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# Does (and how) the entrepreneurial orientation of scientists affect publication performance? Evidence from the advanced materials research in Japan

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## ABSTRACT

In order to identify the effect of academic entrepreneurial orientation on scientific activity, this work compares the publication performance of entrepreneurial scientists (Edison and Pasteur-scientists) with that of traditional scientists (Bohr and Other-scientists). The majority of contributions found in the literature have generally conveyed that entrepreneurial academics show a better and larger record of publications. Quality is measured basically by means of citations per paper and quantity by number of papers. We contribute to this stream of research by investigating more deeply the differences between more or less entrepreneurial-oriented scientists. In order to do so we take into account the differences in scientists' publication portfolio, in terms of scientific productivity, prestige and research breadth or multidisciplinarity.

Our results shows, entrepreneurially oriented scientists publish more frequently than traditional scientist, while traditional scientists are more favorable to obtain research prestige (forward citation). Pasteur scientists effect to gain research prestige is higher than other scientists in highly cited articles. By comparing diversity of research portfolio, Pasteur scientists have significantly larger diversity than Bohr scientists.

These results show sensitivity and fallibility of research evaluation using bibliographic information. In order to precisely evaluate accomplishments of entrepreneurial scientists, evaluation of their multidisciplinary portfolio is required.

**Key words:** University-industry linkages, Academic entrepreneurship, Pasteur scientists, Quadrant model, Scientific productivity, Advanced materials

## 1. INTRODUCTION

Universities have become increasingly entrepreneurial over the last decades as science and technology policies have been oriented to strengthen the link between academia and industry (Etzkowitz, 1983, 1998; Slaughter and Leslie, 1997). These policy trajectories have put in place initiatives aimed to increase universities' patenting activity and facilitate university spin-off companies. Many contributions to the literature have attempted to explain how academic entrepreneurship influenced firms' innovation activity (Cohen et al., 2002; Mowery et al., 2002; Murray, 2002; Powell et al., 1996; Zucker and Darby, 1996; Zucker et al., 2002) through a variety of university-industry interactions. Also, a number of studies have examined the possible contribution of university-industry relations to scientific productivity, mainly by investigating how scientists' patenting activities influence their publication performances in terms of both quantity and quality (Agrawal and Henderson, 2002; Breschi et al., 2008; Carayol and Matt, 2004, 2006; Fabrizio and Di Minin, 2008; Meyer, 2006a, 2006b). However, the impact of industry-university collaboration remains argument and it is still not clear. Since the impact of industry-university collaboration highly depends on its underlined knowledge specificity, empirical analysis of more diverse domain is required to understand this mechanism further.

In this paper, we investigate whether academic entrepreneurship affects the publication performance of scientists in the advanced materials field. In doing so, we classify scientists using the classification offered by (Stokes, 1997). Contrasting Bush's linear model of scientific research, the Stokes' quadrant model acknowledges the heterogeneity in research orientations of scientists, whose work spans from fundamental scientific understanding of nature to advancing technological know-how. In Stokes (1997), four types of scientific inquiries are identified: Edison, Bohr, Pasteur and Other. Edison type is pure applied research, oriented to bring about knowledge for real-world utility, having no interest in deepening understanding of basic science. Bohr type is pure basic research, oriented to the pursuit of knowledge for its own sake through scientific discovery, having little interest in the potential uses of their research findings for the real world. Pasteur type is hybrids(Lam, 2010), both basic and applied research, never losing sight of the hope to advance scientific understanding while contributing to real-world utility. The rest of research is considered as Other. By applying this framework, we aim to investigate differences in publication performance among different types of scientists. Adopting the Stokes' analogy, Edison scientists are mainly entrepreneurial, Bohr scientists are typically traditional scientists (or "ivory tower traditionalists", as labeled by Lam (2010)), Pasteur scientists are hybrids (see Baba et al. (2009) for a more detailed explanation). Since scientific performance is multi-faceted concept, we measured it in several ways: scientific production (number of publications), prestige (frequency of forward citation) and research diversity. From this measurement we tried to ask whether entrepreneurial orientation of scientists affect their scientific production, whether it affect their research breadth (multidisciplinarity), whether it affect their prestige within the scientific community.

We chose to focus on the scientific activities carried out in Japan, where the emerging entrepreneurial institutions, modeled on the US system, make it easier for universities and their faculty to engage more directly in commercial activity (Walsh et al., 2008). Reforms have led a great number of scientists to be involved in entrepreneurial activities since the mid-1990s, which is implied by the increasing number of patent applications from universities, university-industry (U-I) relationships, university startups, and technology transfers (Nagaoka et al., 2009). Regarding the focal scientific field, we chose the activities in the field of advanced materials, particularly, in the narrow technological field of the $TiO_2$ photocatalyst. The choice of scientific field derives from the fact that the interaction between science and technology is particularly relevant in the field because it leads, on the one hand, to the generation of new scientific knowledge, and, on the other, to the identification of industrial applications for scientific discoveries (Maine and Garnsey, 2006; Niosi, 1993; Schmoch, 1997). Also, we chose to focus on the sub-field of the $TiO_2$ photocatalyst because emerging academic entrepreneurship in the field has opened up a wide range of industrial applications to bring about sizable markets all over the world (Baba et al., 2010).

The following analysis is mainly based on the bibliographic data taken from the database Scopus (Elsevier, 2010) and patent data taken from the Japanese patent database (IPDL). Additionally we conducted intensive interviews in the mid-2000s on the Pasteur scientists operating in the field, based on semi-structured questionnaires. Armed with our sample of scientific papers published by all the Japanese scientists involved in $TiO_2$ photocatalyst research, we statistically compared the scientific performance of entrepreneurial scientists with that of traditional scientists.

The paper is organized as follows. Section 2 reviews the previous research on the issue, providing an analytical framework to investigate the heterogeneity of scientists, and presents our testable hypotheses. Section 3 describes the data and methodology. Section 4 presents the results of our quantitative analyses. Finally, section 5 provides concluding remarks, some policy implications, limitations and hints for further research.

