Management of Science, Serendipity, and Research Performance: Evidence from Scientists’ Survey in the US and Japan

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Abstract

This study investigates the impact of management-research separation on serendipity and research performance in science. Using the Scientists’ Survey in the U.S. and Japan, this paper explores a random sample of 4410 research projects. If a managerial role was played by a leading scientist in the research team in the survey, we consider it as management-research integration. If a managerial role and a leading role in research were conducted by different members, we regard it as management-research separation. The separation of a managerial role from research has a positive effect on the number of papers published for that research project. This positive effect becomes larger as the project size becomes bigger. It also finds that the management-research integration is positively associated with serendipity. This positive effect on serendipity, however, ceases as the project size gets bigger. These results show that the management of research in science has influenced research performance, even though how management in research is conducted is usually exogenously determined. The results also imply that the project manager has quite an important impact on research performance and that if the project manager understands the nature of scientific research and holds specific expertise in the research project, he/she possibly contributes to increase both research productivity and serendipity.

Key words: science, serendipity, productivity, research management
1. Introduction

How is serendipity managed in science? Exploring the scientists’ survey in the U.S. and Japan, this paper investigates the management-research separation and its effect on serendipity and productivity in science.

Serendipity plays an important role in science. Alexander Fleming’s discoveries of the enzyme lysozyme in 1923, and the antibiotic substance penicillin from the mould Penicillium notatum in 1928, are well cited as examples of serendipity. The cosmic background radiation identified by Bell Lab scientists Arno Penzias and Robert Wilson, the circular structure of benzene discovered by Friedrich Kekulé, X-rays developed by Antoine Henri Becquerel, and Hans Christian Ørsted’s findings of the fact that electric currents create magnetic fields are also well-quoted examples of serendipity. There are too many serendipitous findings in science to comprehensively list them. Many of the major discoveries have been made by people who were looking for something very different.

This paper explores how serendipity can be managed in a research organization. It has been pointed out that the pattern of scientific research, often called “Big Science,” has changed during and after World War II. The size of the research project in science has increasingly become larger. The number of researchers in a research project has increased as well (Adams et al., 2005). Advanced research instruments used in science have required large budgets and a wide range of specific expertise. Thus, the large-scale, inter-disciplinary, and inter-organizational research has been of significance (Agrawal and Goldfarb, 2008, Austin et al., 2012). The importance of priority in scientific discovery has also increased (Ellison, 2002, Stephan and Levin, 1992). Since research is increasingly accomplished in teams across nearly all fields (Wuchty et al., 2007), management of the research team becomes significant to the research performance in science.

Serendipity began to be studied in the sociology of science. Now it is being studied in management studies as well (Dew, 2009, Hollingsworth and Hollingsworth, 2000, Nonaka and Takeuchi, 1995). The studies on serendipity and management have been either anecdotal case studies or theoretical and normative. However, there has not yet been much empirical research.

Exploring the scientists’ survey, this paper investigates the impact of managerial and leading research role distribution in a research organization pertaining to serendipity and productivity. First, it shows that serendipity has a positive effect on citation. It is consistent with the anecdotal evidence suggesting that major scientific discoveries are likely to be serendipitous.

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1 Criticism has been presented from different perspectives. For instance, the massive scale of defense related funding channeled research in physics from basic to applied (Forman, 1987). This paper does not necessarily suppose that the Big Science is favorable to progress in science and technology.
Second, it shows that the integration of a managerial and leading research role has a positive effect on serendipity. However, this effect ceases as the project increases. It implies that the integration reduces coordination costs between management and research and provides flexibility in research to scientists, while the advantage of the division of labor in management and science increases as the project size gets larger. Third, the separation of management from research has a larger positive effect on the number of papers as the project becomes bigger. It suggests the tradeoff between serendipity and productivity in science via who plays the managerial role and leading research role in research management.

