Specialization and Team Production in Science

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Abstract

This paper investigates current issues on team production in science and establishes research agenda on how to organize the production of scientific knowledge. The trends of increasing team production and the determinants of the trends are examined. Then whether specialization and team production enhance the rate and quality of research outputs is examined. Especially, whether the participation of private firms enhances the rate and quality of research is critically reviewed. Finally, implications for science policy and management are discussed.

Ⅰ. Introduction

Specialization and team production have been regarded as source of innovation and economic growth. Since Adam Smith discovered the power of the division of labor in

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the manufacturing industries (a tale of "pin factory"), specialization and team production have contributed to unprecedented productivity increased and technological progress in human history. For instance, Smith observed that a worker's productivity increased from 2 pins per day to 4,800 pins per day after introducing the division of labor and team production (Brickley, Smith and Zimmerman 2009). As can be seen in the history of car and other manufacturing industries, production system based on specialization and team production revolutionized the way of producing goods and services in modern economies. Then question is raised: if specialization and team production have enhanced the production of physical goods, could we expect that the team production based on specialization also enhance the production of scientific knowledge?

Science has been generally perceived that a single genius scientist in his isolated lab generates breakthrough sporadically. The production of scientific knowledge requires, however, combination of inputs such as knowledge, effort, equipment and material from diverse scientific communities. Moreover, how to organize the inputs can influence the efficiency in the production of scientific knowledge (Stephan 2012). Whether the team production is better way of generating scientific knowledge, however, is not decisive. When the team production can be an effective way of producing scientific knowledge and how public and private leaders need to respond to the diffusion of the team production in science become critical issues for innovation and economic growth.

In order to examine whether and how specialization and team production are effective in knowledge production, we need to confirm first whether the adoption and diffusion of team production in doing science are universal. We also need to examine why and when scientists prefer team production to sole production in conducting their research. More importantly, we also need to understand how the shift toward team production of scientific knowledge will influence the rate, quality and direction of scientific research. Since innovation and economic growth require scientific knowledge more than ever, these questions are high on the research agenda of science and innovation and also critical to scientific researchers, policy makers and business leaders..

In critically reviewing the determinants and effects of team production in science,

this paper adopts the knowledge production function framework: Scientific discovery is a function of research inputs such as effort, equipment, knowledge, and materials (Jones 2010; Stephan 2012). Team production influences the relationship between inputs and scientific discovery like knowledge production function. This paper examines research issues on team production in science as follows: In the next section, whether the team production is dominant in science and the increasing team production is universal across subfields of science is discussed. In section 3, reasons why team production becomes dominant recently are examined. In section 4, whether the shifting toward team production increases the rate and quality of scientific research outcomes is analyzed. Especially, the focus will be on whether the division of labor between private-public will be productive as generally expected. In section 5, the implications for science policy and management are discussed. Section 6 is conclusion.

Ⅱ. Increasing Team Production of Scientific Knowledge

The advance of science is reported to depend more on teams of scientists than on individual researchers' effort recently (Wuchty, Jones and Uzzi 2007). Three questions are raised. First, is increasing team production of scientific knowledge a universal or field specific phenomenon? Second, is the growth of team production accelerating? Third, what are the popular structures of team in doing science?

2.1 Is team production field-specific or universal across fields?

Rising trend in team production of scientific knowledge has already been reported in specific fields of science. For instance, Merton (1973) showed that research collaboration had increased in physics, biology and chemistry during the period between 1900 and 1959; de Solla Price (1986) recognized increasing team size in chemistry from 1910 to 1960. Because chemistry and biology are scientific fields requiring high experimentation and capital investment, their findings were not decisive on whether increasing use of team is specific to physics, biology and chemistry or universal across all other fields of science.