## 2. THEORETICAL BACKGROUND AND RESEARCH QUESTIONS

There has been a research tradition examining the nature of the interaction between science and technology. In contrast to the common view emphasizing the causality as running from science to technology, a series of seminal papers explain that scientific knowledge of a wide generality sometimes grew out of a particular technical problem in a narrow societal context (Dosi, 1982; Dosi, 1988; Murmann, 2003; Nelson, 1962; Rosenberg, 1982). From this viewpoint, which holds that the causality runs from technology to science, it can be inferred that there are some cases when university and industry (U-I) linkage could positively contribute to progress in scientific research (Agrawal and Henderson, 2002; Breschi et al., 2008; Carayol and Matt, 2004, 2006; Fabrizio and Di Minin, 2008; Meyer, 2006a, 2006b). A number of studies have recently been published that examine the contribution of U-I linkage to academic research, mainly by investigating the relation between scientists' patenting activities and their publication performances, both in quantity and quality. Briefly summarizing, scientists who engage in patenting are, broadly speaking, more productive in scientific research (Carayol and Matt 2004; Carayol and Matt 2006; Breschi, Lissoni et al. 2008; Fabrizio and Di Minin 2008), or their research is of higher quality (Agrawal and Henderson 2002; Meyer 2006a; Meyer 2006b). Similarly, in patent-publication pair perspective, the event of a patent is more likely to produce an increase in the number of publications in the year of the invention, or in the following 1 to 2 years (Calderini and Franzoni 2004; Azoulay, Stellman et al. 2006; Breschi, Lissoni et al. 2008; Fabrizio and Di Minin 2008). Besides, research funding from industry to universities through contract research expands the scale and raises the quality of scientific research (Breschi, Lissoni et al. 2005), and it is suggested that linkages with industry have the potential to contribute to the training of researchers at universities (Blumenthal, Gluck et al. 1986).

In some cases university patenting and licensing activities are perceived and proved to be detrimental, producing a decline in the quality of publications and inducing a substitution effect between patents and publications, as in the case of the biotech field (Murray and Stern 2005). As Powell et al. claimed, "paying excessive attention to blockbuster patents and potential licenses, and not enough to planting seed corn, can produce a failure to 'restock the R&D pantry'" (Powell, et al. 2007: 140). Certainly, patenting skews scientists' research agendas toward commercial priorities (Blumenthal et al., 1996; Krimsky, 2003), but interacting with industry has, broadly speaking, a positive influence on their experimental work (Siegel et al., 2003), without negatively altering publishing rates (Agrawal and Henderson, 2002). Recently, based on the comparison between patenting and non-patenting scientists, Fabrizio and Di Minin (2008) found a statistically positive effect of academics' patent stocks on their publication counts, and Stephan, Gurmu et al. (2007) demonstrated, through a survey on the cross-sectional relationship between patenting and publishing, that patenting and publishing relate positively.

## 2.1. SCIENTISTS'HETEROGENEITY

From the viewpoint of the theory of technical change, it is not worthy to discriminate between basic and applied research, because drawing "the line on the basis of the motives of the person performing the research – whether there is a concern with acquiring useful information (applied) as opposed to a purely disinterested search for new knowledge (basic)," is irrelevant, since some of the most fundamental scientific breakthroughs have come from people who thought they were doing applied research (Rosenberg 1982:149). From the viewpoint of the sociology of science, it is known that heterogeneity of scientists' motivation is more complex than the dichotomy of professional rewards in scientific community and private financial gain (Merton, 1973), which includes motives such as intellectual challenge as well as contribution to society (Sauerman et al., 2010). The number of patents is traditionally taken as a measure of scientists' motivation for pursuing commercial activities, but financial returns are not the key reason why scientists active in fields such as bio-medical sciences get involved in patenting. Scientists use several types of logic and reasoning in solving scientific problems (Dewey, 1938; Peirce, 1932; Rao, 1997; Sebeok and Umiker-Sebeok, 1980).

### 2.1.1. EDISON-SCIENTISTS

In solving scientific problems, among many types of logical reasoning, the importance of abduction is widely recognized. Abduction is originally advocated by C.S. Peirce, a nineteenth-century pragmatist (Peirce, 1932); it is the cognitive process of articulating a hypothesis that provides a consistent explanation of the various observed data and phenomena (Sebeok and Umiker-Sebeok, 1980). In solving problems, skilled inventors (corresponding to the type of Edison scientists) are known to use abduction, i.e. creation of new knowledge by intuition, without data (Rao, 1997)[1], largely based on a synthetic knowledge base (Baba and Nobeoka, 1998; Takeda et al., 2001). Taking the example of Thomas Edison, although he is notorious for his weakness in mathematics, he had a "talent for asking questions that could be translated into hypothesis, which in turn established the strategy and tactics of experimentation"(Hughes 1983:26).[2]

### 2.1.2. BOHR-SCIENTISTS

The Bohr scientist acts as a traditional academic. Bohr scientists set the goal of producing codified theories and models that explain and predict natural reality and embark on a course of research that involves stipulating preconditions by simplification and reduction of the number of observable variables. The essential skills of conventional academics are known "to simplify the essential to allow modeling and prediction" (Pavitt 1998:795). Those scientists usually use

1 The distinction between induction and abduction is somewhat subtle (Rao 1997). In induction, scientists are guided by experimental data and its analysis to provide an insight. But the ultimate step in the creation of new knowledge does depend on previous experience and a flight of imagination.

2 When Edison began his research on the incandescent light bulb, the technology already existed for lighting up a filament inside a glass bulb by conducting an electric current into it. However, the filaments that existed at the time would burn out in two hours, making it difficult to market them as replacements for gas lamps. Scientists at the time took it for granted that filaments would burn out (oxidize) quickly at temperatures high enough to give off light, so they did not work on ways to extend the life of incandescent bulbs. Edison, on the other hand, did not have the scientific understanding that it was physically difficult to create the phenomenon of illumination while simultaneously prolonging that phenomenon. As a result, he carried out a process of trial and error, using 7,000 different types of materials before he succeeded, by chance, in extending the life of his incandescent bulbs to 300 hours.

logical methods of deduction (verification of proposed theories) and induction (creation of new knowledge based on observational data) to solve scientific problems.