2. Previous Literature

Research is rarely done in isolation. It has been pointed out that research is increasingly being done by a team. For example, the mean number of authors per paper shows an increase from 2.8 in 1981 to 4.2 in 1999 (Adams, Black, Clemmons and Stephan, 2005). Adams et al. (2005) observed that team size increased by 50% over the 19-year period. This trend towards larger teams is found to accelerate, rising from a 2.19% annual rate of growth in the 1980s to a 2.57% rate in the 1990s. Showing that scientific output and influence increase with team size, the authors imply that research productivity increases with the division of labor in research.

There are several factors behind this increasing trend in team size. For example, a significant number of research has showed that collaborative research produced better outcomes with higher citation rates (Andrews, 1979, Presser, 1980, Sauer, 1988, Wuchty, Jones and Uzzi, 2007). It suggests that the importance of interdisciplinary research has become greater. The diffusion of the Internet and the institutional change has decreased communication costs and promoted the increasing trend of team size (Agrawal and Goldfarb, 2008). The increase of team size in scientific research in the U.S. was attributed to the deployment of the National Science Foundation’s NSFNET and its connection to networks in Europe and Japan after 1987 (Adams, Black, Clemmons and Stephan, 2005). Advancement of research equipment (e.g., cyclotron, particle accelerators, and high-flux research reactors) has been pointed out as one of the factors pushing collaboration and team size. The experimental design has also changed from table-top experiments to large-scale projects. It accompanies changes in the pattern of collaborations among researchers because experimental tools require much different expertise.

Many articles have discussed that diversity in a research team can lead to a greater level of creativity (Allen, 1977, Garvey, 1979, Kasperson, 1978, Pelled et al., 1999). Singh and Fleming discuss that collaboration reduces the probability of very poor outcomes because of more rigorous selection processes, while simultaneously increasing the probability of extremely successful outcomes because of greater recombinant opportunity in creative search (Singh and
Fleming, 2010). Exploring Nobel Prize winners, Zuckerman (1977) showed that nearly two-thirds of the 286 winners named between 1901 and 1972 were honored for work they did collaboratively. By investigating the conditions under which major discoveries or fundamental new knowledge occur in science, Hollingsworth (2006) stated that scientists are likely to develop new and alternative ways of thinking if they interact with scientists with diverse sets of expertise and background with high intensity and frequency. With the advancement of information and communication technology and the institutional changes, scientists could obtain relevant but different knowledge by collaborating with other scientists in discipline areas outside the scientists’ own areas of specialty. Based on the technological and institutional changes and the importance of diversity in a team, accessing external complementary knowledge and different expertise through networking becomes of significance in promoting innovation not only in science but also in business (Fleming et al., 2007, Hagedoorn, 2002, Heinze et al., 2009, Powell et al., 1996).

The increase of team size and diversity in a team suggests that management becomes of importance in science. Managing and coordinating research processes and different expertise and synchronizing team members’ effort into a team goal does not naturally happen (Barnard, 1938, Simon, 1976). If the size of the research team becomes larger and the research becomes more inter-disciplinary and inter-organizational, a role played by research management will be significantly better. For example, it is important to manage certain space, called “trading zone,” in which groups of different expertise learn to interact for utilizing a variety of expertise and delivering breakthrough in science (Collins et al., 2007, Galison, 1997).

Furthermore, competition in science becomes fiercer. The importance of priority in scientific discovery has risen (Ellison, 2002, Stephan and Levin, 1992). Competition exists not only for priority in scientific discovery but also for research funding. Thus, it is increasingly important for a research team to choose a research area and method, and to set a research goal to minimize the threat of being scooped (Dasgupta and David, 1994, Stephan and Levin, 1992).

As research increasingly gets large scale and requires a high level of technical and scientific knowledge, and competition becomes fiercer, it is supposed that management of science is becoming increasingly important. Following the division of labor and coordination costs framework (Becker and Murphy, 1992), this paper regards the research team as closely linked with specialization and the division of labor and explores the impact of management on performance in scientific research. More concretely, this paper directs its attention to the managerial role played in a research team in order to explore the management effect on serendipity and productivity in science research in three aspects.

