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Task Allocation of Academic Biology Laboratories

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ADAPTATING ORGANIZATION IN SCIENCE: HOW CONTEXTUAL ENVIRONMENT AFFECTS TASK ALLOCATION OF ACADEMIC BIOLOGY LABORATORIES

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ABSTRUCT

This study examines the contingency of organizational design in academic organizations drawing on a survey of biology laboratories in Japanese universities. It investigates the intra-laboratory task allocation between a lab head and members (e.g., junior staff, PhD students) in three research phases (i.e., planning, execution, and writing) and how different patterns of task allocation affect lab-level scientific productivity. Results suggest that organic organizational structure with limited division of labor suits basic research, where exploratory approach is common with high unpredictability, while mechanistic structure is fitter for applied research, which is relatively exploitative and predictable. Thus, academic organizations, just as industrial organizations, need to adapt their organizational design to contextual environment to maximize their performance.

KEYWORDS

Laboratory; task allocation; contingency; division of labor; organizational design; biology

JEL CODE

I23, L23, O32, D23

1. INTRODUCTION

Because the modern economy heavily relies on knowledge production from the academic sector, fostering competitive academic organizations is essential in vitalizing the economy (Etzkowitz and Leydesdorff, 2000; Stephan, 1996). Scientific research in academia is usually undertaken in university laboratories, where a diverse range of expertise from some researchers is integrated under the supervision of a lab head (also called principal investigator or PI) and the process of research is accelerated by division of labor (e.g., Carayol and Matt, 2006; Latour and Woolgar, 1979; Owen-Smith, 2001). The continuous nature of laboratories, unlike temporary cross-organizational collaboration, enables researchers to pursue ambitious research goals, and laboratories function as a place of training junior researchers (Delamont et al., 1997; Knorr-Cetina, 1999). These characteristics of laboratories contribute to scientific production in the long term. As such, science policy literature has suggested that laboratory is the most appropriate unit in analyzing scientific production (Carayol and Matt, 2006; Latour and Woolgar, 1979), but few studies have focused on the lab-level scientific production.

Organizational theory suggests that organizational structure and business processes should be adapted to a variety of contextual factors (e.g., Burns and Stalker, 1961; Minzberg, 1979; Tidd et al., 1997). Especially, in the lab context, though in industry, previous literature has shown, for example, that information flow and communication patterns are contingent on task characteristics (Allen and Cohen, 1969; Tushman, 1978). These studies seem to imply that academic organizations also have to adapt their organizational design depending on circumstances. Though academic organizations at the level of university or college may lack flexibility for this requirement and appear bureaucratic (Minzberg, 1979), university laboratories, given a high level of autonomy, can be flexible to adjust themselves to the dynamic nature of science. In fact, some literature finds an analogy between university laboratories and small startups in that lab heads act as a president who raises funds and organizes a team of researchers to win the competition and to market new products in the form of scientific knowledge (Stephan, 2012). Nevertheless, prior literature on organizational theory has been developed mainly in the industrial context, and it is not totally clear if implications from industry can be directly translated into academia.

University laboratories is peculiar in that lab heads supervise members including students and junior researchers, who may need training for short of experience (e.g., Knorr-Cetina, 1999; Owen-Smith, 2001). That is, lab heads have to play a dual role of an educator and a manager in their relationship with young members. With this regard, sociology literature offers in-depth illustration based on ethnographies of one or a few university laboratories mostly in life sciences and physics (Fujimura, 1997; Knorr-Cetina, 1999; Latour and Woolgar, 1979; Lynch, 1984; Owen-Smith, 2001; Salonius, 2008). However, general picture on the organizational behavior of university laboratories is still lacking, and their implication for scientific production is limited.

The objective of this study is three-fold. First, it aims to draw a broader picture concerning the nature of organizational behavior of university laboratories especially in terms of task allocation on the basis of a structured survey data, whereby to reinforce the prior findings largely based on ethnographies. Second, in so doing, this study attempts to identify productive organizational designs under different contexts, whereby to extend the application of organizational theory, mostly formulated in the industrial context, to the context of academic organizations. Third, this study aims to answer two managerial questions on task allocation in university laboratories: first, whether lab members should be engaged only in labor-intensive tasks, and second, whether lab heads should stay away from the bench as a pure manager or engage also in labor-intensive tasks as player mangers. That is, prior literature roughly assumes that lab heads are the pure manager and members are workers, but we challenge this simplistic view. In particular, we hypothesize that different modes of task allocation should be employed depending on research areas and other contextual factors. To empirically test our hypotheses, we conducted interviews of 30 researchers and a survey of 396 lab heads from Japanese universities in the field of biology.

2. ORGANIZATIONAL ASPECTS OF LABORATORY WORK

Research activities in natural sciences are usually undertaken in laboratories that consist of a lab head and some members under the lab head’s supervision (e.g., Carayol and Matt, 2006; Latour and Woolgar, 1979; Owen-Smith, 2001). Lab heads are usually professors, and members include students, postdocs (postdoctoral researchers), junior faculty members,[1] and technicians. Universities provide lab heads with certain space, where they can install necessary facilities and employ a group of members to solve their research questions. Unlike temporary cross-organizational collaboration, laboratories allow a continuous form of teamwork and lab heads can pursue relatively long-term goals. In this long-term perspective, lab heads arrange a portfolio of research projects, some of which may be challenging but with potentially great impact and others of which less novel but likely to succeed, so that they can spread the risk and constantly produce certain output (Knorr-Cetina, 1999). Laboratories allow division of labor. In biology, research techniques are well embedded in individual researchers (Knorr-Cetina, 1999; Latour and Woolgar, 1979), and thus, coordinating multiple

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[1] Depending on university systems, junior faculty members (e.g., assistant professors, lecturers) may be supervised as members under a lab head or may become independent lab heads. In Japan, junior faculty members are usually supervised by a lab head.

researchers with different technical expertise is often essential. Lab tasks are also vertically divided. That is, lab heads are usually responsible for setting up the research environment (e.g., budget, funding, and recruitment) and coordinating a series of projects, while members commit to executing specific projects (Traweek, 1988). Importantly, laboratories also function as a place of education. Young researchers typically consider their lab experience as opportunities to acquire research technique, which is requisite for their future employment (Delamont and Atkinson, 2001; Delamont et al., 1997). With this pedagogical function of university laboratories, the science community can transfer skills and knowledge from old to new generations, stabilizing the practice of science (Delamont et al., 1997).

In terms of task allocation, prior literature has mainly focused on the roles of lab heads and assumed that they are occupied with fund raising, arrangement of research environment, employment of members, and research planning (National Research Council, 1998). For example, Knorr-Cetina (1999) has found that researchers often stop bench work after becoming lab heads in high energy physics and molecular biology. National Research Council (1998) mentions in a report on American life scientists' career design that "[a] principal investigator builds a research group by defining the scientific questions to be addressed, specifying the methods to be used, obtaining necessary funding, finding the suitable research environment, and attracting the research personnel…. The research personnel in the group usually work on more specific tasks that pertain to the construction of research tools or the acquisition and analysis of data." As for the role of members, on the other hand, much less has been studied. A few studies on sociology of education, focusing on postgraduate education, have examined the relationship between lab heads and students (Delamont and Atkinson, 2001; Delamont et al., 1997; Salonius, 2008). An ethnography of British universities suggests that lab heads are responsible for identifying research projects and assigning them to students (Delamont et al., 1997). Becher et al. (1994) also point out that determining research subjects is rarely the responsibility of students themselves. For students, mastering tacit lab skills is the most important goal in lab experience (Delamont and Atkinson, 2001). Thus, learning and engaging in technical tasks seems to be regarded as the students' primary role. This division of labor between lab heads and members may be particularly clear in biology. Whitley (1984) suggests that work techniques in most natural sciences are rather reliable and standardized. In fact, many experimental techniques in biology are available as commercial kits and outsourcing services. This may allow lab heads to delegate technical work to members easily.