Regarding the nature and direction of the research activities, we know that the incentive for conventional academics (Bohr scientists) is to obtain appraisal from their peers and improve their standing in the scientific community (Merton, 1973), and research policy employed by them could be constrained by the scientists' incentive to present their research results in a form that can be properly evaluated and preferably cited by their peers. They must be traditional enough to establish strategic similarities that connect their work to that of others in the field, yet original enough to establish strategic differences that impart novelty to their work (Hackett, 2005; Hackett et al., 2004). Under the circumstances, those scientists are assumed to opt for research whose agenda and experimental protocol do not differ considerably from those used in earlier research in the field, and to use conventional deductive/inductive reasoning to carry out their analyses.

### 2.1.3. PASTEUR-SCIENTISTS

As inferred from the fact that Pasteur's interest in the phenomenon of fermentation, derived from his relationship with the French distilling industry, was also led by "preconceived (scientific) ideas" that enabled him to become the founder of bacteriology (Geison 1995: 95), a Pasteur scientist is a hybrid academic, who shows an ambidextrous attitude towards basic and applied science, and an interest not only in promoting his reputation within the scientific community, but also in benefiting society through the commercialization of science.

His ambidexterity appears to fuel his scientific production, and it is supported by a twofold viewpoint. Following the definition of Pasteur scientists, we assumed that scientists under this category would resemble both Bohr and Edison scientists. Pasteur scientists have two faces, which allows them to use either deductive/inductive or abductive reasoning depending on the type of problem they are solving: when wearing their Bohr face, they use deductive/inductive reasoning for deepening the understanding of science; when wearing their Edison face, they use abductive reasoning for developing use–inspired technologies. Partially borrowing from Edison scientists, Pasteur scientists set the goal of arriving at an understanding of how the phenomenon behaves under a given set of conditions and embark on a course of research that explores the technological possibilities for satisfying user needs in a society. The research processes are "often complex, involving numerous components, materials, performance constraints and interactions, and are therefore analytically difficult to handle," and the essential skills of Pasteur scientists are "to integrate the essential to ensure target performance" and "to identify performance limits" (Pavitt 1998:795). Armed with these two faces, "many able scientists, of whom Pasteur is a fine example, have found no conflict in focusing on particular fundamental problems because of their practical utility" (Metcalfe, 2010).

Recently, due to the motivation to make a socio-industrial contribution through U-I linkages, there emerges substantial evidence that prevailing academic entrepreneurship may undermine the university's core mission of promoting "public science" (Dasgupta and David, 1994; Nelson, 2004) and the norms in the scientific community (Etzkowitz, 1998; Glenna et al., 2007; Nelson, 2004; Owen-Smith, 2003): we see increases in the likelihood of encouraging academics to select research projects on the basis of commercial rather than scientific merit (Dasgupta and David, 1994; Heller and Eisenberg, 1998; Thursby and Thursby, 2003); avoiding sharing information about their current research and delaying publication for business reasons (Blumenthal et al., 1997; Blumenthal et al., 2006); and denial of requests for transferring research materials to peers (Walsh et al., 2007). Accordingly, it can be inferred that entrepreneurial academics (Pasteur scientists) paying attention to their socio-industrial profiles would have other types of motivation for advancing their research than publishing papers for their peers in the scientific community.

Particularly, since those scientists are living up to their socio-industrial commitments, they may be less interested in the essential tension between tradition and originality that conventional academics usually face. Pasteur scientists are liberated—even if only partially so—from the incentive to present their research findings in a format that their peers are most likely to evaluate. When they acquire novel scientific knowledge, those scientists stressing the importance of disseminating knowledge for the society are willing to publish papers in a wide variety of journals without concern for the degree of influence the journals they publish in have upon the scientific community. Since U-I linkages tend to shift scientists' research from basic to applied (Blumenthal, et al. 2003), and applied research journals tend to have a lower impact factor than journals that publish papers on basic research (Narin et al., 1976), even if Pasteur scientists publish a greater number of papers on their research results, those papers are cited less frequently on average. Overall, although the research that Pasteur scientists conduct sometimes leads to the publication of high-impact papers (Murray, 2002; Murray and Stern, 2007; Stokes, 1997), when comparing the publishing portfolios of such scientists with those of Bohr scientists, it is inferred that they will be characterized by relatively low numbers of highly cited papers and relatively high numbers of infrequently cited papers.

### 2.1.4 HYPOTHESIS

Research orientation differs among the four types of scientists in the Stokes's quadrant model, affecting the nature and direction of their scientific performance. And the above observation leads to the following hypothesis, in relation to the scientists that are more entrenched in the scientific community, that is, Bohr and Pasteur scientists:

*Hypothesis 1: Entrepreneurial-oriented scientists (Edison and Pasteur-scientists) publish more paper than traditional scientists (Bohr and Other-scientists).*

If scientists submit their papers to high-impact journals, although the risks of being rejected cannot be overlooked, they can expect a number of citation counts proportionate to the impact of the journal in which the papers are published. On the other hand, when pre-existing research agendas and experimental protocols make it difficult to achieve R&D objectives they have established in accordance with their socio-industrial commitments, Pasteur scientists tend to develop hypotheses and advance their research through unorthodox research agendas and experimental protocols. At the same time, they acknowledge the possibility of their hypotheses being fallible, since they proceed to create knowledge by intuition without relying on supporting data. When this happens, although the percentage of successful intuitions is only slim, Pasteur scientists are bestowed with an opportunity to ensure both an industrial solution and progress in the existing scientific frontier. Consequently, if we control appropriately for the impact factor of scientific journals in which articles are published, we expect that the publication performance of Pasteur scientists is better than that of Bohr scientists.

