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# IS-Supported Innovation for China's Research Community

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# IS-SUPPORTED INNOVATION FOR CHINA'S RESEARCH COMMUNITY

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## ABSTRACT

*Through the aegis of the National Natural Science Foundation of China (NSFC), China has embarked on an ambitious effort to regain prominence in innovation and academic contribution to knowledge after decades of relative neglect precipitated by the "cultural revolution." Unfortunately, initial efforts made during the last decade of the 20th century resulted in quick growth in knowledge quantity (e.g., publications) that failed to generate sound growth in knowledge quality (e.g., citations). Incentives in place were not producing desired results. An innovative collaborative Internet-based Science Information System (ISIS) was applied nation-wide in 2003 in China's Research Community (CRC) with a variety of embedded incentives to rectify the situation. The system has been well received. In the year 2005 alone, ISIS helped the NSFC to process more than 53,000 on-line funding applications and 250,000 electronic reviews from 1,400 universities and research institutes in China. This paper is aimed at exploring Information Systems (IS) innovation impact from the perspective of incentive alignment based on CRC empirical results. Since the nation-wide application of ISIS in 2003, CRC outcomes have markedly improved. Discussion and directions for future research examine generalizability in the context of information systems for innovation and collaborative business. Conclusions are drawn.*

*Keywords: incentive alignment, game theory, electronic knowledge repositories, reward system, IS design*

# 1 INTRODUCTION

Academic research and subsequent contribution to literature by Chinese scholars are only beginning to recover after the impact of the “cultural revolution.” Unfortunately, initial efforts in inducing contribution resulted in: perceived inequality for funding support, misconduct leading to publication quantity without quality, and general lack of recognition by the rest of the world. Quick growth in publication quantity saw only meagre growth in the number of citations. Simply put, incentives in place were not producing desired results. A game theory model is used to demonstrate that incentives to produce without appropriate inducements and attention to quality control tend to cause the situation that occurred. Counter-productive Nash equilibriums exist that require special attention to overcome. This burden fell upon the National Natural Science Foundation of China (NSFC) which is the largest and most prestigious government funding agency for basic research in China.

To effectively and efficiently encourage sustained research and contribution to globally recognized literature, NSFC has embarked on an emphasis on the Internet-based Science Information System (ISIS, <https://isis.nsf.gov.cn>). ISIS now annually manages qualified peer review, sharing of information and openness for critique, which culminated in research funding distribution for over 60,000 grant submissions in 2006; this exemplifies an annual increase rate of over 15%. Independent, rationally-driven, merit-based research funding separating governmental politics from academic achievement and recognition has begun to be achieved. Empirical results to date (reported in this paper) illustrate solid progress in attaining system goals and objectives. Academic behavioral change has occurred and performance has improved. Information Systems (IS) supported innovation is on the way to illustrate positive results in a real-life complex domain.

Use of ISIS for knowledge innovation leads us to several research questions: What is the innovation that ISIS puts into practice to win the trust of scientists? What are the incentives that ISIS conveys to support collaborative research and knowledge sharing among scientists? What are the influences of the application of ISIS from the perspective of knowledge management? What are the implications of ISIS for innovative and collaborative business? The first two questions are intended to explore the characteristics of ISIS within the framework of: Technology Adoption Model (Davis 1989), Incentive Alignment (Ba et al. 2001) and Game Theory modelling (Zhang et al. 2006). The last two questions are open questions and we draw conclusions based on our investigations.

In this paper, we provide additional details of IS-supported innovation for China’s research community, including game theory analysis and empirical results to date. Discussion and directions for future research examine generalizability and comparison to other global systems in the context of information systems for innovation and collaborative business. Conclusions are drawn.