To further the discussion of task allocation, we distinguish three phases of research process. In general, scientific research starts from setting research questions and developing research plans, then, the questions are tested by experiments, simulations, and other approaches, and finally, the test results are interpreted and used to advance extant knowledge (Nightingale, 1998). This advanced part of knowledge often raises new questions for future research, and the whole process is repeated. We split this process into two functional phases: *planning*, or determining research subjects and hypotheses, and *execution*, or testing the hypotheses usually by experiment and data analyses in biology. In addition, we consider the phase of *writing*. The planning and execution are iterated until sufficient findings are accumulated that make up a convincing story as a scientific paper. For these three phases, prior literature roughly implies that lab heads engage in planning and members in execution, but it has paid limited attention to task allocation in writing. In what follows, we describe general qualities of each phase and discuss the rationale of task allocation.

Execution phase. Biology is strongly governed by the notion of empiricism (Bertalanffy et al., 1962: p.100), and thus, biological research heavily depends on experiment except for a few purely computational and theoretical subfields. In the execution phase, researchers aim to transform some material substances into interpretable information, which often takes the form of figures and tables, and part of them are used in the next writing phase as “Results” in publications (Latour and Woolgar, 1979: Ch. 2). This transformation may be processed through some devices and facilities (e.g., typical examples in biology include NMR and DNA sequencers, etc.) or may be done more manually. Experimental procedures usually follow protocols. Some procedures are well-established and may be made available as commercial kit and somewhat automated, while others are less so and researchers may have to start from developing or optimizing protocols. It is particularly noteworthy that execution in biology usually draws on living organisms such as bacteria, cultured cells, mice, and even humans in clinical research. Since they often need maintenance on a daily basis, researchers tend to be chained to laboratories. Experimental procedure could take varying ranges of time from minutes to overnight and from weeks to months, and researchers have to arrange their job schedule depending on the life cycle of these organisms and the type of experiment. Experimental techniques requires substantial tacit knowledge and generally takes high level of concentration (Knorr-Cetina, 1999; Latour and Woolgar, 1979). Particular care must be taken, for example, when they use bio-hazardous materials or handle pathogenic agents. For these reasons, execution tasks are highly labor-intensive and time-consuming. Although efficient experimental methods have been developed, they simply enable more trials and errors and do not necessarily mitigate the burden of labor. Therefore, it seems natural that members but not lab heads are regarded as the main player in this phase (Delamont and Atkinson, 2001; Delamont et al., 1997).

Writing phase. The next phase, writing, is the process of producing a scientific paper for publication from given results. Although the process of creating a paper may span all three phases in that literature review may be done in planning and figures and tables are produced in execution (Latour and Woolgar, 1979: Ch. 2), we define the writing phase in a narrow sense. Still, writing can be more than a mechanical process of summarizing experimental results and can be an intellectual process of interpreting results, placing them adequately in the context of concurrent scientific debate, and creating a convincing story that interests peer researchers. These tasks call for some special skills. First, biological research usually draws on multiple research techniques, and one project may involve multiple members. Thus, the first step in writing is to select appropriate results from many results possibly done by many members. Such coordination seems manageable only by lab heads who have the authority and a holistic viewpoint beyond each member's. Second, biological research is often serendipitous and, experimental results are unpredictable (Shimizu et al., 2012). To write a paper with unexpected results, writers may have to start over from literature review and revise the planned story. With this regard, the quality of papers can be greatly affected by writers' theoretical knowledge. Third, the writing process may involve informal communication with other researchers. Before submitting a paper for peer review, authors attempt to improve the possibility of acceptance by incorporating the knowledge of leading researchers. Some of our interviewees emphasized that negotiation with journal editors is also indispensable. Overall, this phase requires intellectual and social skills, which seems better exercised by experienced lab heads rather than by young members.

Planning phase. The planning phase starts with choosing research subjects and identifying specific questions. The goal of academic research is to advance knowledge, but the advancement is acknowledged only after publication, and the credit is awarded basically only to the first discoverers (Merton, 1973). Thus, researchers have to carefully choose research agenda so that they can win the competition, for which they have two options: to find new niche ones, or to outperform competitors in extant ones. In either case, outside extant knowledge, or the status of competitors, is essential information for planning, where even unpublished information may have to be collected. For the latter option, researchers typically extend a line of their own past research because it tends to be most advanced in a certain area. Thus, their own past research is another essential information source for planning. With this regard, the planning and writing phases are closely related. Once research areas and questions are identified, researchers have to translate their hypotheses into technically operational plan (i.e., the plan of execution). Thus, this phase also takes technical knowledge. Researchers have to process and integrate these various types of knowledge and develop a strategically feasible plan. Therefore, it seems natural to assume that lab heads' supposedly higher-level intellectual capabilities and longer research experience better serve this phase (Delamont and Atkinson, 2001; Knorr-Cetina, 1999).

3. VARIATION IN TASK ALLOCATION AND SCIENTIFIC PRODUCTIVITY

Although the prior assumption in task allocation seems reasonable, it does not have to imply complete division of labor. Thus, we ask whether members should concentrate on execution as if they were technicians or be encouraged to take part also in planning and writing, and whether lab heads should stay away from execution tasks as a pure manager or participate in them as a player manager (Golden et al., 2000), and we argue that answers to these questions depend on contexts (Burns and Stalker, 1961; Minzberg, 1979; Tidd et al., 1997).

3.1. Members' Engagement in Planning

Based on the assumption that lab heads are primarily responsible for this phase, our question is if members also should be engaged. The answer to this question from prior literature, though limited, is rather negative for their observation that members are allowed to decide their own research subjects (Delamont and Atkinson, 2001; Delamont et al., 1997; Salonius, 2008). While this is understandable for members' limited research experience, it is exactly why they need training. Perhaps, mastering experimental skills may be the first priority for young members (Delamont and Atkinson, 2001), but learning how to design and coordinate research projects should be indispensable. Thus, one could argue that members must be engaged in the whole process of research for educational purposes even if it may compromise scientific productivity. In the long term, well-trained researchers should better serve the science community. This argument highlights the conflict between the two roles of academic organizations, education vs. research, (Hackett, 1990), and lab heads face the dilemma of whether to prioritize their own research productivity or to give their young subordinates opportunities for learning even at the sacrifice of productivity. Many of our interviewees referred to this point, suggesting that there are two types of laboratories: one where members are treated like blue-collar workers in a factory, and the other where members are decently trained as would-be researchers. One interviewee mentioned as follows:

> In natural sciences, it may be common that young members (especially students) are exploited to produce experimental results as if they were technicians. Some laboratories even do attendance management like a factory. However, I believe that such an approach cannot develop good researchers, and that those who obediently follow lab head's instructions, if being successful, will not become a leader of whatever world. I believe that universities are the place for education, and thus, students must be respected more than professors.

Although the above argument implies that members need to be given opportunities to experience other phases than execution, it still maintains the assumption that it has, if any, negative impact on productivity. However, motivation theory might suggest otherwise. In general, researchers place great emphasis on autonomy and independence (Amabile and Gryskiewicz, 1987; Hollingsworth and Hollingsworth, 2000). As such, Roach and Sauermann (2010) imply that academically-trained researchers show strong preference for freedom to choose research projects. Involving members from the outset of research process can motivate them to seriously engage in later phases. With autonomy in project selection, members attribute their success or failure to their own actions, and their intrinsic motivation is facilitated (Hackman and Oldham., 1976). Put differently, it can be counterproductive to keep members away from this upstream phase. A lab head we interviewed mentioned as follows:

> Because the execution phase in life science research is painstakingly laborious, members would not go through it without strong intrinsic motivation. With this regard, having members engage in planning is effective. I try to respect members' choice of research topics even if they seem likely to fail, hoping them to reach a serendipitous discovery.

Then, the question comes down to the balance between potential loss of productivity due to members' inexperience and potential gain due to reinforced motivation. We argue that this depends on contexts, particularly, on research areas in terms of being basic vs. applied. Here, we briefly discuss the concept of basicness. Biology is a broad discipline and is related to many research fields such as medicine, agriculture, and pharmaceutical. This diversity can be attributable to many aspects, but one that can be relevant in coordinating lab work is the nature of research goals (Sauermann and Stephan, 2012). Some researchers seek general understanding of certain phenomena (i.e., *basic* research), while others are guided by consideration for practical use (i.e., *applied* research) (Stokes, 1997). Although this distinction of research orientation may be controversial, researchers show some consensus. Calvert (2004) lays out a few characteristics of basic research. First, basic research is unpredictable, where researchers aim to find a new concept or push the boundaries of existing knowledge. This feature in basic research leads to exploratory approach compared to more exploitative and confirmatory approach in applied research. Second, basic research is general in that its results can be used for a wide range of instances and phenomena while applied research helps to solve a specific problem. Third, basic research is driven by the internal theoretical dynamics of the discipline. This is also related to the generality because theories involve statements of general principles. We assume that these features of basic and applied research affect how lab tasks should be allocated.