*Hypothesis 2a: Broadly speaking, traditional scientists are more prestigious than entrepreneurial-oriented scientists*

*Hypothesis 2b: For highly prestigious papers, their prestige is favored by authorship of Pasteur scientist.*

Reflecting their research motivations, when pre-existing research agendas and experimental protocols make it difficult to achieve R&D objectives, Pasteur scientists try to understand how the phenomenon behaves under a given set of experiments and embark on a course of research that explores the use-inspired technology. Those scientists are assumed to use abduction by articulating a hypothesis that provides a consistent explanation of the various observed data and phenomena. Since the research processes are complex, involving numerous components, materials, performance constraints and interactions, Pasteur scientists do not necessarily carry out their research based on a single scientific discipline. Whereas Bohr scientists (opting for research whose agenda and experimental protocol do not differ considerably from those used in earlier research in the field) tend to use conventional deductive/inductive reasoning to get academic results, Pasteur scientists would continue the search process, occasionally with a new protocol based on multiple theories crossing over several scientific disciplines for the purpose of getting industrial results. Therefore the third hypothesis is put forward:

> *Hypothesis 3: The research breadth of entrepreneurial-oriented scientists is larger than that of traditional scientists*

## 3. METHODOLOGY

### 3.1. METHODOLOGICAL NOTES

Among the various types of advanced materials, eco-friendly $TiO_2$ materials and their applications (e.g., $TiO_2$ coating films for self-cleaning applications, $TiO_2$ nano-fiber membrane and its applications for water treatment) are considered to be industrially promising because their properties are activated only by sunlight. When $TiO_2$ absorbs ultraviolet light, the $TiO_2$ photocatalyst demonstrates a very strong oxidation power that decomposes most organic compounds adsorbed on substrate. Such catalytic reactions induced by light are called photocatalysis (Fujishima et al., 2000). These findings have opened up a wide range of industrial applications and brought about a series of product developments. Photocatalyst Industry Association of Japan (PIAJ) estimated the size of the worldwide commercial photocatalyst market as 1 billion US dollars in 2009.[3]

Evaluating research activities of individual scientist is far from easy, since in the scientific fields where experimentation plays a crucial role in problem solving, scientific inquiry is carried out collectively, led by the head of the laboratory, who happens to be either a professor or the principal investigator of a funded project. In this paper, we aim at focusing on the activities of these principal investigators (PIs), who have full responsibility for research at laboratories by initially setting research agenda and experimental protocol. Although previous research uses individual researcher or professor (Breschi and Lissoni, et. al, (2008) and many other articles) as a unit of analysis, this choice inevitably includes the performance of co-authors collaborating with the PIs. Those co-authors (graduate students, post-docs and so on) are often members of a laboratory headed by a PI. For the purpose of sorting out those subordinate co-authors and identifying the PIs in the field, we collected the publishing record of all the individual authors and compared their publication patterns. If a certain author's research portfolio (i.e. a set of publications) is broadly similar with other authors, we selected the scientist with the top research portfolio (i.e. largest number of publications) and assumed he/she as a PI. By using the method of

[3] The first product design utilizing oxidation power makes it possible to develop anti-bacterial ceramic tiles and so forth; the second design, utilizing super-hydrophilicity, develops self-cleaning building materials and anti-fogging window glasses, leading to the creation of new markets.

filtering junior co-authors, we obtained a sample of PIs, i.e. the laboratory heads in universities or public research organizations (PROs), which we considered our unit of analysis.[4]

## 3.2. DATA AND SAMPLING PROCEDURE

### 3.2.1. PUBLICATION DATA

To evaluate the performance of scientists involved in photocatalyst research, we searched scientific papers related to the keyword “photocatalyst” using the bibliographic database Scopus (Elsevier, 2010).[5] As a result, we obtained 15,219 articles published worldwide from 1960 to 2010. Since our present observation is focused on the papers with authors who are affiliated with Japanese universities or PROs, our sample comprises 3,832 articles that contains at least one author whose is geographically located within Japan. For those articles, first, we canonicalized the name of an individual author. If two authors shared the same notation of name, we employed affiliation data to reveal whether they are actually the same person or not. To

[4] By way of using the research portfolio of those researchers, we tried to sort out what we called leading scientists. The filtering process is as follows: 1) authors of papers are sorted according to the number of articles. Comparison of publication patterns is done from the author with the largest to the one with the smallest number of articles; 2) first scientist (the author with the largest number of articles) is treated as a leading scientist; 3) portfolio vector of scientists is defined as $v_c \equiv (p_{1,c}, p_{2,c}, \ldots, p_{n,c})$ where $p_{i,c} = 1$ if scientist *c* is included as author of article *i*, otherwise 0. 4) To evaluate the similarity of portfolio, we calculate Salton's cosine similarity measure of candidate's portfolio vector $v_c$ and each leading scientist’s portfolio vector $v_I$ defined as $\frac{v_c \cdot v_I}{|v_c| \cdot |v_I|}$. If the similarity measure is larger than 0.5, we assumed that the candidate's portfolio is too similar to that of the leading scientist, hence the candidate is eliminated as a junior author. This threshold value (0.5) is arbitrary although the result does not change much (less than 5%) if we change threshold to 0.3 – 0.7.

[5] Here the search expression TITLE-ABS-KEY(photocatal*) is used to extract articles whose title or abstract or keywords matches with "photocatal*". Since the asterisk means wildcard, this expression matches with photocatalyst, photocatalysis, photocatalytic and so on.

eliminate canonizalization failure, various other data sources, including the national researcher database (JST, 2010), the JSPS funding database (NII, 2005-2010), as well as personal and organizational web pages are used. As a result, we identified 3,537 individual scientists, spanning over 127 academic organizations. In the next step, we excluded a body of junior co-authors by using publication-similarity based filtering.[6] In the end, we identified 66 PIs, namely, 52 belonging to universities, and 14 belonging to public research organizations.