# 2 BACKGROUND

Within the academic community, ideas are formed (based, in part, on existing literature) that lead to proposals which (when subsequently funded) support research contributing to knowledge that is

reported and subsequently cited in the academic literature. This tends to generate even more ideas and the cycle continues as we build up an ever larger body of knowledge. However, a number of problems can easily arise. For example, perceived inequalities in research funding support can be disruptive, as can proliferation of papers of dubious quality. Within the decade, misconduct (e.g., fraud and plagiarism) in the Chinese research community (CRC) has been frequently reported that has drawn considerable attention, e.g., Nature (Cyranoski 2006, Wang 2006) and Science magazine (Xin 2006). A survey (Li 2004) based on 769 scientists funded by NSFC from 1995-1999 reported that 30% of the scientists had perceived misconducts occurring around them; 45.87% thought the problem was more serious than other countries and 48.66% thought it was as serious as others. Another survey (Chen & He 2006) based on 1,072 scientists within CRC showed that 32.2% had strongly perceived misconducts occurring around them, up to 30% reported the problem to be serious or even worse.

Another phenomenon within the scope of the CRC is the significant contrast between rapid increase in quantity versus low quality of the output. Although the rank of China in SCI counts changed from 15th in 1991 to 6th in 2002 (Jin 2004), its rank in Essential Science Indicators is only the 14th in the world and the 18th if SCI citation counts weighed. Since SCI was admitted as the only criteria in evaluating research productivity, such an incentive did not seem to lead CRC to enhance Research and Development (R&D) quality. Over 2 decades, researchers were striving to publish as many papers as possible, at the expense of quality. They are, however, facing ever increasing demands now for better performance coming from the government, industry and global scientific societies, accompanied by the inducement of Chinese innovation in conjunction with the most recent 5 year plan.

Generally, quality improvement is likely to be limited without quantity but quantity is no guarantee that quality will occur (Jin 2004). Accompanied by a lack of synthesized evaluation standards, large percentage of scientists did not focus on contributing high-quality knowledge to the community. Therefore, we have reason to believe that the incentives in place were not producing desired results.

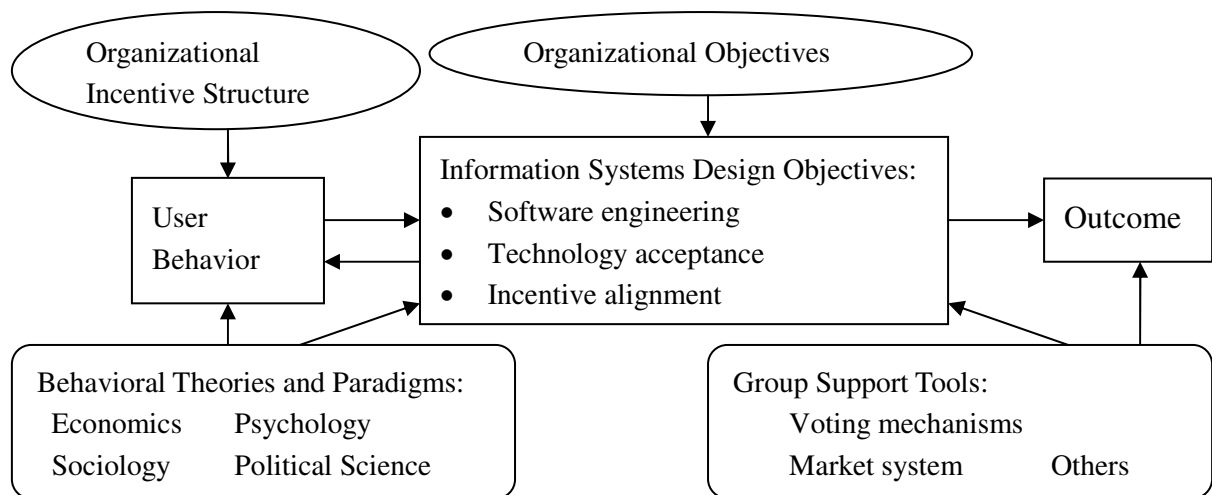


Figure 1. Information Systems Design Framework for Incentive Alignment

(From Ba, Stallaert and Whinston, 2001)

In the context of incentive alignment, Ba, Stallaert and Whinston (2001, figure 1) developed a framework that presents factors which could be influenced by IS design (square boxes) and which

theories or disciplines (rounded boxes) might be relevant to explain the relationship between user behavior, the system’s objectives and the overall outcome. Central to the framework is the dialectical relationship (represented by the two arrows in the opposite directions) between user behavior and the mechanism incorporated in the information system. In the following part of our research, we are trying to explore both the user behavior and the outcome on the road to understanding incentive consistency and impact.