In recent study, Wuchty, Jones and Uzzi (2007) examined whether team production is universal across all fields of science. By examining 19.9 million papers and 2.1 million patents over five decades, the authors confirmed that the team production became the dominant way of doing science and engineering. The team size measured by the number of authors per paper increased in 99.4 percent of the 171 subfields of science and engineering (Wuchty, Jones and Uzzi 2007). The ratio of team to solo authorship also showed that team was favored as a way of doing science: The ratio was greater than one across all subfields of science. Even mathematics, a field that had been regarded as experimentation and capital investment are not critical, showed that the use of team increased from 19 to 57 percent of Mathematics publications (Wuchty, Jones and Uzzi 2007).

Adams et al. (2005) also insisted that team production became dominant in science. They provided evidence that the number of authors per paper increased across all twelve fields of science during the periods between 1981 and 1999. Physics was a field where team production was adopted the fastest during the periods between 1981 and 1990: The team size increased with the annual rate of 5.46 percent. Astronomy was a field where team production grew the fastest during the periods between 1991 and 1999; it increased with the annual rate of 4.57 percent (Adams et al. 2005). As in Wuchty, Jones and Uzzi (2007), Adams et al. (2005) also observed that team production increased even in Mathematics. Thus, that team production has become the dominant way of advancing science is empirically established fact. .

2.2 Is team production accelerating?

Team production has become a dominant way of doing science. Then, is the growth of team production accelerating? Wuchty, Jones and Uzzi (2007) report that the adoption of team production in science has been accelerating. According to authors, the mean of team size in science and engineering fields doubled from 1.9 to 3.5 authors per paper during the past 45 years: the mean increased during the periods between 1980 and 2005 much faster than during the periods between 1955 and 1979.

Using different set of scientific publications, Adams et al. (2005) also confirmed the

accelerating trends in team production of scientific knowledge. The average growth rate of team size during 1981-1990 periods was 2.19 percent and that in 1991 - 1999 periods increased to 2.57 percent; The growth rate increased more rapidly in the 1990s in 10 science subfields. Thus, recent empirical evidence strongly supports that team production is becoming a dominant way of doing science very fast.

2.3 What type of team production becomes popular?

The types of team in science are diverse. Scientists within a university or across different institutions may work together to produce scientific discovery; Scientists in different countries may work together as a team. Jones, Wuchty and Uzzi (2008) examine which type of institution is the most popular in scientific team production. Among solo authorship, within-university and between-university collaboration, the author found that the between-university collaboration increased most; Solo authorship papers decreased and single university collaboration has been stable.

When between-university collaboration team has increased by significant margin, what type of universities played a significant role in the collaboration? Did top research universities collaborate mainly with other top research universities? Or did top research universities share their resources with lower rank universities? Jones, Wuchty and Uzzi (2008) found that multi-university collaborations are increasingly stratified by in-group university rank: Top universities tend to mainly collaborated with top universities and lower rank universities with lower rank universities. The stratification in multi-university partnership means that top research universities have played a significant role in the production of scientific knowledge (Jones, Wuchty and Uzzi 2008).

Agrawal and Goldfarb (2008) insist, however, that information technology weakened the stratification in multi-university teams. The authors examined how the use of BITNET— a prototype of the Internet— differently influenced team production if the characteristics of "collaborating pairs" were different: The authors specified the quality of institutions and geographic distance as the moderating characteristics. According to the authors, middle-tier universities collocated with top-tier institutions

increased their collaboration the most - by 40 percent increase - after the BITNET was adopted. The authors suggested that the adoption of BITNET was likely to provide better opportunities to middle-tier universities in terms of access to research equipment and other resources of top-tier universities. In other words, scientific teams of middle-tier and top-tier universities were more likely to be developed than those of top-tier and top-tier as the use of information technology increases.

On team between university and industrial firm, Adams et al. (2005) reported that the collaboration increased and the increasing trend in the collaboration accelerated in 1990s: Top 200 R&D firms per paper increased by about 50 percent during 1980s and doubled during 1990s. The authors suggested that increasing federal programs designed to promote university - firm joint research and increasing placement of graduate students in industry might accelerate the university-firm joint research (Adams et al. 2005).