The first is related to the relationship between serendipity and research performance. One might suppose that serendipity can increase research performance and it is seemingly
considered to do so. However, there is a serious endogeneity problem between serendipity and research performance. A research team pursues for publication only when it considers it to be valuable. Therefore, one might suppose that the high citation reflects not the fact that they find a serendipitous event in research but its selection criterion that the serendipitous event will be valuable. This selection criterion may be different with or without the serendipitous event. Therefore, this paper tries to detect to what extent serendipity increases research performance by introducing instrumental variables. The following is a hypothesis to be explored in this paper.

H-1: The existence of serendipity has a positive effect on quality of research

The second is related to the discussion about information asymmetry between management and research, which is closely related with the discussion on serendipity. Serendipitous discovery is one of the important natures of scientific research (Merton and Barber, 2004). Many of the discoveries in science are unexpected, anomalous, and serendipitous (Merton and Barber 2006). Serendipity has been defined in slightly different ways (Barber and Fox, 1958, Cunha, 2005, Merton and Barber, 2004, Svensson and Wood, 2005, Van Andel, 1992, Van Andel, 1994). However, in a general sense, serendipity is regarded as the making of happy and unexpected discoveries, either by accident or when looking for something else. In order to operationalize the concept of serendipity, this paper defines it as “the act of finding answers to questions not yet posed,” following Paula Stephan’s definition (Stephan, 2010).

Scientists possess specialized and domain-specific expertise. As previous literature on scientific discovery has expressed, the nature of scientific discovery is highly unpredictable (Polanyi, 1962) and tacit and uncodified knowledge play an important role in research, even though the outcomes of research are usually codified and published (Collins and Harrison, 1975, Polanyi, 1967). Learning is highly situated in the on-site context (Brown and Duguid, 1991, Kogut and Zander, 1992, Lave and Wenger, 1991). When scientists are committed to actual research, they face quite situated and unexpected observations and findings. Thus, if a managerial role in the research project team and a leading role in the actual research are played by different people, it is believed that the research project will have information asymmetry between management and actual research. When a scientist observes unexpected but potentially creative serendipitous findings or encounters a serendipitous idea, he/she needs to talk to the person who plays a managerial role in order to change his/her initial research plan to pursue serendipity. However, if the managerial role is not played by a leading scientist in the project, the serendipitous encounter may not be able to be realized because of the communication costs between management and actual research. Presenting a serendipitous encounter to a manager may be risky, particularly when the new idea or observation is contrary to accepted ways of
doing things or thinking about things (Pelz and Andrews, 1966). Thus, even if a surprising fact
or relation is observed, there is a case in which it is not (optimally) investigated by the
discoverer (Barber and Fox, 1958, Van Andel, 1992). If a core scientist is not separated from the
managerial role, the coordination and communication costs for shifting its research in order to
pursue the serendipitous encounter will be decreased. Flexibility is important to profit from the
discoveries are in nature unpredictable, extreme decentralization, permitting exceptionally
productive scientists a high degree of autonomy and flexibility, is a key characteristic of
organizations where major discoveries occur (Hollingsworth, 2006). Shifting research goals
during the course of research has also been indicated as an important factor (Nelson, 1959). It is
possible to suppose that if a core scientist is not separated from management, he/she will be able
to flexibly deal with unintended finding. Thus, this paper investigates a following hypothesis.

H-2: Serendipity is negatively related to the separation of core-scientists from management

However, if a core scientist plays a managerial role, the advantage of division of labor
in science will not be much realized. Efficiency is increased by specialization and concentration
on one’s single subtask. Managing a research team and conducting research require apparently
different sets of expertise. Thus, it is possible to suppose that if a core scientist is separated from
a managerial role, he/she can focus on the research. It is important, particularly for a large scale
research project, because it requires many bureaucratic procedures, paper work, and managerial
tasks. This paper, therefore, explore a following hypothesis.

H-3: Research productivity is positively related to the separation of core-scientists from management

3. Data, Estimation Strategy, and Variables

This paper investigates the scientists’ survey in the U.S. and Japan. The survey was jointly
conducted by three institutions: the Institute of Innovation Research of Hitotsubashi University;
the National Institute of Science and Technology Policy (NISTEP) of the Ministry of Education,
Culture, Sports, Science and Technology; and the Georgia Institute of Technology.