### 3 GAME THEORY MODEL

As noted, different incentive strategies can cause knowledge users and knowledge contributors to take different actions, moderated by exogenous variables. Then under what conditions will rewards be misleading? How can we design mechanisms to deal with the public good problem? In Zhang et al. (2006), we designed two game-theory models: a simple model and a complex model. The assumptions and proofs are omitted here, that is, only the concept and result are provided.

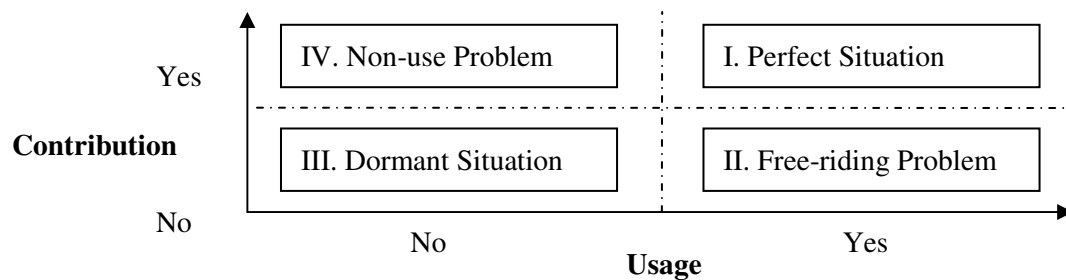


Figure 2. Knowledge Sharing Dynamics

In public goods theory, individual rationality may lead to collective irrationality (Kollock 1999). We designed a 2 by 2 matrix as shown in figure 2, where the two decisions are the axes (Contribute - yes or no and Adopt - yes or no). We can also find similar problems in the context of “knowledge sharing dilemmas” (Cabrera & Cabrera 2002). Each quadrant represents a situation. Situations II, III, IV are considered to be troubling.

A simple model considers the “contribution or not contribution” decision. There are four possible Nash-Equilibriums (N-Es) (four quadrants are possible). The perfect situation is the N-E attained only when the threshold of users and contributors are all positive. Each user will contribute his/her knowledge, and they all use others knowledge from systems. If the time cost of usage is sufficiently low, situation I is the only N-E. If reward is sufficiently high, situations I & IV are two possible N-Es.

A complex model considers the contribution of high or low quality knowledge. There are more possible N-Es than the simple model, which means that several situations may lead to the same equilibriums, and that users are more sensitive to the reward. When the reward is sufficiently high, it misleads participants to an ineffective situation, which is unique N-E, and the participants contribute a considerable quantity of low quality knowledge but do not use knowledge. This indicates that reward needs to be controlled at a certain level to generate an effective result. The role of incentive alignment is indispensable.

Theoretically, we can identify the amount of reward that will lead to certain equilibriums. However, empirically, we are not able to calculate that. Therefore, our empirical study can shed light on the users' behavior and the outcome of the IS application. If results show a certain situation occurring, we can deduce the possibility of inappropriate rewards being added.

#### **4 INTERNET-BASED SCIENCE INFORMATION SYSTEM (ISIS)**

The NSFC is a government organization directly affiliated to the State Council. It is the largest and most prestigious government funding agency for basic research in China. Since 2000, ISIS has been introduced by NSFC and generalized to nation-wide use in 2003.