### 3.2.2. PATENT DATA

To evaluate the amount of entrepreneurial activities of scientists, we collected all the patents applied by the 66 sample scientists to the Japan Patent Office (JPO) in the field of Photocatalysis in the period 1970-2008. We counted the number of patents applied by each PI as an inventor.[7]

### 3.2.3. IDENTIFICATION OF THE QUADRANTS

We allocated the 66 PIs to each category in the Stokes's quadrant model (Stokes, 1997) according to two measures: the number of patent applications (PAT), which is used as a measure of orientation toward delivering utility to society (in the vertical axis), and the average citations

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6 By comparing research portfolio, 3032 candidates' portfolios were found to be fully included by certain independent researchers. The remaining 505 candidates were further examined and 439 candidates were dropped due to similarity criterion.

7 Since the result of this search method includes type I errors (i.e. including patents of a different inventor sharing the same name), spurious patents were removed, after examining the address of each patent inventor.

(ACITE - number of his/her citation counts divided by the number of his/her publications), which is a measure of orientation toward deepening scientific research (in the horizontal axis). By choosing a reference line the median of each variable, we classified the 66 PIs into four categories. Table 1 illustrates the attributes of each scientist category in terms of (i) average number of scientific papers published per-researcher, (ii) average sum of citations counts per-researcher, and (iii) number of researchers belonging to the category.

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Insert Table 1 about here

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## 3.3. VARIABLES

In order to investigate scientists'heterogeneity in terms of publication performance, we conducted an analysis based on three dependent variables: scientific productivity, prestige and multidisciplinarity.

**Scientific Productivity (PUB)**

We measured the scientific productivity of scientists by means of the number of articles published in the target research field.

**Scientific Prestige (CITE)**

As a dependent variable, number of forward citation (CITE) is used as a proxy variable to evaluate scientific prestige. To measure this, the sum of forward citation number for all articles published by focal scientist are calculated.

**Research breadth/Multidisciplinarity**

How to assess the coverage of scientific discipline or interdisciplinarity of scientific outputs remains controversial, and there is no consensus on the appropriate frameworks and methodologies (Bordons et al., 2005; Huutoniemi et al., 2010). Recently, a series of bibliometrics researchers (Leydesdorff and Rafols, 2009; Rafols et al., 2010; Wagner et al., 2011) created a methodology to calculate interdisciplinarity of scientific outputs, named Rao-Stirling diversity.

In Stirling (2007), a general diversity heuristic is proposed, where diversity indices ($\Delta_{\alpha,\beta}$) can be explored for different valuations of the properties of diversity – variety, balance and disparity – by changing the parameters $\alpha$ and $\beta$:

$$\Delta_{\alpha,\beta} = \sum_{i,j} (1 - s_{i,j})^{\alpha} (p_i p_i)^{\beta}$$

Where $s_{i,j}$ means similarity between category i and j, $p_i$ means proportion of category i, respectively. Here we call Rao-Stirling diversity index the variant where $\alpha = 1$ and $\beta = 1$ initially introduced by Rao (1982). In calculating Rao-Stirling diversity, we used journal level scientific genre categorization used in “Web of Science” (Thomson Scientific). In “Web of Science,” each academic journal is classified to one or more scientific categories (SC). In order to calculate Rao-Stirling diversity, information of inter-category similarity ($s_{ij}$) is needed. We used the co-citation based inter-category (SC) similarity matrix proposed by Rafols and his colleagues (Leydesdorff and Rafols, 2009), and diversity is calculated on the portfolio of each scientist type.

## 4. EMPIRICAL RESULTS

### 4.1. TESTING HYPOTHESIS 1: SCIENTIFIC PRODUCTIVITY

To compare scientific productivity of entrepreneurial scientists and traditional scientists, Statistical difference was determined by two-sided Mann-Whitney’s U-ttest. Difference with p<0.001 was considered significant The result shows there is a statistically significant difference between the underlying distributions of the publication count of entrepreneurial scientists and the publication count of traditional scientists (z = -3.659, p = 0.0003).

## 4.2. TESTING HYPOTHESIS 2: PRESTIGE

In order to identify the patterns of forward citation for each type of scientist, we focused on the 1957 articles authored by the 66 PIs in photocatalyst research in Japan. First, we classified the articles into four classes according to the number of forward citations they received: large citation counts (top 25% articles in citation counts ranking), medium-large citation counts (top 25% to 50% articles), medium-small citation counts (top 50% to 75% articles), and small citation counts (bottom 25% articles). Second, we re-classified the articles in each class into four categories: those articles that include at least one Pasteur scientist as an author, and the same for the Bohr and Edison scientists, and others. Although 210 articles have more than two types of PI as authors, the overlap is possibly small (less than 11%). The result derived from the classification is shown in Figure 1. As for the large citation counts class, we found that the share of Bohr scientists is 39%, that of Pasteur scientists is 29%, and that of Edison scientists is 22%, respectively. Also, as for the class of small citation counts, we found that the share of Bohr scientists is 12%, that of Pasteur scientists is 20%, and that of Edison scientists is 22%.

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Insert Figure 1 about here

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If we read Figure 1 through the lens of traditional research evaluation criteria, the pattern of Bohr scientists seems more favorable than those of Pasteur and Edison scientists. A large amount of papers published by Bohr scientists are frequently cited and a small amount of papers fail to be properly cited. In stark contrast, relatively fewer papers published by Pasteur scientists are frequently cited and a large number of papers published by Pasteur scientists fail to be properly cited. Since citation rank is not normally distributed, we used the two-sample Wilcoxon rank-sum test to determine whether there were significant differences of relative citation distribution between Pasteur scientists and Bohr scientists. As a result, by using Mann-Whitney U-test, statistically significant difference (P=0.0001) is found in citation rank distribution between two scientist types.

Thus we can suggest that the pattern of Bohr scientists is more favorable than that of Pasteur scientists (and even Edison scientists) from the viewpoint of traditional research evaluation.