Lastly Adams et al. (2005) reported that the geographic distance between team members increased. After calculating the mileages from "head" institutions to other institutions in a team, the authors showed that team research among distant scientists increased across all fields of science. Especially, scientists in Astronomy, Biology and Earth Sciences tended to collaborate with partners far from their location (Adams et al. 2005).

Ⅲ. Factors that Promote Team Production in Science

Scientific discovery requires research inputs such as effort, equipment, knowledge and materials. Team production is more likely to be adopted when the change in these inputs makes team production favorable to scientific discovery. These factors are (1) increasing costs and complexity of R&D equipment, (2) individual scientists' preference and ability, (3) the adoption and diffusion of information technology (IT), (4) the nature of knowledge evolution, (5) different organizational resources and (6) funding policy.

3.1 Increasing Costs and Complexity of R&D Equipment

Increasing R&D costs can cause increasing team production because scientists want to share the costs through team production. Adams et al. (2005) examined whether the increasing R&D costs was one of main drivers in team production of scientific knowledge. The authors found, however, that the effect of R&D costs was not as strong as generally expected. By using the "equipment intensity" (i.e., equipment expenditure/R&D expenditure in three year), the authors showed that the effect of equipment costs on collaboration was not significant. The authors suspected that "capital-labor substitution" in scientific team might be stronger than the expected incentive to share the increased costs. Collaboration between university and firm was also negatively associated with equipment intensity, which suggested that corporate firms might not be able to support expensive scientific equipment (Adams et al. 2005).

Increasing complexity of scientific equipment and vast amount of data from large scientific projects can encourage team production (Stephan 2012). For instance, the Large Hadron Collider (LHC) project at CERN has about 6,000 researchers as a team in order to operate four large detectors. It also generates data such that "if all the data...were burned onto disks, the stack would rise at the rate of a mile a month." (Stephan 2012). Another example is the Human Genome Project (HGP) and its associated GenBank database. The HGP was the first "big science" project in international biological and medical communities: twenty centers in six countries participated. The HGP also required state-of-art gene sequencing techniques (Collins, Morgan and Patrinos 2003; Stephan 2012). Both examples show that the complexity of critical equipment and related database make team production inevitable in order to conduct scientific research.

3.2 Individual Preferences

Individual scientists may want to collaborate with other colleagues in order to diversify their research portfolio and reduce risk in the "publishing game" (Stephan 2012). The "preferential attachment" of scientists to international science networks

may also be a source of increasing trends in international team production (Wagner and Leydesdorff 2006). Although the authors acknowledge the specialization of scientific fields or the difference in innovation capacity across countries may induce researchers to collaborate, they argued that these factors might not be main drivers of international collaboration: The specialization and capacity difference might cause regional collaboration rather than international collaboration (Wagner and Leydesdorff 2006). The theory of preferential attachment of individual researchers, however, does not seem to provide reasons why researchers increasingly prefer to collaborate with researchers in other organizations or foreign countries despite the lack of "physical proximity," which seems to be critical for successful collaboration (Hoekman, Frenken and Tijssen 2010).

3.3 Information Technology

How the adoption and diffusion of information technology (IT) influence the team production in science is being actively discussed. Relevant questions are (1) whether the use of IT enhances team production ("collaboration-enhancing effect") and (2) whether its use has a differential effect across different user subgroups ("democratizing effect") (Ding et al. 2010).

The use of IT in production of scientific knowledge will encourage team production because IT "provides greater access to materials and equipment" and enables scientists to exchange their ideas at a lower cost and across greater distance (Ding et al. 2010). When scientists are acquiring narrower expertise, the adoption and diffusion of IT will also increase team production because it can facilitate integrating distinct expertise across experts (Jones 2010). By measuring the gain in the number of coauthors per paper by 3,114 life scientists over a 25-year period, Ding et al. (2010) confirmed that the adoption of early IT innovations such as BINET and the Domain Name System (DNS) enhanced team production among scientists.