ISIS is an end-to-end solution for researchers, universities/research institutes and NSFC to manage and disseminate their research information (e.g., projects and research outputs). It has greatly simplified the administration processes for application, evaluation and management of NSFC projects. It avoids duplication of data entry and reduces the administrative workload and human errors. It also standardizes the processes and technologies for R&D project administration. Its core functions are:

- Project Application: XML-based electronic document management and submission as well as decision-making support and online review and analysis of application statistics;
- Project Management: Project risk control, analysis of project statistics and project progress and completion reports; and
- Dissemination of Research Outputs: Submission of research results and search and publication of research results.

Any individual researcher can obtain general information on projects approved by the NSFC through ISIS, e.g., project history searches and duplication checks. NSFC program directors, research administrators in universities and research institutions can use ISIS for managing and monitoring the progress of NSFC projects. A major advantage of ISIS is that it allows non-registered users to obtain project information for public supervision (Li 2008). ISIS also accepts data exchanges from internet-based research information systems (IRIS) from participating universities and research institutions, which provides opportunities for extended system application such as institutionally developed database-access-interface to ISIS, Data-exchange Software Packages and virtual research centres for international cooperation (Li 2008, He et al. 2007, Xie et al. 2008, Huang et al. 2003). Good adoption comes from good IS design regarding to the TAM (Davis 1989) model, in the rest of the research, we do not track the trivial evidences of good IS design, but rather, the mechanism behind which brings innovation for CRC to overcome previous disadvantages.

With the application of ISIS, the R&D resource distribution process is becoming increasingly transparent. Scientists from all over the world as well as any individuals interested in the CRC are able to obtain information related to the grants, successful research projects and research outputs. Further, the mechanism of resource allocation goes toward an independent, rationally-driven, merit-based direction, while gradually separating governmental politics and academic achievement recognition. Growing participating and exchanging behavior has emerged, making it appropriate for us to study the problem in the context of electronic knowledge repositories.

## 5 RESEARCH APPROACH

Based on previous theory model and the framework of “Information Systems Design Framework for Incentive Alignment” (Ba et al. 2001), our research approach is illustrated in figure 3.

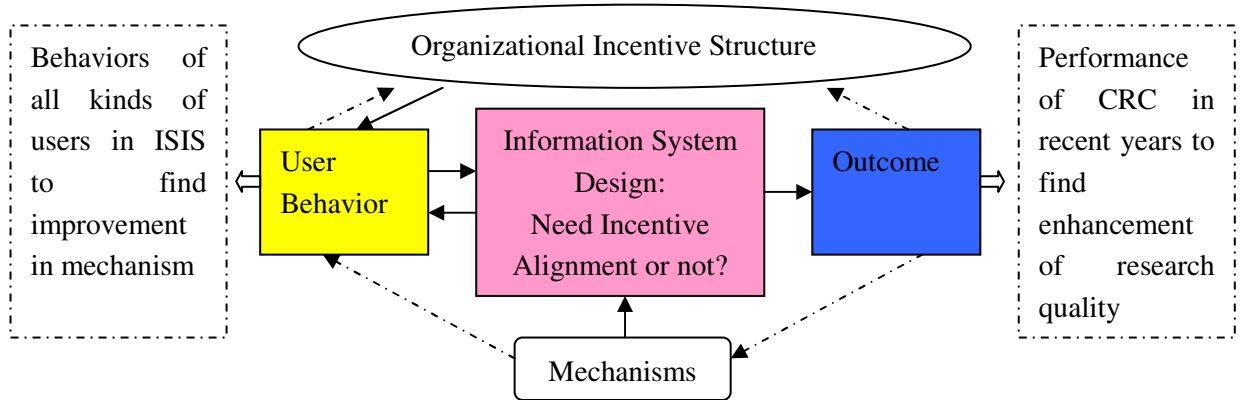


Figure 3. Research Approach Framework

We focused on the path of user behavior to the outcome of IS design. The dashed boxes are measurements for each end of the path. We compared the outcomes to the objectives of IS design to answer the questions posed in the introduction. Two exogenous factors (organizational incentive structure and mechanisms) are discussed via empirical results (the dashed arrows shows the explanation relationships).