Particularly, in the planning phase, the basicness of research agenda could affect productive modes of task allocation for two reasons. First, intrinsic motivation is regarded as an indispensable antecedent for exploratory and divergent thinking (Amabile, 1996), which is more relevant in basic research (Calvert, 2004). As such, Sauermann and Cohen (2010), based on a survey of corporate researchers, show that intrinsic motivation contributes to productivity to a greater extent in upstream R&D activities than in downstream. Second, the exploratory nature of basic research implies that research plan in basic agenda is prone to frequent update. That is, researchers have to frequently adjust their research plan in accordance with experimental results. Thus, the feedback loop between planning and execution runs quickly (Nelson, 1959), and it could be streamlined by members' engagement in the planning phase. In contrast, this potential benefit seems limited in applied agenda, where the goal of research is rather clear and members can stick to original plans. Thus, we hypothesize:

Hypothesis 1: Members' engagement in planning has greater positive effect on productivity in basic research than in applied research.

3.2. Lab Head's Engagement in Execution

The second question is whether lab heads should stay away from the bench as a pure manager. As above discussed, prior assumption is that members have comparative advantage in this labor-intensive and time-consuming phase (Delamont and Atkinson, 2001; Delamont et al., 1997). Though we accept that members are the main player in this phase, we further ask if co-participation of lab heads contributes to productivity. Our interviewees suggested that quite a few lab heads actually engage in bench work, not because they are in short of labor, but simply because they enjoy it. They mentioned that most researchers have become researchers for their taste for doing experiment, which allows direct interaction with the nature, so they will not abandon it to become a pure manager. Such laboratories must be sacrificing productivity if the argument of comparative advantage is correct. We suppose that this is generally the case but that lab head's execution can be justified in a certain situation.

A potential source of benefit from lab head's execution is the proximity between a lab head and members in daily research activities. Through direct supervision, lab heads could find out and help solve problems in members' execution tasks in a timely fashion. This could make enormous impact on the progress of members' work. Biological experiment could easily take weeks or months to produce results, and inexperienced members could be unaware of fatal problems that are obvious to experienced researchers. Furthermore, collocation can increase the social proximity because lab members spend most of their time at bench. Then, communication between a lab head and members is facilitated, contributing to the efficiency of team work (Teasley et al., 2002). Shimizu et al. (2012), drawing on a survey sample of natural scientists in the US and Japan, indicate that the integration of management and execution roles is positively associated with serendipitous discoveries. When members are separated from a lab head and their communication cost is high, unexpected findings are more likely to be overlooked for members' lack of holistic viewpoints, and they might be even deliberately ignored for fear that the lab head might hate to hear unexpected news (Barber and Fox, 1958; Van Angel, 1992).

Another benefit from lab head's engagement in execution is technological catch-up. A lab head we interviewed suggested that it is difficult even for experienced lab heads to follow state-of-the-art techniques without engaging in experiment at all.

> When interpreting experimental results, researchers have to distinguish true from false signs of discoveries and to find out hidden serendipitous signs. They may be obvious for experimenters but not for non-experimenters. It is not rare that pure-manager lab heads misinterpret experimental results and make silly instructions to their members. Unfortunately, members often have to follow the instructions and tend to blindly do so especially when the lab head is renowned.

This is because most experimental techniques (even commercially available kits) take a great deal of tacit knowledge. Knorr-Cetina (1999) suggests that an experimental technique is a "package" of lab protocol, material objects, and researchers. Lab heads may be able to understand the theoretical mechanism of new techniques, but only experimenters know the knack of techniques. Thus, lab heads would become technically obsolete if distancing themselves from bench work (Salonius, 2008), which can be a serious problem when experimental techniques are rapidly advancing as in biology.

We hypothesize that these points are particularly important in basic research. In basic research, because of its exploratory nature and abstract goals, research plans tend not to be strictly predetermined and are frequently updated, which requires tight communication between a lab head and members. As autonomous trials and errors are encouraged, the risk of being stuck in trivial problems and unpromising lines of research becomes higher, which justifies the cost of lab head's direct supervision. Furthermore, since the success of basic research depends more on unplanned findings, a keen eye for serendipitous signs in experimental results is essential. Given that young members have limited capabilities with this regard, lab heads need to maintain their technical capabilities by catching up with the latest technologies. Thus, we hypothesize:

Hypothesis 2: Lab heads' engagement in execution has positive effect on productivity in basic research while it has less positive or even negative effect in applied research.

3.3. Task Allocation in Writing

We above argued that writing is more than summarizing experimental results and takes substantial knowledge, and thus, that lab heads have comparative advantage to members. More precisely, however, this depends on how much value is added to papers in this phase. For example, if research goals are practical, not much theoretical knowledge may be required, and if experimental results are predictable, the storyline of a paper can be determined before execution. Then, the value added in the writing phase may be limited. Again, we argue that the basicness of research is relevant. First, the ultimate goal of applied research is, by definition, application (Calvert, 2004; Stokes, 1997). Thus, publications in applied research can be appreciated if it is practically useful even if it does not advance theoretical understanding. For example, research on clinical medicine can be published if it proves the efficacy of a drug substance but does not elucidate its mechanism. On the other hand, the goal of basic research is to advance knowledge and tends to refer to general and abstract concepts (Calvert, 2004; Stokes, 1997). Thus, researchers have to understand up-to-date theoretical debate and incorporate their own findings in the extant knowledge. With this regard, lab heads' advantage over young members in writing is more relevant in basic research than in applied research.

The unpredictable nature of basic research could strengthen this tendency. Basic research takes more exploratory approach and applied research more confirmatory approach (Calvert, 2004). Basic research often starts from a broad question without having a precisely testable hypothesis, and experimental results might be applied to a diverse range of scientific discussion. If researchers have a broad range of knowledge not only about originally intended areas but also about surrounding areas, serendipitous discoveries are more likely to occur. With this regard, writing in basic research can be more a creative process of generating a novel story. Our interviewee referred to this point, suggesting the necessity of substantial knowledge and experience for writing in basic research.

> Serendipitous discoveries are important in biological, particularly basic, research. I think that even young researchers could find unintended results if they are careful enough. However, it does not guarantee a publication. For publication, serendipitous discoveries must be theorized and proved in accordance with the extant theories in the field. This takes substantial knowledge and is not feasible for inexperienced researchers.

On the other hand, applied research tends to have a clear focus on application (Calvert, 2004). To the extent that research goal is specific, the room for creative interpretation is limited. Thus, writing in applied research can be relatively a process of summarizing experimental results according to the predetermined plan. Then, members' inexpensive labor may lend them comparative advantage in this phase as in the execution phase.

Assuming that the skills of writing are better addressed by lab heads, especially in basic research, we must further ask whether non-involvement in writing demotivates members. With this regard, the motivation for writing is importantly different from that for the other two phases. That is, researchers are intrinsically motivated for curiosity until they make discoveries. However, writing is driven more by extrinsic motivation for the recognition from the peer and for other incentive systems (Merton, 1973). Thus, as long as members admit that their lab head is a better writer and they are given authorship, members would not insist on their engagement in this phase. In sum, we hypothesize:

> *Hypothesis 3: Lab heads' engagement in writing has greater positive effect on productivity in basic research than in applied research, and members' engagement in writing has greater positive effect on productivity in applied research than in basic research.*

4. DATA & METHOD

4.1. Sample and the Context of Japanese Universities

This study draws on a survey of Japanese university laboratories in the field of biology. To prepare a sampling frame for the survey, we employed the following criteria. First, we chose researchers currently in the position of a full professor. Japanese universities have a three-level promotion system with full professor at the top followed by associate professor and assistant or lecturer. Before obtaining an entrance position (assistant or lecturer), academics tend to experience a few years of postdoc term. Typical biology laboratories consist of senior staff (full and/or associate professor), who are the lab head, and members including a few junior faculty members (assistant or lecturer), postdocs, students, and technicians. Unlike American universities, junior faculty members are often under the supervision of lab heads. Some associate professors have independent laboratories, and others work in the same laboratory with a full professor, often co-supervising a laboratory. Second, we chose researchers who have received national grants at least once in the field of biology in the last three years (2007-2009), which implies that they are active researchers. Drawing on the list of recipients of Grants-in-Aid for Scientific Research (the primary competitive funding source for Japanese university scientists),[2] we prepared our sampling frame of 1,378 researchers. After re-examining their research fields and

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[2] Japan Society for the Promotion of Science (http://www.jsps.go.jp/j-grantsinaid/index.html).

affiliations on the Internet, we chose 900 lab heads in 56 universities as a final sample.