The purpose of this survey is to collect the objective data that show structural
characteristics in the knowledge creation process in science and the process of creating
innovation from scientific knowledge based on comprehensive questionnaire surveys for
researchers in all fields of science both in the U.S. and Japan (Nagaoka et al., 2011).
The survey was comprised of articles and letters in the Web of Science database of Thomson Reuters. It covers nearly all of the natural science areas. Roughly one-third of the samples are from highly cited papers (top 1% in the world) in each science field; the rest are from randomly selected papers. The survey explored research environments, inputs, and outputs, such as the motivation of the research projects, the knowledge sources which inspired the projects, uncertainty in the knowledge creation process, research competition, research team composition, research funding, etc.

The survey in Japan was conducted from the end of 2009 to the summer of 2010. The survey in the US was implemented from the autumn of 2010 to early 2011. This survey collected approximately 2,100 responses from scientists in Japan and 2,300 responses from scientists in the US regarding their research projects. The response rate was 27% in Japan and 26% in the US.

Based on the survey, this paper explores the impact of management on serendipity and productivity in science.

3.1 Estimation Framework
To examine our three hypotheses, we employ the following estimation methods respectively. For H-1 model in which the relationship between research productivity and the degree of management-research integration is examined, we use a Negative Binomial regression (NB).\(^2\) Since research productivity is measured by the number of papers produced by the entire research project, our dependent variable is necessarily discrete and its empirical distribution concentrates at 1. For these reasons, linear regression may not be suitable for this data. Since NB regression is Quasi Maximum Likelihood, the obtained estimator is robust to hypothesized distribution of dependent variable. That is, it yields a consistent estimator as long as the specification of the conditional expectation of regressand is correct.\(^3\)

H-2 model explains the relationship between the serendipity and research quality. Here, we use Two-Stage Least Squares (2SLS) to deal with the endogeneity of serendipity. This endogeneity problem is considered below.

We conduct Probit regression for H-3 model since the dependent variable, the existence of serendipity, is a binary. One crucial problem with probit regression is its fragility to

\(^2\) More specifically, we use a version of NB regression in which the dependent variable is truncated at zero. This is because we only have data on research projects, which published at least one paper.

\(^3\) See Cameron and Trivedi (2005) for its textbook treatment. Also, see Ding et al. (2010) for an application in a related context.
heteroscedasticity of the error term. Hence, we have tested whether our results are robust to the
misspecification of the error term and we find that our hypotheses still hold.

3.2 Definition of Variables
This section introduces the definitions of variables used in our models. Table 1 gives summary
statistics of all variables used in our models.

3.2.1 Dependent Variables
Different models adopt different dependent variables respectively. To measure research
productivity, we use the number of articles published by the entire research project. Research
quality is measured by the number of citation in 2009. As for H-3 model, the existence of
serendipity is a dependent variable. Respondents are asked whether his/her paper was produced
through serendipity or not. If he/she answers yes, this variable takes 1, otherwise 0.

3.2.2 Independent Variables
Management structure is measured by two mutually exclusive variables: Integration is a dummy
variable that indicates 1 only if the researcher takes a leading role in management of the whole
project. On the other hand, separation is a dummy variable that indicates 1 only if the researcher
plays no management role.

Variables that describe a research project's characteristics contain project size, project duration,
fund size, competitor threat, and inter-organizational communication. The definition of project
size includes corroborative researchers (excluding coauthors), graduate students, undergraduates,
and technicians. Since not all projects had been terminated by the time of the survey, project
duration is calculated by subtracting the year when the project had started from the year when
the project published the most recent paper. Fund size is the total sum of research funds
prepared for the project. Competitors threat is a binary variable and takes 1 only if the
researcher considered the possibility of competitors who may have priority over the research
results. If the project developed a community for communicating with researchers beyond
his/her laboratory, inter-organizational communication indicates 1, otherwise takes 0.

Scientist's characteristics are captured by the following variables; age, degree, past award, past

\(^4\) Some paper might considerably increase its citation number after 2009. But since 70\% of papers in 2008 increases less than 10 in their citation number, the number of citation in 2009 can be used as an approximation.