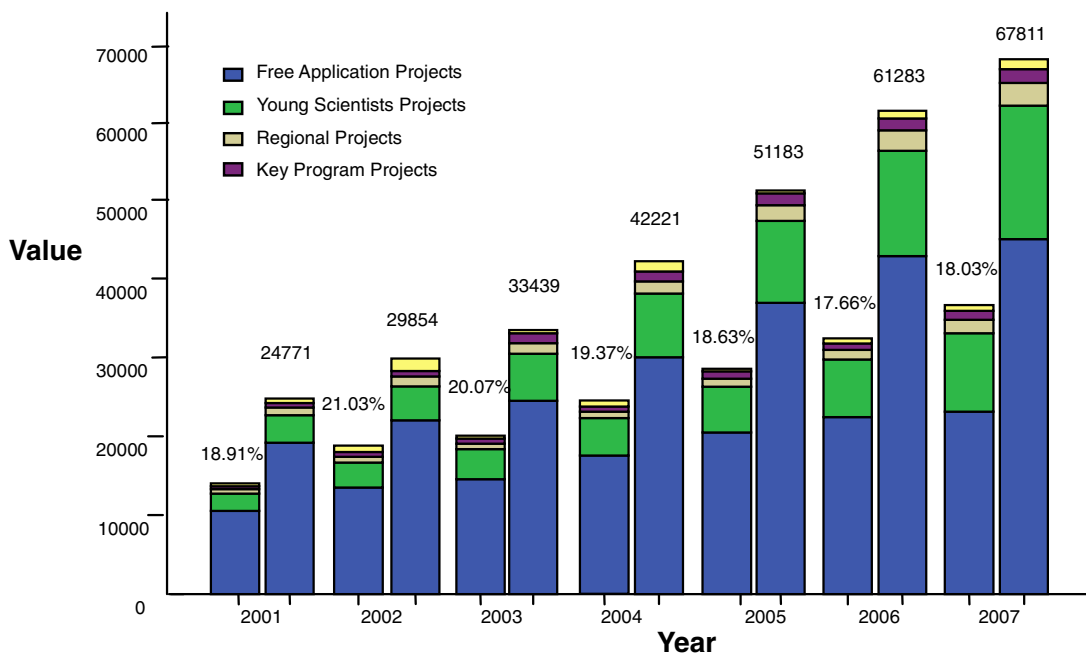
### 5.1 Assessing mechanism improvement

In the allocation of R&D resources, a number of biases were possible, e.g. gender, topic, education, etc. The statistical data on submissions and the decisions of NSFC funding from 2001 to 2007 are used in this study. If incentives were not appropriate, the biases could be high from the result of funding decisions. On the other hand, if incentives were aligned, there could be a trace left on the results of the decisions during the years of the study. In the CRC, many scientists believe that the “Power-Orientated” culture plays a role above mechanism suggesting that the fairness of the running mechanism of ISIS could be questioned. Under such circumstances, we would expect that a scientist would receive more scientific resources as his academic status rose. We collected the information of Academicians of Chinese Academy of Sciences who represents the highest academic status in the Science Community of China, and also measured the scientific resources by the number of research projects they received annually from NSFC. We additionally examined information transparency and richness as well as punishment for violations in the context of incentives. Rewards were considered to be a positive incentive and punishments a negative incentive, which works well as alignment. We observed the change of regulations and the report given by the Supervision Committee of NSFC. There were few reported incidences in the Misconduct Report before 2003. After 2003, it has been clearly published each year and provides specific project information. We also examined organizational level incentives to find how the NSFC monitors institutional performance and how institutions encourage their members to submit high quality proposals. More detail is available in the results section.