The survey instrument was developed based on semi-structured interviews with 10 Japanese researchers. We mailed the survey to the 900 lab heads and collected 396 responses (response rate = 44%). The survey was conducted from May through July 2010. We also collected publication data from *Web of Science* to measure scientific productivity. To examine non-response bias, we randomly selected 50 non-respondents and found no significant difference between the response and non-response groups in publication productivity, organizational rank, and gender ($p > 0.1$).

Japan has three types of universities offering four-year undergraduate or postgraduate education: national, public, and private universities.[3] Among them, national universities are the primary player of academic research while most private universities are education oriented. For example, while 73% of undergraduate students were in private schools whereas 22% were in national universities as of 2010. On the other hand, only 36% of graduate students were in private schools and 58% were in national universities. Among national universities, top seven universities (Universities of Tokyo, Kyoto, Osaka, Tohoku, Hokkaido, Kyushu, and Nagoya) are designated as pre-imperial universities and have been enjoying exceptionally prestigious status both in research and in education. For example, they receive approximately 50% of national research funds (Shibayama, 2011) and produce 30% of PhDs among all universities (Ishibashi and Ohtake, 2009). In our sample, 83% of the respondents are from national universities and 43% are from the top seven universities.

4.2. Measures and Description

Lab productivity. We prepared two measures of productivity at the lab level. First, we count the number of publications authored by lab heads (respondents) in the last five years of 2007 through 2011 (*pub count*). In biology, lab heads usually become an author for any paper published from their laboratories, regardless of their extent of engagement. Thus, we assume that publications authored by lab heads should cover most publications from their laboratory. Second, to gauge more qualitative aspect of scientific production, we drew on citation count. To address the age effect of citation count, we summed up age-weighted citation count for the above publications (*citation count*).[4] Further, we divide *pub count* and *citation count* by the number of lab staff (lab heads and junior researchers) to compute per-staff productivity.

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[3] As of 2010, Japan has 86 national, 95 public, and 597 private universities (School Basic Survey by Ministry of Education, Culture, Sports, Science and Technology: http://www.e-stat.go.jp/).

[4] Since we collected the publication data in 2012 (1- 5 years after publication), newer papers should have fewer citation counts than older papers. We divided the citation count of each paper by the number of elapsed years and summed them up.

Because these two measures are highly correlated and the regression results are similar, we mainly report the results based on citation count.

Organizational structure and task allocation. We inquired for the number of senior staff (full and associate professors), junior researchers (assistant, lecturer, and postdocs), PhD students, and technicians in each laboratory. The summation of these members is used as a measurement of *lab size*. On average, a laboratory consists of 1.6 senior staff, 2.6 junior researchers (assistant, lecturer, or postdoc), 2.8 PhD students, and 1.1 technicians. To examine task allocation, we define six research tasks for the three phases: 1) choosing a subject, 2) formulating a hypothesis, 3) planning experiment, 4) doing experiment, 5) analyzing data, and 6) writing papers. We suppose that 1) – 3) corresponds to the planning phase, 4) and 5) to the execution phase, and 6) to the writing phase. For each of these six tasks, we inquired as to the extent of the involvement of full professor (our respondent), associate professors, junior researchers, and PhD students, respectively. The response takes three-point scale, 0: no role, 1: supportive role, and 2: leading role.[5] Using this instrument, we prepared measurements of task allocation (detail shown in the result section). In the following analyses, we focus on laboratories that have at least one junior researchers and one PhD student.[6] Those without either junior researchers or PhDs tend to be very small. Among 396 laboratories, 77% (309 laboratories) satisfy this condition with the mean size of 9.2 and the standard deviation of 5.2.

Basic research. To measure research orientation in each laboratory, we asked “which describes your research goal, basic (aiming at advancement of theory and knowledge) or applied (aiming at solving problems in the real society)?” with five-point scale, 1) mostly basic, 2) more basic than applied, 3) both to a similar extent, 4) more applied than basic, and 5) mostly applied. Of our respondents, 55% chose 1), implying that their research goal was completely basic. For these basic laboratories, a dummy variable is coded one, and other laboratories are regarded as applied with the dummy coded zero (*basic research*). The inclination to basic research is due to our sampling.[7] To validate this subjective measurement, we drew on the type of journals where the respondents publish their papers. Based on the classification of “basicness” of journals (Narin et al., 1976), we calculated the percentage of respondents’ papers in basic journals and confirmed that basic laboratories tend to publish in basic journals (r = .29, p < .001). Second, we surveyed the number of patent applications in 2009–2010 and confirmed that basic laboratories have significantly fewer patents than applied laboratories (.31 vs. .85 applications per year; p < .001). Third, we identified a research field in which each

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[5] This measurement may need careful interpretation in that we do not know actual time spent on each task.

[6] There is no laboratory without a full professor. In terms of task allocation, we assume that technicians are not very relevant because they usually engage only in the execution phase.

[7] The majority of our sample are from schools of sciences while the rest are from schools of medicine, agriculture, pharmaceuticals, etc.

respondent received the majority of national grants (*field*). We categorized these fields into basic and applied fields[8] and confirmed that this measure is correlated with *basic research* (r = .41, p < .001). In addition, we tested the assumption that basic research is more exploratory and applied research is more confirmatory (Calvert, 2004). We surveyed "which describes the quality of your research, exploratory or confirmatory?" with a similar five-point scale and found that this is significantly positively correlated with the measurement of being basic vs. applied (r =.23, p < .001).

Control variables. The productivity of individual lab members should affect lab productivity and could possibly change task allocation. To incorporate lab head's productivity, we draw on publications first-authored by lab heads before they obtained the tenure position (i.e., before they opened their own lab).[9] We summed up the age-weighted citation count of these papers and averaged it by the number of years for the pre-tenure term (*pre-tenure citation count*). As a proxy of members' productivity, we use the university rank. In the Japanese academic context, for its admission and employment system, the ability of students and junior researchers are strongly affected by the university prestige. We prepared a dummy variable for the top seven pre-imperial universities (*top 7 univ*). As measures of research input, we also include *per-staff research budget* (JPY in million) and lab head's average hours spent on research activities (*time for research*). Time for research was measured with six-point scale, 1) less than 10 hours, 2) 10-20 hours, 3) 20-30 hours, 4) 30-40 hours, 5) 40-50 hours, and 6) 50 hours or longer per week. Some measures for individual background are included. We controlled for the number of years since lab heads opened their own lab (*lab age*). We asked the experience of research abroad with six-point scale, 1) none, 2) less than half a year, 3) one year, 4) 2 years, 5) 3 years, and 6) 4 years or more (*foreign experience*). If the current laboratory is where they obtained their degree, a dummy variable is coded one (*inbred*). If a lab head obtained a degree of medical doctor, a dummy variable is coded one (*medical doctor*). If a lab head is female, a dummy variable is coded one (*female*). In addition, following regressions include fixed-effects of *field* identified by past national grants. Table 1 presents the descriptive statistics and correlation matrix of these variables.

5. RESULTS

5.1. Variation in Task Allocation

Figure 1 illustrates the extent of engagement by the three ranks of lab constituents (lab heads,[10]

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[8] Basic fields include basic biology, biological science, basic medicine, neuroscience, and genome science. Applied fields include agriculture, pharmaceutical, and medicine.

[9] In biology, the first author implies that the author made the most important contribution to the paper.