\(^5\) Hence, both variables taking zero means he/she is involved in management to some extent.
transfer, past publication, and affiliation. Age is respondent's age. Degree shows 1 if he/she has a Ph.D. or equivalent degree. Award is a binary variable that takes 1 if he/she received a distinguished paper award or a conference award. If the respondent had changed his/her academic or research positions across organizations before the survey, past move takes 1. Past publication measures the number of referred papers in English the researcher published during past three years, from 2006 to 2008. Affiliation takes 1 if he/she works for universities.

We control respondent's research field following the survey's classification (Nagaoka et al., 2011). All scientific areas are divided into 10 fields, Chemistry, Materials Science, Physics & Space Science, Computer Science & Mathematics, Engineering, Environment/Ecology & Geosciences, Clinical Medicine & Psychiatry/Psychology, Agricultural Sciences & Plant & Animal Sciences, Basic Life Sciences, and Social Sciences. We also take account of researcher's research skill, his/her specialty in theory or experiment.

3.3 Estimation Caveats
3.3.1 Sampling Bias
As we explained above, one third of the samples are randomly chosen from researchers who wrote top 1% cited paper. Hence, our samples are not randomly drawn from the entire population. We must consider this problem to yield a consistent estimator for H-2 model since the stratification depends on the regressand (i.e. the number of citation). Ignoring this endogenous stratification yields biased estimator, so that all estimated coefficients are not interpretable.

A straightforward provision for this problem is to introduce a weighting matrix whose $i$ th diagonal element is $Q_j / H_j$, where the numerator is the probability that a randomly drawn observation from the population falls into stratum $j$ and the denominator is the fraction of observations in stratum $j$ for each observation $i$. Under reasonable regularity conditions, this weighted least squares estimator is ensured to be consistent and asymptotically normally distributed. Also, with a slight modification on White (1980) heteroskedasticity-consistent

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6 Exhibit 1 of Nagaoka et al. (2011) shows a correspondence between their classification and the 22 ESI journal fields.

7 Social Sciences may be a fairly broad field compared to other categories. However, since about 95% of respondents are natural scientists, this makes no significant differences.

8 In our regressions, we have only two stratum and weights are 0.032 for samples from highly cited group and 1.433 for others.

9 For the formal treatment, see Wooldridge (2001) and Imbens and Wooldridge (2007).
3.3.2 Endogeneity Problem

The endogeneity problem is a central issue in applied econometrics (Angrist, 1990, Angrist and Krueger, 1991, 2001). In our case, the existence of serendipity is endogenous in a following sense: It is reasonable to assume that a scientific finding is pursued only when the researcher evaluates its quality and then believes that it is worth doing. In general, the researcher may be less experienced in the field where serendipity occurs than in the field with his expertise. Hence, the finding seems more novel to him/her and, as a result, he/she overestimates the value of serendipitous finding. If so, without crowding out the correlation between the existence of serendipity and researcher's tendency to overestimate, we underestimate the effect of serendipity on research quality.

To deal with this problem, we use instrumental variables (Angrist and Pischke, 2009). Here, a candidate of instruments is the variables that correlate with the existence of serendipitous finding but not affect to the ex ante evaluation of finding. For this purpose, we instrument serendipity with two variables, skill diversity and knowledge sharing. Skill diversity is a dummy variable that takes 1 if the researcher answered that it was very important as an external knowledge source to communicate with researchers who have different research skills, for example experimental researchers for theorists. Knowledge sharing is also a dummy variable that indicates 1 if the researcher answered that it was very important as an external knowledge source to communicate with visiting researchers or postdoctoral researchers in his/her organization. The existence of serendipity is considered to be correlated with these two variables since complementarity in knowledge and skills are key to improve creativity. Our argument is supported by, for example, Heinze et al.(2009) who observes that most important type of communication to generate a creative idea is communicating with specialists who are equipped with key skills the researcher himself does not possess. We have no reason to assume that these instruments and the ex ante evaluation of finding are correlated, in addition, since the former is related to the entire project not only to the focal paper our use of instruments is justified.