## 5.2 Ascertaining enhancement of Research Quality

To empirically examine enhancement of research quality, three disciplines (Earth Science, Chemistry and Management Science) were randomly chosen from the six disciplines that NSFC supports: Physics, Chemistry, Maths, Earth Science, Biology and Management Science. Three or four top journals were selected (also randomly) in each discipline with high Impact Factor in Journal Citation Reports database (JCR Science Edition 2006, ISI Web of Knowledge). The Nature and Science Magazine (from 2000-2007) was also selected to reflect the trend for all natural science research outcomes. Papers published by Chinese scientists from 1987-2007 were counted, within which papers sponsored by NSFC were calculated. If the percentage of the NSFC sponsored papers increased, we felt we had reason to believe that the NSFC was doing a better job than other foundations in China in the field of basic research funding. Since the total amount of funding did increase, a higher percentage illustrates the enhancement which, in part, eliminates other factors influencing paper quality. We then tracked the funding record of the authors of those sponsored papers. First, we examined their performance among all the applicants for the fund; then, we looked into their collaborative behavior. The joint research fund for overseas Chinese young scholars represented the cross-district collaboration of researchers. We examined data for joint research funding from 2001 to 2007. By analyzing the funding percentage and award per project, we could see if NSFC rewards through the years encouraged researchers to collaborate. We also examined the number of proposals each year to reflect the researchers' intention to share project knowledge.

## 6 RESULTS



Note:

1. In each year's result, right bar represents the number of proposals with sum number on top, while left bar represents the number of accepted proposals with average acceptance ratio on top (ratio is not to scale);



2. Data is from Annual Report of NSFC and NSFC web site (<http://nsfc.gov.cn>).

*Figure 4. Funding for NSFC, from 2001 to 2007*

Figure 4 illustrates NSFC funding from 2001-2007 with respective program proposal acceptance submission ratios. In general, we note the relatively increased equality and balance across all of the programs supported since the ISIS introduction in 2003 in conjunction with peer review in the presence of ever increasing submissions and funding. Competition remains keen in that over four out of five proposals go unfunded. Retaining motivation for contribution and sharing is a challenge.

As we mentioned previously, many Chinese scientists have believed that the “Power-Orientated” culture plays a role above mechanism so that the fairness of the running mechanism of ISIS could be questioned. We now examine that issue in more detail. From 2001 to 2005, the Chinese Academy of Sciences accepted 159 new Academicians every other year. The number of newly elected Academicians was 56 in 2001, 58 in 2003 and 45 in 2005 (<http://www.cas.ac.cn>). Based on the project history search function of ISIS, we found among all the newly elected Academicians, there were 29(52%) in 2001, 15(24%) in 2003 and 18(40%) in 2005 that had been funded by NSFC. We tracked the record of the projects and counted the number of projects that they were in charge of from 1999 to 2007, and then we ran tests for 4 groups of data through Wilcoxon Test to test if there was a significant increase in the number of projects. The groups were:

- Group 1: 2 years’ data before and after 2001 for newly elected Academicians in 2001
- Group 2: 2 years’ data before and after 2003 for newly elected Academicians in 2003
- Group 3: 2 years’ data before and after 2005 for newly elected Academicians in 2005
- Group 4: 4 years’ data before and after 2003 for newly elected Academicians in 2003

In the results, we indicate whether the changes are significant before and after the raise in their status.

Group	Sample	Time Section	Mean	Standard deviation	Z-value	Asymp.Sig (2-tailed)
1	29	[2000,2001]	0.3793	0.49380	-2.977 *	0.003
		[2002,2003]	0.8621	0.63943		
2	15	[2002,2003]	0.6667	0.61721	-0.333	0.739
		[2004,2005]	0.6000	0.50709		
3	18	[2004,2005]	0.3333	0.59409	-0.632	0.527
		[2006,2007]	0.4444	0.51131		
4	15	[2000,2003]	1.2000	0.73679	0.000	1.000
		[2004,2007]	1.2000	0.77460		

Note: “\*” represents significant under 95% confidence interval.