[10] If a laboratory is co-supervised by full and associate professors, the maximum value of full and associate professors' engagement is used as lab head's engagement.

junior researchers, and PhD students) in six research tasks. It indicates that the planning phase is primarily conducted by lab heads and execution by members (junior researchers and PhDs). Thus, this confirms the assumption in the previous literature (National Research Council, 1998; Delamont and Atkinson, 2001; Knorr-Cetina, 1999). However, the extent of lab heads' engagement in execution and that of members' planning show some variation, suggesting that the division of labor is not completely stringent. As for the writing phase, lab heads are highly committed but members are also engaged (only about 10% of members play no role in writing).

We further analyze the extent of deviation from the typical task allocation in Table 2. For three rank-phase combinations (members' planning, lab head's execution, and members' writing), we computed the proportion of laboratories where the leading role is played by the supposedly atypical rank. In the whole sample, about one-third of laboratories engage members in planning, and about half engage lab heads in execution and members in writing (Rows 1-3). Again, these results suggest that the division of labor is not very strict. When the sample is split by research areas, members' writing is more common in applied than in basic laboratories (57% vs. 50%, $p > .1$). In addition, we examine the patterns of task allocation with the eight possibilities of three rank-phase combinations (Row 4-11). Rows 4 and 5 are the supposedly typical pattern, which accounts for 35%, but other patterns are not rare (12-20%) except Rows 8 and 10. Rows 8 and 10 correspond to members' planning but members' not writing, which implies that laboratories engaging members in planning tend to engage them also in writing.

To further scrutinize the pattern of task allocation, we ran a factor analysis for the 18 (three ranks x six task types) measures, which yielded a six-factor solution based on the Kaiser-Guttman criterion (i.e., eigenvalues greater than one) (Table 3). The six factors correspond to 1) member's planning, 2) researcher's full responsibility, 3) lab head's planning, 4) PhD's execution, 5) lab head's execution, and 6) lab head's writing (and member's not writing). This solution is consistent with our instrument design in that items intended to fall in the same concept belong to the same factor. Based on this result, we prepared three measures corresponding to factors 1), 5), and 6), taking the average of original measures for easier interpretation as our key independent variables.[11]

5.2. Prediction of Scientific Productivity

Table 4 presents the results of regression analyses. We estimate scientific productivity with

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[11] For Factor 6), we took the inverse of professor's writing and averaged them with PhD's and researchers' writing. We do not include Factors 2), 3), and 4) because they are not significant (Appendix 1). As for 2) and 3), this is possibly because they have very small variation (Figure 1).

fixed-effect ordinary least squares models. We use the logarithms of *per-staff citation count* and *pub count* as the dependent variables in Tables 4A and 4B, respectively. As for citation count (Table 4A), Model 1, based on the whole sample, shows that members' planning and members' writing have significantly positive effect (b = .273, p < .05; b = .285, p <.1, respectively). It shows that lab head's execution does not have significant effects (p > .1). As for control variables, pre-tenure citation count as a measure of lab head's ability shows positive effect (b = .033, p < .01) and female shows strongly negative effect (b = -.833, p < .01). To investigate the difference between basic and applied research, we split the sample into basic and applied laboratories (Models 3 and 4). As for the planning phase, members' engagement show significantly positive effect in both lab types (b = .418, p < .05 and b = .357, p < .1, respectively), and the effect is slightly weaker in applied laboratories. This is supportive to Hypothesis 1. Interestingly, lab head's execution has opposite effects between two lab types: significantly positive (b = .465, p < .01) in basic laboratories but significantly negative in applied laboratories (b = -.390, p < .01). This supports Hypothesis 2. This implies that the cost of lab head's engagement in execution exceeds its benefit in applied laboratories. As for lab head's writing, positive effect is observed in basic laboratories (b = .465, p < .1) and weaker and insignificant effect in applied laboratories (b = .145, p > .1). This is supportive to Hypothesis 3. To further examine the difference between basic and applied laboratories, Model 2 introduces interaction terms of task allocation and basic research with the whole sample. The result shows a strongly significant coefficient for the interaction term for lab head's execution (b = .833, p < .001), confirming Hypothesis 2. However, the interaction terms for members' planning and lab head's writing do not show a significant coefficient although the direction is as expected.

Table 4B shows qualitatively similar results with *pub count* as the dependent variable. However, in applied laboratories, members' planning and lab head's writing become rather negative, though insignificant (Model 4). Furthermore, Model 2 shows that the effects of three task allocation measures are significantly smaller in applied laboratories than in basic laboratories (interaction terms: b = .274, p < .1; b = .500, p < .001; and b = .333, p < .1, respectively). This supports Hypotheses 1-3. These results imply that the effect of task allocation could be different for qualitative and quantitative aspects of scientific production. Especially in applied laboratories, members' planning contributes to the quality (citation count) but not the quantity (pub count) of production, and likewise, lab head's writing improves the quality but not to the quantity. For better interpretation, Figure 2 illustrates the effect of task allocation in three phases for two dependent variables.

5.3. Supplementary Analysis

Sensitivity analysis. We consider three factors for sensitivity analysis. First, task allocation can be affected by external collaboration. When multiple laboratories participate in a project, each phase is likely to involve participants from multiple laboratories. Then, lab heads are more likely to be in charge of the phase as a representative of each laboratory, and conversely, members are less likely to be given the leading role. We surveyed the frequency of external collaboration in recent two years and found that some laboratories have collaborated more than 10 times (mean = 2.6). Restricting the sample to low-collaboration labs (once a year or less), we re-ran the regressions (Appendix 2). The result is qualitatively similar, but it shows stronger effects of members' planning and lab heads' writing (and members' not writing) (Model 1).

Second, we examine the influence of the ability of members, which should affect both task allocation and productivity. Assuming that organizational ranks affect the ability of members, we split the sample into two groups of high and low university ranks and ran the regressions (Appendix 3A). Overall, the result shows weaker statistical significance probably for smaller sample sizes. The effect of members' planning is significantly positive in high-ranked universities while it becomes insignificant, though still positive, in low-ranked universities (Models 1-3 vs. Models 4-6). This implies that the positive effect of members' planning is moderated by their ability, which is confirmed by our interview.

> In top universities, students can advance their research on their own. However, in low-ranked universities, students would be at a loss what to do if autonomy is given. I believe that lab heads cannot help treating them more as a technician than as an independent researcher in low-ranked universities.

Third, we analyze the effect of members' planning with the distinction of PhD students and junior researchers; prior ethnographies pointed out that PhD students tend not to engage in planning (Becher et al., 1994; Delamont et al., 1997), but they had no clear mention of more experienced members. Approximately 20% of laboratories allow the leading role for junior researchers only (but not for PhDs) and another 20% allow the leading role for both junior researchers and PhDs, while 60% do not allow the leading role for neither of them.[12] Appendix 4 compares the productivity with the last type of laboratories as the base group. Models 1 and 2 show significantly positive effect for the leading role of only junior researchers. Interestingly, when both junior researchers and PhDs are engaged in planning, the effect becomes slightly weaker. This suggests that the engagement of PhD students have no additional effect when junior researchers are already involved, but that it has rather negative effect especially in basic laboratories. This implies that members' research experience matters in the planning phase. In fact, one of our interviewees in basic research referred to

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[12] Few labs allow the leading role for PhDs but not for junior researchers, and we drop them for this regression analysis.

this point:

> I involve PhD students and junior researchers in the planning phase, and I am trying to allow them to do what they want. However, I do not think that independent planning is plausible for most PhD students. A solid research plan takes minimum experience, and having a PhD or not makes a substantial difference with this regard. One of my PhD students was obsessed with an idea, which I did not believe promising, but I could not change his mind until later literature proved it was wrong.

In applied laboratories, in contrast, the leading role of both ranks of members shows more significant and greater effect than that of only junior researchers. This might suggest that learning the planning skills for applied research takes less time than that for basic research.

Contingency on other contexts. We examine contingency to two additional contextual factors: lab size and lab age. The size is one of relatively well-studied factors though not conclusive (Carayol and Matt, 2006; Horta and Lacy, 2011). As for lab heads' execution, the positive effect in basic laboratories is stronger in larger laboratories (Appendix 3B: Models 2 and 5). To the contrary, the effect of lab heads' writing in basic laboratories is stronger for smaller laboratories. While larger lab size may cause overcapacity for lab heads' active participation (Delamont and Atkinson, 2001; Salonius, 2008), it may allow economies of scale and scope. The result implies that the latter effect is dominant in execution but the former in writing.