4. Results

4.1 Effect of Management Structure on Research Productivity

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10 We can also use White's (1980) covariance matrix. Using this gives conservative results since it is larger (in a matrix sense) than the appropriately estimated covariance matrix taking account of endogenous stratification.
First, we summarize results of the H-1 regression.\textsuperscript{11} Our hypothesis is that the separation of management from research increases research productivity. Table 2 shows estimated coefficients and test statistics.\textsuperscript{12} Results are consistent with our hypothesis. The estimate of the interaction term between separation of management and project size is positive and statistically significant. Moreover, the separation of management alone does not show a statistically significant effect on research productivity. That is, separating management from research is beneficial only when management is highly needed.

4.2 Effect of Management Structure and Serendipity on Research Quality
The H-2 regression results are reported in Table 3.\textsuperscript{13} The existence of serendipity has a positive effect on the number of citation at the 5% statistically significant level. Here, separation of management has a negative effect on research quality, on the other hand, integration of management has a positive effect on it even in the case of a large project. This observation is consistent with recent literature since the researcher will obtain more chances to communication with other researchers if he/she chooses to become responsible for the entire research project (Fleming et al., 2007 and Powell et al., 1996).

4.3 Effect of Management Structure on Serendipity
Table 4 exhibits the result of the H-3 probit in which the connection between management structure and serendipity are examined. Here, we can see that integration of management has a positive effect on serendipity; however, the effect ceases as the project size gets bigger. That is, integration encourages the serendipitous finding itself or selecting the serendipitous idea more often only when management needs are not so intensive.\textsuperscript{14}

4.4 Robustness Checks
We conduct two kinds of robustness check. First, dependent variable for H-1 model is now changed into the number of referred papers in all languages instead of only in English. This result is shown in Table 2. With this specification, the positive effect of the interaction term between separation of management and project size gets weaker but still statistically significant

\textsuperscript{11} Note that here samples are those who answered he/she took a central role of the research project and contributed the most.
\textsuperscript{12} Note that all coefficients in Table 2 can be interpreted as a semielasticity.
\textsuperscript{13} Different from previous regression, here our unit of analysis is a focal paper, not the entire research project. Hence, samples are those who are named as the first author of focal paper.
\textsuperscript{14} As Girotra et al. (2010) shows, identifying the difference between idea generation and its selection process is essential. Future research may consider either effect is more significant in our context.
Second, for H-3 probit we test the robustness to the heteroskedasticity of the error term. The error term is heteroskedastic with a variance of $\sigma_i^2 = \exp(\delta z_i)$, where $z_i$ is an exogenous variable. We choose two candidates for $z_i$, project duration and man-month for the entire project. Model 3-2 and 3-3 in Table 4 shows these results, and we can see that implications are in general same.

4. Conclusions

This paper explores the scientists’ survey in the U.S. and Japan conducted between 2009-2011 by Hitotsubashi University, NISTEP, and Georgia Institute of Technology. It investigates the influence of management-science integration on serendipity and productivity in scientific research. The major estimated results show that the integration of a managerial and a leading research role has a positive effect on serendipity. However, this effect ceases as the project gets bigger. It implies that the integration reduces coordination costs between management and research and provides flexibility in research to scientists, while the advantage of division of labor in management and science increases as the project size gets larger. It also shows that the separation of management from research has a larger positive effect on the number of papers as the project becomes bigger.