To test hypothesis 2, a set of models were estimated using negative binominal regression to evaluate the determinants of citation impact at individual article level. Table 2 describes the variables used in this analysis. In order to evaluate the contribution of distinct scientist types, a dummy variable for each scientist type identified by the attribute of authors is introduced as independent variable. The variable PASTEUR takes value 1 when at least one Pasteur scientist participates as an author to the target article. The variables, BOHR, EDISON and OTHERS are also defined similarly. Since the scientific impact of research is highly correlated with amount of labor used to deliver the observation described in the article, we introduced number of authors (NAUTH) as a proxy for labor input to control the effect on dependent variable. Journal impact metrics (SCImago Journal Rank; SJR) is also introduced as control variable as a proxy for the prestige of the journal, since articles published in more influential journals are likely to obtain more impact than articles published in less influential journals. The duration from the publication year to 2010 (AGE) is included as control variable, since the amount of received citations is highly dependent on the duration of exposure to the academic community.

As discussed earlier, the photocatalyst field is already industrialized and its economic impact is quite large, so a growing number of industrial scientists are found as authors of scientific articles. Accordingly, a considerable number of articles are co-authored with industrial scientists, although the effect of participation of industrial scientists may possibly vary across scientist types. Since Pasteur scientists are more interested in social benefit through industrial application and have more experience in creating industrially useful knowledge, they are more likely to utilize contributions of industrial scientists effectively. Thus, the dummy variable UI is introduced as control variable, which denotes the existence of industrial scientist as co-author of target article.

Table 3 shows the descriptive statistics; Table 4 shows the correlation matrix. The result of estimation is shown in Table 5.

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Insert Tables 3,4,5 about here

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In Table 5, model (1) shows estimated result in all samples while model (2) shows estimated result of top 25% citation ranking articles only. In both results, SJR and AGE remains highly ($p<0.001$) significant. The significance of SJR suggests that citation impact of a paper is highly dependent on the journal in which it appears. The significance of AGE suggests that citation increases according to time. In model (1), the effect of Bohr scientist authorship is significantly higher ($P<0.001$) than that of Pasteur scientist authorship. Thus hypothesis 2 is supported. The order of magnitude of the effect of scientist authorship is Bohr (highest), Pasteur, Other, Edison (lowest), this results again suggests traditional scientists favors better than entrepreneurial scientists according to individual articles' citation level.

To see the situation in more detail, further investigations are performed limiting to top 25% citation ranking articles. In model (2), the effect of Bohr scientist authorship does not have significant effect to leverage prestige of article. To the contrary, the effect of Pasteur scientist authorship has the only significant effect in leveraging prestige.

## 4.3. TESTING HYPOTHESIS 3: RESEARCH BREADTH/MULTIDISCIPLINARITY

From the observations obtained in previous two hypothesis, the two sets of productive scientists, Pasteur and Bohr, possibly having quite different research strategy, while concentrating to the same research target. To see this, diversity of their research portfolio (scientific category level Rao-Stirling diversity) is evaluated. The distribution of research portfolio diversity of Pasteur scientists and that of Bohr scientists are shown in Figure 2

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Insert Figure 2 about here

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Mean of diversity of Pasteur scientists (0.48) is higher than that of Bohr scientists (0.41). Using a two-tailed t-test, significant difference ($p<0.008$) of mean diversity is found between these two scientist types. Thus hypothesis 3 is supported.

## 5. CONCLUSION AND DISCUSSIONS

When we compare the research performance of entrepreneurial scientists with that of conventional academics, the results of quantitative analysis applied to a sample of 1957 scientific papers published by 66 scientists active in the advanced materials research in Japan confirm that: (i) entrepreneurial scientists (Pasteur and Edison scientists) publish more papers than less entrepreneurial scientists (Bohr and Other scientists) do, (ii) whereas the papers published by Bohr scientists demonstrate a good citation performance on average (many of their papers are frequently cited, and few of them fail to be properly cited), the papers published by Pasteur scientists demonstrate a relatively poor citation performance on average (the proportion of frequently cited papers is lower, and the proportion of marginally cited papers is higher than those published by the latter); (iii) Pasteur scientists show higher propensity to leverage citation impact than do Bohr scientists; and (iv) the degree of multidisciplinarity of the papers authored by Pasteur scientists is higher (more diverse) than that of Bohr scientists.

Whereas our finding, that is, although the quantity of research output if larger for the entrepreneurial scientists, overall citation performance of Pasteur scientists is not as good as that of Bohr scientists, suggests that prevailing academic entrepreneurship exerts a seemingly negative influence on scientific productivity if we limit our comparison only mean performance. We also find that the former makes a relatively large contribution to furthering the scientific frontier by not relying on conventional research traditions. Bohr scientists may resemble Isaac Newton, who famously remarked, “If I have seen a little further it is by standing on the shoulders of Giants.” Comparatively speaking, when Pasteur scientists see a little further, they may rely less on the shoulders of “Giants,” meaning, in this case, the impact factor of the scientific journals in which their papers are published. Also, our finding, that is, the coverage of scientific disciplines of the papers of Pasteur scientists is more diverse than that of Bohr scientists, suggests that the impact of influential papers authored by Pasteur scientists is derived from the amount of citations coming from heterogeneous scientific articles crossing over several scientific disciplines.

Certainly, our findings are due to the specificity of the research subject: in the field of advanced materials, two-way interaction between science and technology provides scientists with the opportunities to extend their scientific research into unexplored areas, and it is the type of entrepreneurial scientists that benefits mostly from such opportunities. Recently, the role of Pasteur scientists, especially those in the field of advanced materials, has become highly esteemed in that their search process can afford to cultivate the unexplored research areas left behind in the march of the traditional Bohr scientists (Kitazawa, 2008, 2010). Overall, Adam Smith’s combinatorial benefits of knowledge refinement and fragmentation resulting from the division of labor between university and industry are realized by the offspring of boundary spanners such as Pasteur scientists in some scientific fields (Baba et al., 2009; Metcalfe, 2010; Murray, 2002).