The use of IT, however, does not eliminate the importance of local proximity in team production. Agrawal and Goldfarb (2008) examined how a decrease in collaboration costs from the introduction of BITNET facilitated the team production of scientific

knowledge. Especially, they suggested that communication through IT network was complementary to face-to-face meetings and thus that co-location was an important moderator of IT effects on collective work in science.

The effect of IT can differ across different user groups. When a scientist is positioned in the low rank of scientific hierarchy, the gain from the introduction of IT would be greater. Scientists at the top already have competent colleagues and graduate students and strong financial support while scientists at the lower rank have less. The connection to better opportunity through IT may be more influential to scientists at the lower rank than ones at the top rank in the hierarchy (Ding et al 2010; Stephan 2012). Ding et al. (2010) confirmed that IT had such "democratizing effect." The authors showed that scientists at non-elite institutions and female scientists collaborated more after the introduction of BINET and DNS.

Do all underdog researchers benefit from the use of IT? Agrawal and Goldfarb (2008) show that researchers at middle tier universities benefited the most from the introduction of BINET: Scientists at middle tier research universities could collaborate with those at top tier research universities the most among other institutional combinations such as top tier and top tier. Although the democratizing effect of IT does exist, the effect is limited to middle tier research institutions: low tier institutions did not benefit from the use of IT much. The effect of IT on the production of scientific knowledge is differential across different users.

3.4 Cumulative Nature of Scientific Knowledge

Wuchty, Jones and Uzzi (2007) implied that the growth in knowledge might be the main driver of specialization in the knowledge production. They doubted that increasing "capital intensity of research", "increasing number of researchers", and "shifting authorship norms" might be the main drivers of the division of labor in scientific production because team production also increased in fields that did not experience such changes as capital intensity, researcher supply and authorship norms. The authors are not sure about the effect of "declines in communication costs" on team production.

Examining drivers of team production in science further, Jones (2010) argued that

the increasing "burden of knowledge" was closely related to specialization and team production in science. His logic is as follows: First, knowledge stock and flow keep increasing. During the year of 2006, 941,000 research articles were published worldwide and those articles cited 4,372,000 articles published in previous years. The numbers of journal publications and citations are exploding (Jones 2010). Second, if a scientist knows only a fraction of knowledge, the amount of knowledge that the scientist has will decline (Jones 2010). Let N be the total number of papers, which is growing at rate g_N. And let Q be the fixed (maximum) number of papers that a scientist can learn and *s* be the share of extant knowledge that the scientist knows, which is $s = Q/N$. Then the share *s* of extant knowledge known by the scientist will decline at the rate of negative g_N. Third, if the share of individual knowledge declines, then team production based on specialized knowledge becomes inevitable to generate new scientific knowledge (Jones 2010).

This explanation implies that the life cycle productivity and knowledge scope of scientists are significantly changing. Because of the "burden of knowledge", longer education periods are required to scientist and thus breakthrough research may become less likely at young ages (Jones 2010). In addition, due to the fast increasing amount of knowledge stock and flow, scientists tend to pursue narrower expertise than before (Jones 2010). This tendency in narrowing expertise and knowledge suggests that the organization of scientific activities shifts toward team production (Jones 2010).

Major breakthroughs in science tend to occur from interdisciplinary research or emerging disciplines because of new combination of specialized knowledge. Thus, team production is important for combining knowledge and skills from different fields and for developing emerging fields (Stephan 2012). For instance, in identifying nerve-growth-promoting agent, Rita Levi-Montalcini collaborated with Stan Cohen. Stan possessed biomedical technique that Rita lacked. As a team, they won the Nobel Prize in Physiology and Medicine in 1986 (Stephan 2012). System biology, where breakthroughs are frequently reported, is the "intersection of biology, engineering and physical science." Scientists in system biology tend to work as a team (Stephan

2012). Those cases demonstrate the importance of specialized knowledge and team for scientific breakthrough.