Serendipity plays an essential role in discoveries not only in science but also in technology, management, business practices, art, daily life, and even in robbery (Jacobs, 2010, Svensson and Wood, 2005, Van Andel, 1992). This paper examines management and research in science. But the findings have implications for corporate R&D. The findings of this paper imply that bureaucratic coordination, which enlarges information asymmetry and incommensurability between management and research, profits from serendipitous encounters. It is quite consistent with contingency theory between complexity of environment (e.g., demand, strategic positioning, and technology) and organizational structure (Burns and Stalker, 1961, Lawrence and Lorsch, 1967, Scott, 1981). They have pointed out that decentralized and less formalized management that allows a high degree of flexibility is suitable when an organization faces a high frequency of exceptional problems and when analysis for the problem solving is not easy (Perrow, 1967, Woodward, 1965). It suggests that decision making should be done at the place where important information is gathered and knowledge is created, if environmental change is uncertain but highly frequent. The more embedded the knowledge, the greater autonomy of the R&D unit (Birkinshaw et al., 2002). However, operational managers are usually trained to complete the project’s goal. In fact they tend to manage as far as possible to eliminate uncertainty in their affairs so that they can meet budgets and target deadlines (Udwadia, 1990).
It is possible to suppose that this is one of the reasons that makes it difficult for corporate R&D managed by a central business manager to profit from serendipitous findings at the laboratory.

To conclude this paper, we mention some limitations of this paper that future research should address more explicitly. A key result suggests that if scientific research is bureaucratically controlled in a research organization, serendipitous encounters will not be realized in a society. In other words, even when a managerial role and a leading research role are played by different people, serendipity will be realized if a manager shares tacit and domain-specific knowledge with leading scientists and understands the nature of scientific discovery. This paper presupposes a certain degree of incommensurability, which was proposed by “Khunian paradigm arguments” (Kuhn, 1970) between a manager and leading scientists. However, the degree of incommensurability depends on a manager’s expertise and capabilities. Since the scientists’ survey does not allow investigating a manager’s capabilities, this paper does not explore the quality of managers in a research organization. The Council for Science and Technology Policy in Japan also considers that a managerial role should be played by a specialist who can share tacit and domain-specific knowledge with leading scientists so that the leading scientists can focus on research in a large-scale research project and the research project can hold managerial flexibility for realizing serendipitous encounters. The previous literature on how scientists with different expertise and different paradigm communicate has indicated that scientists communicate in groups where they can agree on rules of exchange, learn language, and share tacit knowledge, called “trading zone” (Collins, Evans and Gorman, 2007, Galison, 1997, Galison, 1999). However, since to what extent managers and scientists can reduce the degree of incommensurability depends on a manager’s ability, it is important to explore a manager’s expertise and capabilities on the research outcome in detail.
Table 1: Summary Statistics

<table>
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<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
<th>N</th>
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<td>1</td>
<td>4401</td>
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<td># of published papers</td>
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<td># of citation in 2009</td>
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Table 2: Results of H-1 Model

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<tr>
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<th>(1) Only English Paper</th>
<th>(2) All Referred Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>project size</td>
<td>-0.0073 (0.0155)</td>
<td>0.0089 (0.0135)</td>
</tr>
<tr>
<td>integration</td>
<td>0.0297 (0.1128)</td>
<td>0.0592 (0.1043)</td>
</tr>
<tr>
<td>integration × size</td>
<td>0.0189 (0.0156)</td>
<td>0.0030 (0.0136)</td>
</tr>
<tr>
<td>separation</td>
<td>-0.0338 (0.1789)</td>
<td>0.0435 (0.1689)</td>
</tr>
<tr>
<td>separation × size</td>
<td>0.0691** (0.0320)</td>
<td>0.0576* (0.0298)</td>
</tr>
<tr>
<td>project duration</td>
<td>0.0976*** (0.0166)</td>
<td>0.1131*** (0.0157)</td>
</tr>
<tr>
<td>project duration(2)</td>
<td>-0.0010 (0.0006)</td>
<td>-0.0015** (0.0006)</td>
</tr>
<tr>
<td>competitor threat</td>
<td>0.0700*** (0.0163)</td>
<td>0.0571*** (0.0153)</td>
</tr>
<tr>
<td>inter-org comm</td>
<td>0.2471*** (0.0788)</td>
<td>0.3096*** (0.0740)</td>
</tr>
<tr>
<td>log(fund)</td>
<td>0.2026*** (0.0168)</td>
<td>0.1710*** (0.0155)</td>
</tr>
<tr>
<td>past publication</td>
<td>0.0058*** (0.0010)</td>
<td>0.0048*** (0.0008)</td>
</tr>
<tr>
<td>country</td>
<td>-0.5870*** (0.0872)</td>
<td>-0.8676*** (0.0820)</td>
</tr>
<tr>
<td>award</td>
<td>0.0806 (0.0686)</td>
<td>0.1287** (0.0652)</td>
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<tr>
<td>degree</td>
<td>-0.0219 (0.0500)</td>
<td>-0.0500 (0.0470)</td>
</tr>
<tr>
<td>affiliation</td>
<td>-0.1647** (0.0766)</td>
<td>-0.2344*** (0.0715)</td>
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</table>