Recently in Japan, as in Europe, state backing of universities has been cut, and public support for R&D is predominantly allocated towards "outcome-based basic research" intended to meet specific needs of society (e.g. solving those problems of global environmental issues, cancer treatment, and an aging society). When allocating shrinking public funds, the ongoing science and technology policy aiming to give priority to research intended to solve societal problems seems relevant for its own sake. Additionally, this paper posits a theoretical explanation, which enables us to deepen our understanding of the nature of "outcome-based basic research." In our view, the essence of the policy resides in the research policy typically pursued by Pasteur scientists: while they often publish papers in scientific journals with low impact, which are less likely to be cited in the short term, they sometimes publish papers with potential to contribute to the progress of science, since the contents of the papers can receive positive evaluations in multiple scientific disciplines in the long run.

However, we admit the qualification attached to our policy discussion: the same scientists are willing to adopt different research policies depending on their place in the scientific community or their position in the lifecycle of a scientist (Stephan and Levin, 1992). For junior researchers (i.e. doctoral and postdoctoral students, and assistant professors), the rational strategy will be to begin by adopting the Bohr-mode to produce research results quickly and steadily for securing a position in the scientific community. This understanding gives us the caution that labeling a given scientist as a Bohr scientist or a Pasteur scientist is not an adequate use of the "quadrant model of scientific research" because a junior researcher may prefer the Bohr mode in order to survive in the environment of tightening competition in scientific community, only to switch modes once his position has become more secure. Facing the global trend towards "outcome-based basic research" policy, this paper provides a preliminary discussion which promises to open further lines of investigation on the appropriate policy settings which enable scientists to better qualify as proactive actors for both scientific progress and contribution to society.

Finally, we acknowledge some methodological limits on our study. Since the research was highly focused on a specific industry and nationally bounded, the general applicability of the analysis is limited. First of all, it is likely that the government-driven academic culture recently prevailing in Japan, as well as the idiosyncrasies of individual scientists, are related to the observed performance divide between Bohr and Pasteur scientists. It would be necessary to collect the corresponding data from a couple of other countries to make sure that the results are consistent across different countries. Similarly, the hypotheses derived from the observation of one specific field are not necessarily true for all scientific fields. Again it would be better if a couple of sub-fields from different areas were included in the study to make sure that the results are robust and consistent. Thus, it is important to note that this argument is not about the divide between Bohr and Pasteur scientists in scientific contribution generally, but specifically under these conditions: 1) scientists working in the field of advanced materials, 2) scientists whose scientific production originated and developed mainly in Japan, and 3) scientists who are willing to reach successful achievements of contributing to the society. Further research is needed to develop the conjectures and to see how the conditions that produce the scientific divide differ in other countries and how each type of scientist contributes to furthering the scientific frontier in the long run.

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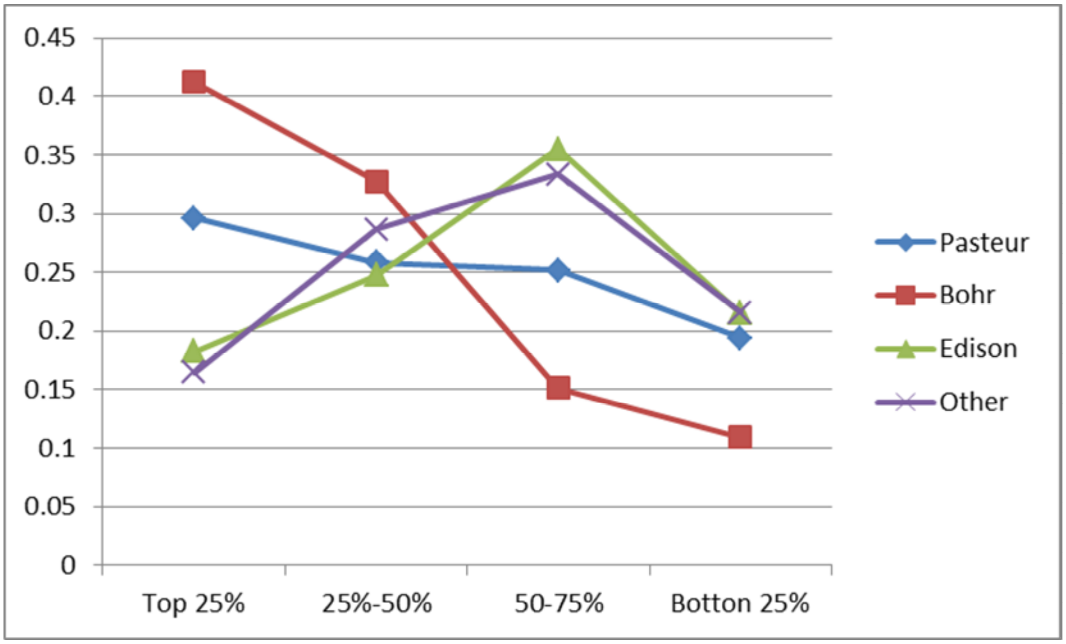