*Table 1. Mean Statistics and Wilcoxon Signed Ranks Test of Different Groups*

Table 1 shows that newly elected Academicians in 2001 received 0.46 unit more projects on average and that this change is statistically significant. Newly elected Academicians in 2003 and 2005 did not show this trend. Before 2001, scientists would receive more scientific resources after their academic status was raised. In 2003 and 2005, this situation no longer existed. This implies that fairness in the process of resource allocation has been improved, especially after the application of ISIS in the year 2003. ISIS submission data from 2003 to 2006 also demonstrate that female researchers are making

more submissions annually (from 24% to 31%). A similar situation existed for Associate Professors compared to Professors (from 13% to 16%), indicative of enhanced equality following ISIS introduction.

From the website of NSFC and the hyperlink to the Supervision Committee, no statistics on misconduct cases were published before 2003. Since 2004, the committee started to publish annual reports on the details of the misconduct cases. They even put the punishment decision reports online, providing detailed information on the misconducts. The numbers of the publicized misconduct cases were 16, 20 and 10 in 2004, 2005 and 2006, respectively. Considering that the number of submissions and funded proposals nearly doubled during the period since the ISIS introduction in 2003, the trends are, indeed, encouraging.

In terms of organizational level incentives, the NSFC puts emphasis on group performance. In each year's annual report, the top 20 universities and top 20 research institutions are listed according to their ability to garner NSFC grants. The number of organizations competing for the grants (shown in table 2) continues to grow. As a result, individual applicants are getting feedback and help from their organizations' intellectual advisors responsible for the quality of proposals before they reach ISIS. In addition, most organizations have tied promotion and award decisions to researcher proposal success (He et al. 2007, Su et al. 2007, Gu et al. 2008). Without organizational filters, ISIS would have to cope with many more low quality proposals that could compromise its effectiveness.

Year	2001	2002	2003	2004	2005	2006	2007
Applying for general projects	-	657/1200	672/1126	705/1319	768/1417	816/1576	857/1569
Funding Ratios	-	54.75%	59.68%	53.45%	54.20%	51.78%	54.62%
Funding over 2 million RMB	94	129	137	181	222	259	-

Note: XXX/XXX represents organizations accepted / organizations applied.

*Table 2 Organizational Funding Statistics*

Chinese Scientists have also started to gain global recognition by improved research quality as noted through publications in top-tier journals. In table 3, the number of papers published by CRC in the selected top journals in Earth Science, Chemistry and Management Science has grown in recent years. On average, nearly half have been published with NSFC funding through the use of ISIS. Taking into consideration that the total time span is 20 years (1987-2007), it is noteworthy that more than half of the papers have been published in the most recent 4 years. To further understand the influence of the fund, we checked the background of those researchers who published papers under the NSFC fund in Earth Science and Chemistry. It turned out that 64.3% of researchers in Earth Science and 65.7% researchers in Chemistry were funded by multiple NSFC grants. This implies that they are not only productive researchers, but also active ISIS contributors and users.

Journal	Impact Factor	Total	NSFC	Before	After
Area: Earth Science 1987-2007					
CLIM DYNAM	3.468	27	12	4(33.33%)	8(66.67%)
ACTA ASTRONOM	3.451	1	1	0(0.00%)	1(100.00%)
B AM METEOROL SOC	3.055	16	1	0(0.00%)	1(100.00%)
Area: Chemistry 1987-2007					
CHEM REV	26.054	25	13	4(30.77%)	9(69.23%)
ACCOUNTS CHEM RES	17.113	33	21	12(57.14%)	9(42.86%)
A NNU REV PHYS CHEM	11.25	3	2	0(0.00%)	2(100.00%)
Area: Management Science 1987-2007					
PROD OPER MANAG	2.516	12	3	1(33.33%)	2(66.67%)
J OPER MANAG	2.042	9	2	0(0.00%)	2(66.67%)
TRANSPORT RES B-METH	1.761	63	13	6(46.15%)	7(53.85%)
MANAGE SCI	1.687	31	0	0(-)	0(-)
Science 2000-2007	30.028	269	78	35(44.87%)	43(55.13%)
Nature 2000-2007	26.681	188	72	32(44.44%)	40(55.56%)

Note: Meanings of the columns are as below:

Total - total counts of papers with Chinese authors; NSFC - counts of papers sponsored by NSFC;

Before - paper was received before 2003 (Including 2003); After - paper was received after 2003.