N 1731 1731
ll -5944.0352 -6253.3672

Standard errors in parentheses

* p < 0.10, ** p < 0.05, *** p < 0.01
Table 3: Results of H-2 Model

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<td>serendipity</td>
<td>0.0349 (0.0726)</td>
<td>1.3394** (0.6535)</td>
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<td>project size</td>
<td>-0.0306** (0.0128)</td>
<td>-0.0395*** (0.0149)</td>
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<tr>
<td>integration</td>
<td>-0.0643 (0.1117)</td>
<td>-0.1792 (0.1363)</td>
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<tr>
<td>integration × size</td>
<td>0.0287** (0.0128)</td>
<td>0.0380** (0.0150)</td>
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<tr>
<td>separation</td>
<td>-0.3058* (0.1791)</td>
<td>-0.3558* (0.1929)</td>
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<td>separation × size</td>
<td>0.0392 (0.0269)</td>
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<tr>
<td>year in paper</td>
<td>-0.0123 (0.0254)</td>
<td>-0.0340 (0.0303)</td>
</tr>
<tr>
<td>(year in paper)^2</td>
<td>-0.0005 (0.0015)</td>
<td>-0.0002 (0.0016)</td>
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<tr>
<td>competitor threat</td>
<td>0.0795*** (0.0201)</td>
<td>0.0605** (0.0245)</td>
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<tr>
<td>log(fund)</td>
<td>0.0498** (0.0210)</td>
<td>0.0308 (0.0258)</td>
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<tr>
<td>age</td>
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<td>-0.0371 (0.0357)</td>
</tr>
<tr>
<td>(age)^2</td>
<td>0.0005* (0.0003)</td>
<td>0.0002 (0.0003)</td>
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<tr>
<td>degree</td>
<td>-0.0513 (0.0452)</td>
<td>-0.0393 (0.0510)</td>
</tr>
<tr>
<td>award</td>
<td>0.0160 (0.0768)</td>
<td>-0.0016 (0.0883)</td>
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<tr>
<td>past move</td>
<td>0.0907 (0.0755)</td>
<td>0.2002** (0.1002)</td>
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<tr>
<td>past publication</td>
<td>0.0031*** (0.0009)</td>
<td>0.0023** (0.0010)</td>
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<tr>
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<td>0.2962*** (0.0883)</td>
<td>0.6303*** (0.1927)</td>
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<td>-0.1680** (0.0847)</td>
<td>-0.1937** (0.0972)</td>
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<tr>
<td>theory</td>
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<tr>
<td>experiment</td>
<td>0.1502 (0.1142)</td>
<td>0.1645 (0.1348)</td>
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N = 1405
F = 8.1178

Standard errors in parentheses

* p < 0.10, ** p < 0.05, *** p < 0.01
Table 4: Results of H-3 Model

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<td>model3-2</td>
<td>model3-3</td>
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<td>(0.0053)</td>
<td>0.0151</td>
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<tr>
<td>integration</td>
<td>0.0676*</td>
<td>(0.0385)</td>
<td>0.1752**</td>
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<td>integration × size</td>
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<td>(0.0053)</td>
<td>-0.0152</td>
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<tr>
<td>separation</td>
<td>0.0219</td>
<td>(0.0613)</td>
<td>0.0547</td>
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<tr>
<td>separation × size</td>
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<td>(0.0134)</td>
<td>0.0304</td>
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<td>inter-org comm</td>
<td>0.1090***</td>
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<td>0.1974**</td>
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<td>N</td>
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</tr>
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Standard errors in parentheses

* p < 0.10, ** p < 0.05, *** p < 0.01
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