As for lab age (Appendix 3C), the result shows that members' planning and lab head's writing in basic laboratories is significantly positive in old laboratories but not in young laboratories (Models 2 and 5). This may be because longer experience of senior lab heads allows them to supervise members better in planning and to draw on deeper and wider knowledge in writing. In addition, the negative effect of lab head's execution in applied laboratories is more evident in old laboratories than in young laboratories (Models 3 and 6). This may be because the opportunity cost of lab head's execution is greater for senior lab heads than for junior lab heads.

Training policy and task allocation. Finally, we attempt to examine the drivers behind task allocation. In the survey, we asked several questions about respondents' (lab head's) policies on PhD training, based on which we analyzed what policies are associated with particular types of task allocation (Appendix 5). The result shows that members' planning is positively correlated with "giving scientifically important project" and "monitoring frequently." Thus, when lab heads are given challenging subjects, members are likely to be engaged in the planning phase and their work is closely monitored. This is especially significant in basic laboratories, and this is consistent with our discussion for the benefit of collocation. In applied laboratories, “giving safe project” (so that PhD students can finish dissertation without delay) is negatively correlated with members’ planning. That is, some lab heads assign easy subjects to students without engaging them in planning. “Giving safe project” is also negatively correlated with lab head’s execution, implying that some lab heads choose easy projects and avoid participation in execution. With lab head’s writing, “giving independent project” is negatively correlated; i.e., some PhDs are assigned writing tasks as part of an independent project. “Giving team project” is positively correlated with lab head’s execution and writing, implying that lab heads regard the typical division of labor as a form of teamwork.

6. DISCUSSION AND CONCLUSIONS

Drawing on a survey data of Japanese biology laboratories, this study investigates the variation in task allocation and its impact on scientific productivity under different contexts. First, this study confirms the prior assumption that lab heads primarily engage in planning tasks while members in execution tasks (Delamont and Atkinson, 2001; Delamont et al., 1997; Salonius, 2008). However, this study also shows that lab heads engage in the execution phase and members in the planning phase to some extent in many laboratories. Thus, the task allocation in biology laboratories is more flexible than prior literature has assumed. In addition, this study shows that writing tasks are allocated to both lab heads and members to varying extents. These results help draw a general picture of organizational behavior in university laboratories. Importantly, this study shows that the variation in task allocation affects scientific productivity, and that this effect is contingent on environmental contexts, which is consistent to the prediction of organizational theory (Burns and Stalker, 1961; Minzberg, 1979; Tidd et al., 1997).

This study distinguishes three phases of research process and examines the effects of task allocation. In the planning phase, the result suggests that members’ engagement increases productivity, possibly because autonomy stimulates members’ intrinsic motivation (Amabile and Gryskiewicz, 1987) and may encourage their effort in later phases. This effect seems stronger for experienced members (e.g., postdocs) than for students, consistent to the prior ethnographies (Becher et al., 1994; Delamont et al., 1997). This effect also seems stronger in high-ranked universities than in low-ranked universities. Comparing basic and applied research, members’ engagement seems more effective in basic research possibly for its exploratory nature and the relevance of intrinsic motivation than in applied laboratories. The result also shows that the effect of task allocation is stronger for citation count than for publication count, implying that members’ participation in planning is more relevant for the quality of production than for the quantity.

In the execution phase, members are the primary players, and intuitively, lab heads seem too expensive for the labor-intensive tasks. However, the result indicates that many lab heads actually engage in this phase. Our interviewees pointed out some rationale for lab heads' execution, such as catching up latest technologies and giving members timely input through collocation. Interestingly, the regression results show opposite effects of lab heads' execution between basic and applied laboratories. Thus, in basic laboratories, the benefit of lab heads' engagement seems to exceed its cost possibly because of exploratory nature of basic research. That is, in exploratory approaches, sharing workspace with members, having frequent discussion, and updating research plans in a timely fashion may be more important. In contrast, in applied laboratories, which tend to take more exploitative and confirmatory approach, research plans are more deterministic and frequent input from lab heads may be less needed. The positive effect in basic laboratories is even stronger in high-ranked universities, which might be due to members' higher ability.

In the writing phase, the result shows that lab head's greater engagement and members' weaker engagement improves productivity particularly in basic laboratories. Since writing scientific papers is a highly intellectual task, lab heads' expertise seems more suitable than members'. This argument is more relevant in basic research, which is more theory-driven and exploratory and takes theoretical knowledge of experienced researchers (Calvert, 2004). Consistently, this positive effect is strengthened when lab heads are more experienced. Again, this effect is clearer for citation count than for publication count, implying that lab heads' capabilities contribute more to quality than to quantity.

These results are in line with organizational theory, which argues that flexible organizational design is essential for uncertain tasks (Thompson, 1967; Tidd et al., 1997). Namely, there is an analogy between basic vs. applied laboratories and organic vs. mechanistic organizations. As above discussed, basic research is characterized by exploratory approach and high unpredictability, which is better addressed by organic organizational structure; on the other hand, applied research is relatively stable with less uncertainty, to which mechanistic organizational structure is suitable (Burns and Stalker, 1961). Specifically, prior literature suggests that non-routinized decision-making requires flexible organizational structure (Perrow, 1967), and that complex tasks do not allow decentralized organizational structure (Marengo and Dosi, 2005). As such, our results suggest that division of labor in planning and execution improves productivity in applied research while it compromises productivity in basic research. Thus, this study offers empirical evidence that the fundamental prediction of organizational theory is applicable to academic organizations.

From a practical perspective, this study offers implications for two managerial questions in university laboratories. First, we asked whether members should be given training opportunities not only in execution but also in planning and writing. In applied laboratories, members' engagement in planning shows positive effect, and members' engagement in writing (opposite of lab head's writing) shows negative effect on qualitative aspect of productivity. As long as quality matters, members should be involved in planning both for educational and for strategic reasons. As for members' writing, at least, the result does not provide statistically significant evidence that engaging inexperienced members in writing compromises productivity. Thus, one may well favor members' writing for educational purposes. In basic laboratories, since the positive effect of members' planning is more clearly observed, members should be engaged in planning. However, members' writing shows significantly negative effect. This presents a dilemma for lab heads, who are under pressure for productivity but have to train their members. With this regard, our data shows that experienced lab heads tend to give writing tasks to members. This is understandable for their relatively stable status. Apparently, this dilemma is more serious for younger lab heads, especially when the competition is intensifying and job security is destabilizing. Second, we asked whether lab heads should stay away from the bench to be a pure manager or engage in experiment as a player manager. The result suggests that lab head's cost for execution tasks cannot be justified in applied research, and thus, lab heads should concentrate on managerial roles. In contrast, in basic research, lab heads' execution increases productivity possibly for collocation with members and technology catch-up. In reality, it is often the case that lab heads cannot afford the time for execution tasks for administrative and other reasons once they attain high-rank positions. Thus, university administrations should avoid such situations and allow lab heads sufficient time for bench work especially in basic fields.

These results need to be interpreted with reservations for some limitations, which simultaneously suggest some directions of future research. First of all, our key contextual factor, research areas, needs cautious interpretation. Although our argument in this study is based on dichotomous distinction between basic and applied laboratories, task characteristics may be different between, for example, purely basic, purely applied, and basic-applied combinatorial laboratories (Stokes, 1997). In particular, since recent science policies attach more emphasis to practical application (Etzkowitz, 1983), basic laboratories should be under the pressure to engage also in somewhat applied research. Then, they may need more ambidextrous approach in their organizational design to deal with different types of research goals (Raisch et al., 2009). Related to this point, our analysis is based on a cross-sectional data, but laboratories may change their research goals over time. Thus, future research should investigate more details of task characteristics (research areas) and their career trajectory to facilitate the understanding in the contingency and dynamics of organizational design. Also for the nature of cross-sectional data, we cannot rule out the problem of endogeneity. It is likely that task allocation is determined by the ability of lab constituents. Particularly, members' ability is difficult to measure although we tried to control for the ability of both lab heads and members. Finally, this study draws on a sample of Japanese university laboratories. Although the Japanese academia, especially in biology, is highly embedded in the global science community, we cannot rule out the possibility that our results are specific to the context of Japan. In addition, our findings may be specific to the field of biology. Therefore, further research for generalization is needed.