3.5 Different Organizational Resources

How will the different organizational resource influence team production in science? Working in private universities may provide better opportunities to the scientists. This is because at least in the US, private universities tend to have better faculties, better financial and startup package and better students. Adams et al. (2005) showed that scientists in private universities were likely to assemble larger scientific teams. They suggested that private universities received more funding from private foundations and rich families; private universities attracted more talented faculty and able students because of compensation package and working condition better than public universities. Thus, researchers in private universities tended to assemble bigger and better teams from a larger pool of collaborators.

Other organizational resources such as reputation and recognition can influence the buildup of team in science. If a scientist is given awards, the size of his team tends to be larger because reputation attracts competent collaborators and more graduate students who are willing to work under the scientist (Adams et al. 2005; Merton 1973).

3.6 Funding Policy

Government funding agencies have implicit assumption that collaborative team produces better research and provides incentive for participants to share data and materials (Stephan 2012). If government agencies design funding policies based on such assumption, the policies will favor collaborative teams to be selected for funding. System biology is a field that combines knowledge from biology, engineering and physical science. The National Institute of Health (NIH) selectively supported funding centers in system biology straddling multiple disciplines and departments (Stephan 2012). NIH's preferentially funding centers in system biology promotes team production of biologists, engineers and scientists from other relevant fields.

The NIH also designed a grant mechanism (P01) to "support research in which the funding of several interdependent projects as a group offers significant scientific advantages over support of these same projects as individual regular research grants" (Stephan 2012). Similarly, the National Institute of General Medical Sciences (NIGMS) at the NIH provides "Glue Grants" in order to encourage project investigators to conduct research on complex problems in an integrated way (Stephan 2012). We can easily expect that scientists will respond to these funding mechanisms with assembling more teams.

Empirical evidence on how public funding influences the formation of scientific teams begins to appear. Adams et al. (2005) examined the effect of funding on specialization in knowledge production. By using the stock of federally funded R&D divided by paper, the authors found that 1 percent increase in funded R&D is associated with 1 percent increase in the number of authors per paper. Thus, the larger project size is, the more specialized the scientific team is.

Ⅳ. Effect of Team Production on the Rate, Quality and Direction of Science

The shift toward team production in science raises important questions: Will team production generate "better" science? And how will it change the direction of scientific inquiry? Although team production in science can put together better, diverse knowledge, it can be subject to coordination problem or negative externality among team members and may generate lower quality science (Cumming and Kiesler 2007; Wuchty, Jones and Uzzi 2007). These questions become critical because the private-public partnership in science is highly regarded as an efficient way of advancing science.

4.1 Does Team Production Improve the Rate and Quality of Scientific Outcomes?

Wucthy, Jones and Uzzi (2007) empirically showed that the team production improved the quality of scientific research. They defined the research quality as whether the

research generated extraordinary findings and showed that the quality from team production improved in two ways. First, the authors constructed a frequency distribution of the ratio of citations received by team-authored works to citations received by solo authored works. They constructed the distribution of the ratio both for the first five years and for the last five years in their sample periods. The authors concluded that the research quality of team production improved recently because the right tail of the last five-year distribution was higher than that of the first five-year distribution. Second, the authors calculated the relative team impact (RTI) — the mean number of citations received by team authored work divided by mean number of citations received by solo authored work. Again the authors concluded that the research quality from team production increased because the RTI constantly increased over five decades.

In the related subsequent study, Jones, Wucthy and Uzzi (2008) examined the effect of different type of collaboration on research outcomes: They compared the citation impact of multi-university collaboration and single-university collaboration. The authors found the followings. First, the multi-university collaboration had a citation-impact advantage over the single-university collaboration: Citation of between-university collaboration works was higher than that of within-university collaboration by 8.8 percent. Second, collaboration including "elite school" had citation impact advantage over collaboration between similar quality universities. Thus, the authors concluded that multi-university collaborations generate better science when top-tier universities were included.