Table 3. *NSFC Funded Papers in Top Journals*

Table 4 shows the joint research fund of NSFC from 2001 to 2006. The intensity of sponsorship decreased a little in the recent 4 years, which means that it was more difficult for researchers to be rewarded. Also, awards per project remained stable, regardless of RMB inflation, indicating that material incentives reduced each year. However, it is noteworthy that the number of proposals grew each year, representing increased interest in international collaboration.

Year	2001	2002	2003	2004	2005	2006	2007
Funding (Million RMB)	24.6	31.6	31.2	31.6	32	32	32
Proposals	285	316	346	359	426	452	391
Approved Projects	61	79	78	79	80	80	80
Intensity of sponsorship	21.40%	25.00%	22.54%	22.01%	18.78%	17.70%	20.72%
Award per project (Million RMB)	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Note: Information of funding, proposals and approved projects comes from annual report of NSFC.

Table 4. *Joint research fund of NSFC*

## 7 DISCUSSION

Returning to our research questions, we now place our results in the context of assertions we have made regarding ISIS impact and implications. The innovation that ISIS puts into practice to win the trust of scientists revolves around transparency. ISIS provides a systematic and consistent means to gather and evaluate research proposals with a sense of fairness and openness that historically has not

been experienced. Results bear this out in the noted equality of funding (independent of professional status) that distinguishes the years after the ISIS introduction from those prior to 2003 and increased gender equity. Embedded incentives support collaborative research and knowledge sharing. Top scientists are not only knowledge sharers, but also part of the mechanism. They are members of peer-review systems, who have access to all kinds of resources. Maybe in the past, without the supervision from the public, they could benefit themselves easily; however, things have changed with the help of ISIS. Those who used to benefit from role-based privileges have had to contribute high-quality proposals to preserve their reputations.

From a knowledge management perspective, ISIS has provided a platform to deal with increased funding levels coupled with peer-review that provides easy exposure to proposal expectations (and examples for all), generating a positive feedback loop. The slowing of misconduct coupled with increased global recognition of Chinese contributions to knowledge is an end result, as demonstrated through publications in top journals. ISIS has provided an aligned incentive mechanism for positive reinforcement of goals, while providing consistent quality control as noted in the stable funding percentage statistics across programs. The implications of ISIS for innovative and collaborative business extend beyond application in China. The system is undergoing evaluation in other international contexts as well.

Limitations of our research are evident in that China is only one country with a unique history. There is no clear way to conclude that ISIS was the only contributor to the academic rise beyond helping manage the successful increase in funding support and proposal submissions. Future research will focus on continued tracking of Chinese academic influence, including citation analysis, always recognizing that there is a natural bias towards increased numbers of citations for older papers. Extensions to ISIS are also underway. Ease of use and comprehensive reports are the main current advantages of ISIS. It gives clear guidelines at each webpage, contains a demo presenting full processes for all kinds of users, allows seamless integration with IRIS, and provides rich sets of reports for the management with user editable report contents. Extensions focus on using ISIS to help identify prospective reviewers based on qualifications and better manage the review process accordingly.

## **8 CONCLUSION**

In this paper we have sought to illustrate how an information system, ISIS, with embedded incentives consistent with China's goals of increased global recognition can help rectify traditional dysfunctional activity and promote increased contribution. Aspects of transparency and demonstrated equity have been achieved along with the sharing of knowledge that has led to an overall increase in quality proposals resulting in increased global recognition, as witnessed in publications in top journals. Extensive peer review has been supported and quality control has been attained. Global respect and credibility is evident as is reduction in academic misconduct. In short, the aligned incentive mechanisms embedded in ISIS have been successful. Extensions are envisioned to further automate decision making and effectiveness and efficiency.

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