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Figure 1 **Research Process and Task Allocation**

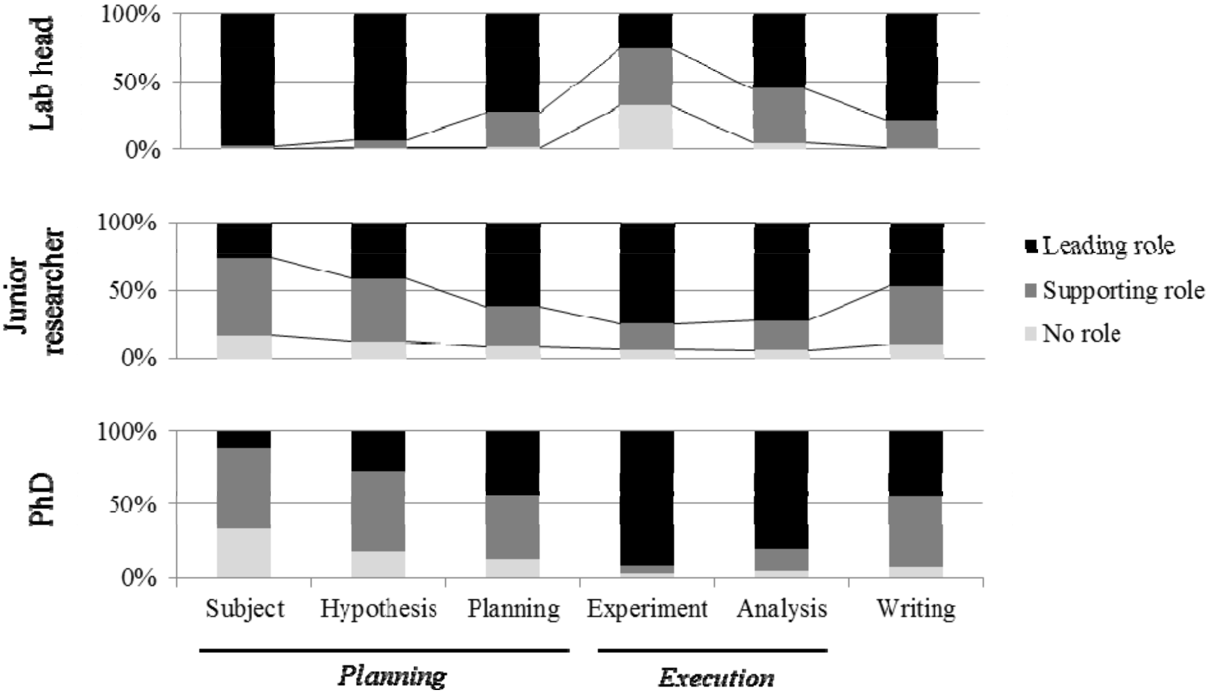
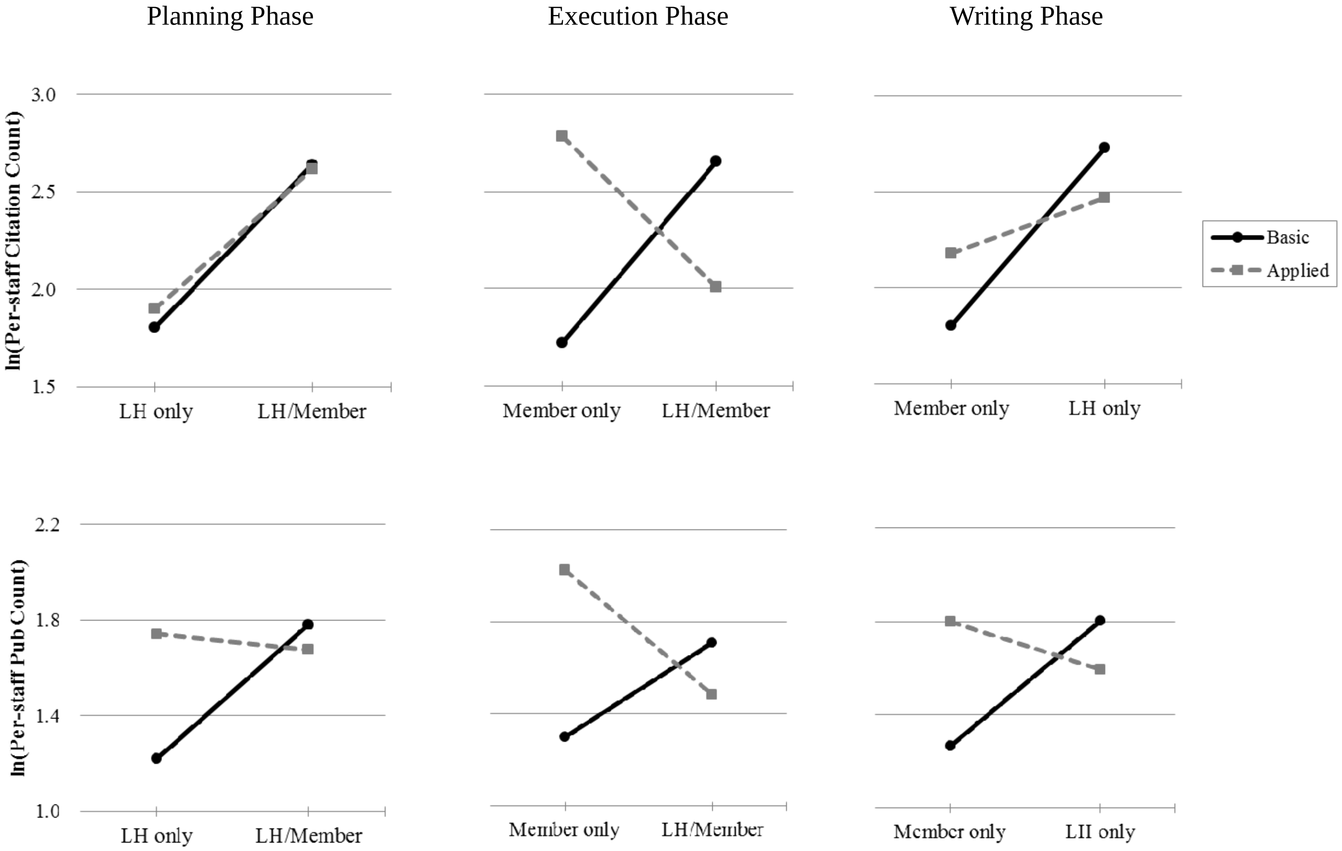


Figure 2 **Prediction of Task Allocation Effect** [a]



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[a] LH stands for lab heads. Based on regression results (Models 3 and 4 in Tables 4A and 4B), we predicted the lab productivity in terms of per-staff citation count (top row) and pub count (bottom row) for basic and applied laboratories. In each phase, we compare two extreme patterns of task allocation. In planning, since a lab head usually plays the leading role, a lab head's solo leading vs. co-leading with members is of the focal interest. Similarly, in execution, members' solo leading vs. co-leading with a lab head is the question. In writing, since a lab head's and members' roles are negatively correlated, a lab head's solo leading vs. members' is the point. For the prediction, the mean values are used for all variables except the focal task allocation variables.