Team production may, however, damage the productivity of scientists because of coordination failure among members. Cummings and Kiesler (2007) examined the outcomes of 491 research projects that adopted team production. The authors found that the participation of additional universities worsened the project outcomes. The authors argued that the lack of coordination activities such as the division of responsibilities caused the negative relationship. Adams et al. (2005) also showed that the expected positive relationship between the number of papers and scientific collaboration was not confirmed clearly. Rather, they showed that scientific collaboration seemed to increase the influence of research output rather than the quantity of research

output: a larger size of team was more likely to generate more influential papers (Adams et al. 2005).

4.2 Does Team with Industrial Scientists Change the Direction of Science?

Whether the collaboration with private companies is good for scientific research has been controversial. The organizational domain of team production is important because most of scientists nowadays work in research organizations either in private or in public sector and these research organizations govern research activities through different norms, organizational structure and reward systems on how to carry out scientific inquiries (Aghion, Dewatripont and Stein 2008; Dasgupta and David 1994; Evans 2010). For instance, David and Dasgupta (1994) insist that universities epitomize the "Open Science" regime while profit R&D organizations represent the "Proprietary Technology" and they have different organizational structures to implement the distinct mode of scientific inquiries.

In order to incorporate such difference in the organizational domain into analysis of team production, we need to be specific about how they differ. There are two views regarding the difference. First, academia and private research organizations differ in terms of distribution of control rights over research activities between researchers and owner/manager (Aghion, Dewatripont and Stein 2008). Second, academia and private research organization differ in terms of commitment to theory development (Evans 2010). Which view is adopted for the difference between public and private research organizations carries different implications of team production between public—private sectors for advance in science.

The first view suggests that research organizations in public and private sectors differently address the control rights of researchers over research activities. For instance, academia is a commitment mechanism that allows researchers "creative control" of research project of their own interests while industrial research organizations "dictate project choice" to researchers (Aghion, Dewatripont and Stein 2008). Because of this difference, governmental initiatives to encourage collaboration between university and industry may not work smoothly: university researchers pursuing the Open Science

tend to share their findings while corporate researchers pursuing the Proprietary Technology tend to prefer secrecy strategy (David and Dasgupta 1994; Moon 2011).

The nature of research influences this tradeoff between creative control and focus and suitable types of research organization (Aghion, Dewatripont and Stein 2008). According to the authors, academia is indispensible for generating basic ideas while firms are suitable for conducting focused research at commercialization stage. Thus, this view implies that ideas under private research organizations become less diverse and more focused than those under academia. Adams et al. (2005) also show that the collaboration with US firms does not seem to increase the quantity and influence of scientific outcomes: the participation of US firms is negatively related to the number of papers and is not significantly related to the academic influence of papers.

The second view suggests that academia and industry are different in terms of commitment to theoretical development (Evans 2010). Academics value the test and development of theories within dominant paradigms while industrial researchers do not commit themselves to the theory development within dominant paradigms. The industrial researchers may value findings of technological and economical implications even if the findings may not lie inside the existing paradigms.

This view provides implications of university—industry research collaboration which is very different from the previous view. Since industrial researchers are not interested in improving and expanding current paradigms, their participation in collaborative research with academics may generate "novel, unprecedented, and theoretically unanticipated" ideas (Evans 2010). Thus, we may observe diverse and novel ideas from industry—universe collaboration more than from university. University research may have strong tendency for "harmonization" with existing paradigms and thus generate "conservative and confirmatory science" (Evans 2010).

V. Implications for Policy and Management of Scientific Knowledge

The recent studies on science suggest that policy makers and business managers should design their polices and strategies by incorporating empirical evidence on

trends in specialization and team production. Based on the recent evolution in science — longer education period for scientists and increasing narrowness in expertise of an individual scientist, Jones (2010) insisted that modern science policy address the following issues. First, science policy should be designed to influence entry of talented individuals into scientific careers. Because significant research results come at the later stage of scientists' life cycle and research grants and other financial support depend on influential research results, funding agencies need to design financial supports for the delayed take-off (Jones 2010). The NIH began to respond to the life cycle issue of young scientists by setting up funding quotas for young grantees (Jones 2010).

