China, which is a typical technology catching up country. Compared with the traditional developed countries in science and technology, there are significant differences in their attention to innovation activities. Therefore, the validity of our conclusions is still to be further confirmed in different technical contexts. Third, knowledge sharing and diffusion are not considered in our measurement of collaboration breadth, which may lead to potential mistakes in our cognition of it. Our study also provides related future research directions. First, is there a similar phenomenon in university-industry collaboration? Secondly, whether the collaboration breadth is affected by knowledge sharing, diffusion and leakage among different subjects? Thirdly, if so, how knowledge affects the relationship between collaboration and innovation in research projects?

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