Table 1 Descriptive Statistics and Correlation of Variables [a]

		Mean	Std.Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Lab Peoductivity																			
1	Per-staff pub count	64.937	96.115	.000	1146.783															
2	Per-staff citation count	21.925	18.092	.000	115.000	***.627***														
	Control variable																			
3	Pre-tenure citation count	2.738	4.929	.000	45.238	***.295***	.063													
4	Time for research	3.770	1.535	1.000	6.000	.087	.007	***.116***												
5	Foreign experience	3.633	1.548	1.000	6.000	-.110	-.087	***-.119***	.084											
6	Inbred	.105	.307	.000	1.000	.046	.108	-.039	-.067	-.071										
7	Medical doctor	.174	.380	.000	1.000	***.133***	.035	***.186***	.068	***.120***	-.016									
8	Female	.033	.178	.000	1.000	-.075	***-.133***	-.041	***.148***	.103	-.063	.061								
9	Budget/#staff	3.960	2.882	.278	17.500	***.130***	.084	***.133***	***.242***	.028	-.045	.083	-.059							
10	Lab age	13.214	7.747	1.000	35.000	-.055	***.132***	***-.229***	***-.165***	.016	***.384***	-.049	-.065	***-.140***						
11	Lab size	9.246	5.204	3.000	45.000	***.365***	***.483***	***.122***	.075	.059	.027	***.265***	-.058	***0.13***	.023					
12	Basic research	.540	.499	.000	1.000	***.122***	-.066	.066	***.166***	-.013	.016	-.054	.022	-0.02	-.097	.037				
13	Top7 univ	.489	.501	.000	1.000	.062	***.133***	.070	.096	-.039	***.136***	-.050	-.033	***0.12***	-.042	***.199***	***.222***			
	Task allocation																			
14	Members' planning	1.179	.489	.000	2.000	.059	.070	.078	.006	-.065	.029	-.051	-.087	.095	.065	***.132***	.035	***.150***		
15	Lab head's execution	1.227	.567	.000	2.000	.004	-.007	***-.128***	.005	***.115***	.080	***.130***	-.009	.052	.094	.022	.037	.028	.074	
16	Lab head's writing (& members' not writing)	1.015	.407	.333	2.000	.027	-.099	.088	***.236***	***.153***	-.110	***.154***	.099	.057	***-.160***	-.017	***.163***	-.026	***-.359***	.093

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[a] N=309. Bold italic: $p<0.05$.

Table 2 **Typologies of Task Allocation** [a]

	Members' planning	Lab head's execution	Members' writing	Total	Research Areas	
					Basic	Applied
1	YES	-	-	99 (32%)	55 (34%)	41 (30%)
2	-	YES	-	148 (49%)	78 (48%)	67 (49%)
3	-	-	YES	163 (53%)	81 (50%)	79 (57%)
4	NO	NO	NO	62 (20%)	30 (19%)	32 (23%)
5	NO	NO	YES	45 (15%)	22 (14%)	23 (17%)
6	NO	YES	NO	61 (20%)	38 (23%)	21 (15%)
7	NO	YES	YES	38 (12%)	17 (10%)	21 (15%)
8	YES	NO	NO	11 (4%)	6 (4%)	5 (4%)
9	YES	NO	YES	39 (13%)	26 (16%)	11 (8%)
10	YES	YES	NO	8 (3%)	7 (4%)	1 (1%)
11	YES	YES	YES	41 (13%)	16 (10%)	24 (17%)
			Total	305	162	138

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[a] YES: leading role and NO: otherwise (Columns 2-4). We computed the mean of the extent of engagement (0: none, 1: supportive, and 2: leading role) in related tasks and ranks, and assigned YES if it is 1.5 or greater. Columns 5-10 show the number of laboratories and its percentage (parentheses) for each pattern of task allocation.

Table 3 Factor Analysis of Task Allocation

		Factor1 Members' planning	Factor2 Junior researcher's full responsibility	Factor3 Lab head's planning	Factor4 PhD's execution	Factor5 Lab head's execution	Factor6 Lab head's' writing
Lab head	Subject	-.077	.133	***.750***	.002	-.032	.088
	Hypothesis	-.020	.088	***.836***	.170	.087	-.057
	Planning	.064	-.062	***.579***	-.007	***.498***	.052
	Experiment	-.006	.046	-.019	-.055	***.857***	.004
	Analysis	.070	.166	.259	.048	***.677***	.125
	Writing	.167	.232	.348	.120	.282	***.629***
Junior researcher	Subject	***.666***	***.423***	.104	-.121	.014	-.087
	Hypothesis	***.748***	***.446***	.115	-.071	.015	.051
	Planning	***.544***	***.594***	.107	.060	-.152	.034
	Experiment	-.036	***.811***	.047	.115	.190	.122
	Analysis	.154	***.822***	.035	.206	.029	.118
	Writing	.174	***.698***	.138	.030	.012	***-.497***
PhD	Subject	***.675***	-.047	-.184	.163	.163	-.268
	Hypothesis	***.812***	-.010	-.090	.323	.043	-.104
	Planning	***.698***	-.028	-.045	.404	-.048	-.117
	Experiment	.052	.144	.072	***.884***	.001	-.046
	Analysis	.303	.125	.114	***.787***	-.035	-.175
	Writing	.261	.003	.065	.273	.013	***-.825***

Table 4 Fixed-effect OLS Models of Scientific Productivity [a]

(A) Dependent Variable = ln(Per-staff Citation Count)

	All labs				Basic labs		Applied labs	
	Model 1		Model 2		Model 3		Model 4	
Control variable								
Pre-tenure citation count	.033**	(.012)	.031**	(.012)	.034†	(.018)	.029†	(.016)
Time for research	.048	(.039)	.045	(.038)	.024	(.054)	.082	(.059)
Foreign experience	-.043	(.038)	-.075*	(.038)	-.115*	(.055)	-.024	(.055)
Inbred	.210	(.202)	.255	(.197)	.413	(.284)	.080	(.279)
Medical doctor	.129	(.182)	.074	(.178)	.045	(.263)	.039	(.257)
Female	-.833**	(.313)	-.775*	(.305)	-1.050*	(.419)	-.309	(.523)
Budget/#staff	.009	(.021)	.007	(.020)	.054†	(.032)	-.029	(.027)
Lab age	.003	(.009)	.003	(.008)	-.007	(.012)	.016	(.013)
Basic Research	.073	(.132)	-1.314*	(.541)				
Top7 univ	.093	(.118)	.027	(.115)	-.201	(.171)	.286†	(.163)
Task allocation								
Members' planning	.273*	(.127)	.289	(.184)	.418*	(.181)	.357†	(.182)
Lab head's execution	-.022	(.103)	-.415**	(.140)	.465**	(.161)	-.390**	(.138)
Lab head's writing (& members' not writing)	.285†	(.159)	.166	(.215)	.465†	(.236)	.145	(.214)
Interaction								
Members' planning x Basic research			.086	(.246)				
Lab head's execution x Basic research			.833***	(.202)				
Lab head's writing x Basic research			.242	(.301)				
F test	2.838***		3.619***		3.466***		2.044**	
Log likelihood	-371.377		-361.085		-193.073		-151.313	
N	292		292		156		136	

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[a] Unstandardized coefficients and standard errors (parentheses). Two-tailed test. † p<0.10; * p<0.05; ** p<0.01;*** p<0.001. The use of fixed effect model is justified with F-test for joint subfield effect (p < .01) and Hausman test (p < .001) in Model 2.

(B) Dependent Variable = ln(Per-staff Pub Count)

	All labs				Basic labs		Applied labs	
	Model 1		Model 2		Model 3		Model 4	
Control variable								
Pre-tenure citation count	.000	(.008)	-.001	(.008)	.004	(.011)	-.003	(.012)
Time for research	.027	(.026)	.022	(.025)	.026	(.034)	.044	(.042)
Foreign experience	-.023	(.025)	-.046 †	(.025)	-.091 **	(.034)	.007	(.039)
Inbred	.155	(.134)	.194	(.131)	.311 †	(.177)	.023	(.199)
Medical doctor	-.066	(.121)	-.085	(.118)	-.074	(.164)	-.101	(.183)
Female	-.387 †	(.208)	-.334 †	(.202)	-.369	(.261)	-.097	(.373)
Budget/#staff	-.018	(.014)	-.018	(.013)	-.007	(.020)	-.021	(.019)
Lab age	.010 †	(.006)	.010 †	(.006)	.002	(.007)	.022 *	(.009)
Basic Research	-.082	(.087)	-1.372 ***	(.359)				
Top7 univ	.051	(.078)	.004	(.076)	-.126	(.106)	.161	(.116)
Task allocation								
Members' planning	.079	(.085)	-.030	(.122)	.281 *	(.113)	-.032	(.130)
Lab head's execution	-.099	(.068)	-.326 ***	(.092)	.206 *	(.101)	-.271 **	(.098)
Lab head's writing (& members' not writing)	.056	(.106)	-.107	(.143)	.267 †	(.147)	-.103	(.153)
Interaction								
Members' planning x Basic research			.274 †	(.163)				
Lab head's execution x Basic research			.500 ***	(.134)				
Lab head's writing x Basic research			.333 †	(.199)				
F test	1.496 *		2.588 ***		2.200 **		1.799 *	
Log likelihood	-252.219		-240.938		-119.329		-105.421	
N	292		292		156		136	