Second, the evaluation of idea in publication and grant application becomes difficult because of "increasing narrowness of expertise" of evaluators (Jones 2010). Scientific projects become more dependent on team production combining various specialized expertise. If evaluators of the projects have narrow expertise, scientific projects with broad scope and implications are difficult to get preferable decisions. Thus, establishing how to evaluate scientific projects with broader scope becomes critical to evaluators in funding and patents institutions (Jones 2010). The NIH tries to promote "cross-field research" and "transformative R01 program" by inviting experts in different fields (Jones 2010).

Third, science policy should be designed to properly reward scientists' effort in the context of team production. For instance, incentive mechanisms that reward only a few researchers among team members will undermine the productivity of the team. So granting prizes to high-status individual researchers can be counter-productive when the way of doing science is shifting toward team production (Jones 2010).

Fourth, how to enhance openness in scientific research should be an important objective of public funding. Increasing collaboration with industrial researchers imply that scientific discoveries from university-firm consortium may not be publicly shared without appropriate contractual design because firms tend to protect the discoveries until commercialization is successful (Moon 2011). Thus, the public funding organizations need to enforce a certain degree of openness when they provide funds to scientific projects.

Lastly, another important issue in modern science policy is how to reconcile the role of elite universities and concentration of resources in scientific research. Jones, Wucthy and Uzzi (2008) suggested the elite universities performed a critical role in multi-university partnership. At the same time the authors detected an increasing stratification in the multi-university partnership because of matching based on status or quality. The capacity of elite universities in supply of scientists is limited. How to improve the research quality of non-elite universities has become an important policy issue.

Ⅵ. Conclusion

From this examination of current literature, research communities seem to have consensus on the following points. First, specialization and team production in science are universal, not limited to a few specific subfields. For instance, the use of team production is increasing even in Mathematics. Second, the diffusion of team production has been accelerating across almost all subfields. Third, multiple factors drive the increasing diffusion of team as a way of knowledge production. Information technology (IT) is one of the main drivers. IT reduces communication costs among team members. Thus, the introduction and diffusion of IT such as BINET has increased collaboration between researchers. In addition, IT has a differential effect across different user groups ("democratizing effect"). For instance, researchers in non-elite universities and female researchers seemed to benefit the most from the diffusion of IT (Agrawal and Goldfarb 2008; Ding et al. 2010). Another notable factor is the accumulation process of knowledge (Jones 2010). Since the "burden of knowledge" keeps increasing, the amount of knowledge that individual scientists can have continues to decrease. Thus, team production in science based on specialization is inevitable (Jones 2010).

Despites such consensus on increasing use of team production, the impact of team production on the quality and direction of scientific research is still controversial. Especially, whether the participation of corporate researchers in science projects is good for research originality is not decisive. Team with private firms may redirect

research projects toward short-term profitable projects. In contrast, team with private firms may generate more innovative outcomes because corporate researchers tend to care less about previously confirmed knowledge than about testing any knowledge for better performance. More empirical research should be done on this topic.

Another important issue in team production is the dominant role of elite universities in science. Although the adoption of IT provided collaborative opportunities to researchers in non-elite universities, this effect may end up with "too much concentration" of knowledge in elite universities. Matching based on status and reputation, combined with the diffusion of IT, may cause severe stratification problem in team production (Jones, Wuchty, and Uzzi 2008).

These issues require university, government and firms to reconsider the effectiveness of current science policy and management of scientific knowledge. Should the government blindly encourage the participation of private companies in basic science project? When can private companies contribute to basic, fundamental science projects? How should the structure of team between private and public organizations be designed? Should we reward only star scientists when research is conducted through team? Will such reward system increase high quality knowledge that generates subsequent discoveries? What incentives can we provide to young scientists who are working as a member of scientific team but not appropriately rewarded? Should we allow stratification in science by elite universities? If such stratification is inevitable, how much should we allow? All these important questions have yet to be answered and should be subject to serious theoretical and empirical consideration in the future.

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