Figure 1 Comparison of publication impact breakdown

Source: Authors' elaborations

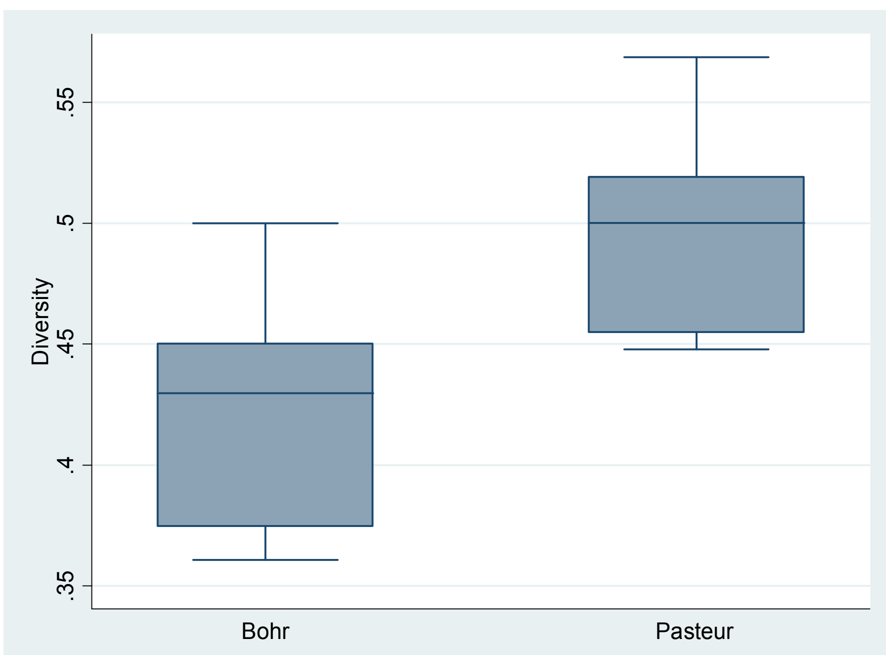


Figure 2 Comparison of Rao-Stirling diversity by scientist types

Table 1 Classification of scientists in the "Quadrant model of scientific research"

| | | Number of patents (PAT)<br>Less<br><=6 | More<br>≥6 | Total |
|---|---|---|---|---|
| Average of citations (ACITE) | More<br>>22.2 | Bohr scientists<br>21.2 papers<br>745.2 citations<br>13 researchers | Pasteur scientists<br>61.5 papers<br>2150.5 citations<br>21 researchers | 46.1 papers<br>1613.2 citations<br>34 researchers |
| | Less<br><=22.2 | Others<br>22.0 papers<br>329.0 citations<br>22 researchers | Edison scientists<br>27.3 papers<br>436.3 citations<br>10 researchers | 23.6 papers<br>362.5 citations<br>32 researchers |
| Total | | 21.7 papers<br>483.6 citations<br>35 researchers | 50.5 papers<br>1597.5 citations<br>31 researchers | 35.2 papers<br>1006.8 citations<br>66 researchers |

Source: Authors' elaborations

Table 2 Variables description (Article level)

| Type | Name | Description | Source |
|---|---|---|---|
| Dependent variable | CITE | Number of cumulative forward citations | Scopus |
| Independent variables | PASTEUR | Dummy variable (1/0) denoting if the paper is authored by a Pasteur scientist | Scopus/IPDL |
| | EDISON | Dummy variable (1/0) denoting if the paper is authored by an Edison scientist | Scopus/IPDL |
| | BOHR | Dummy variable (1/0) denoting if the paper is authored by a Bohr scientist | Scopus/IPDL |
| | OTHERS | Dummy variable (1/0) denoting if the paper is authored by Others | Scopus/IPDL |
| Control variables | NAUTH | Number of authors of the paper | Scopus |
| | SJR | SCImago Journal & Country Rank (2009) | SCImago |
| | AGE | Age of the article (i.e. years passed after publication) | Scopus |
| | UI | Dummy variable (1/0) denoting if the paper is co-authored by a corporate researcher | Scopus |

Table 3 Descriptive statistics (Article level)

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| CITE | 1957 | 26.67 | 59.23 | 0 | 1878 |
| PASTEUR | 1957 | 0.43 | 0.49 | 0 | 1 |
| EDISON | 1957 | 0.08 | 0.28 | 0 | 1 |
| BOHR | 1957 | 0.05 | 0.21 | 0 | 1 |
| OTHERS | 1957 | 0.13 | 0.34 | 0 | 1 |
| NAUTH | 1957 | 3.05 | 1.69 | 1 | 12 |
| SJR | 1957 | 0.22 | 0.36 | 0 | 8.016 |
| AGE | 1957 | 7.72 | 6.14 | 0 | 34 |
| UI | 1957 | 0.08 | 0.26 | 0 | 1 |

Table 4 Correlation matrix (Article level)

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|---|
| (1) | CITE | 1 | | | | | | | |
| (2) | PASTEUR | 0.0803*** | 1 | | | | | | |
| (3) | EDISON | 0.0426+ | -0.1808*** | 1 | | | | | |
| (4) | BOHR | -0.0341 | -0.0551* | -0.0486* | 1 | | | | |
| (5) | OTHERS | -0.0635** | -0.2789*** | -0.1117*** | -0.0405+ | 1 | | | |
| (6) | NAUTH | -0.0014 | 0.1118*** | -0.0305 | 0.0104 | 0.0237 | 1 | | |
| (7) | SJR | 0.2559*** | 0.0238 | -0.0259 | 0.0174 | 0.0125 | 0.033 | 1 | |
| (8) | AGE | 0.1652*** | -0.0299 | 0.1343*** | -0.0179 | -0.0813*** | -0.025 | -0.0211 | 1 |
| (9) | UI | 0.026 | 0.0571* | -0.0729** | -0.0161 | -0.0415+ | 0.0917*** | -0.0144 | 0.0562* |

Significance level: *** for 0.1%, ** for 1%, * for 5%, + for 10%

Table 5 Determinants of citation impacts (Negative binominal regression; article level)

| | (1)<br>All sample | (2)<br>Top 25% |
|---|---|---|
| Dependent variable: cite | | |
| Independent variables: | | |
| PASTEUR | 0.231*** | 0.225*** |
| | (4.72) | (4.95) |
| BOHR | 0.367*** | -0.0267 |
| | (3.59) | (-0.32) |
| EDISON | -0.511*** | -0.227 |
| | (-4.09) | (-1.61) |
| OTHERS | -0.191* | -0.188+ |
| | (-2.21) | (-1.88) |
| NAUTH | 2.129*** | 0.217*** |
| | (11.01) | (4.89) |
| SJR | 0.0117 | -0.0773*** |
| | (0.68) | (-4.96) |
| AGE | 0.107*** | 0.00649 |
| | (15.45) | (1.17) |
| UI | 0.0498 | 0.00713 |
| | (0.47) | (0.08) |
| Intercept | 1.634*** | 4.331*** |
| | (16.98) | (48.62) |
| N | 1957 | 495 |
| Log likelihood | -7958.5 | -2519.7 |
| chi2 | 495.4 | 97.16 |

*Note:* *t* statistics in parentheses

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$