The Effect of Government Consortia on R&D Productivity of Firms
A case study of robot technology in Japan

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Summary: This paper aims at evaluating the government-supported R&D consortia in Japan. These programs have already been the object of numerous studies. We provide further empirical evidences by focusing on the case of the robot technology (RT). Despite RT is one of the priorities in the government policy and one of the most promising field of development, it has been surprisingly relatively ignored by economic studies on R&D consortia.

By comparison to previous studies, our paper has the following characteristics. First, whereas most of papers are using the number of patents as indicator for the outcomes of the programs, we are using indicators of quality of patents like claims or number of citations. It allows us to provide an estimation of quality adjusted research productivity. Second, we investigate indirectly the impact of the evolution of the design and the organization of the government programs in RT. Third we conduct a comparison between government-led collaboration and privately organized R&D collaboration.

Our results are as follows. First, we find that participation by firms to government programs has a positive impact on the quality of their patents. Second, if we divide the sample period into two sub-periods, 1991-1997 and 1998-2004, we find there was no impact during the first sub-period, yet there is a positive impact during the second sub-period. Our interpretation is that this is the consequence of the changing orientation and structure of government programs in this field. Third, if we compare between government-led collaborative patents and private led collaborative patents, we find the significant effect of the former and the non significant effect of the latter.

JEL Classification: L24, L52, L6, O32, O34, O38

Key words: industrial policy, robot technology, Japanese innovation system, collaborative R&D.

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Introduction

Economists generally agree that market will fail to generate sufficient level of R&D as it inherently has some characteristics of public goods and thus admit the government involvement in promoting R&D. However, it does not mean that the government policy on R&D can always be justified. One important counter-argument for the government involvement is that it may crowd out private R&D instead of being the complement to it.

Government sponsored consortia is one of the policy methods to promote firms' R&D activities.[2] There are actually vast accumulations of theoretical studies that discuss the potential benefit of government sponsored consortia as a way to ameliorate this market failure,[3] yet still little has been done to systematically examine these theories with a large number of samples.[4] Examples of these empirical researches is Branstetter and Sakakibara (1998) and Branstetter and Sakakibara (2002). Branstetter and Sakakibara (1998) used the sample of 145 government sponsored R&D consortia in Japan and found that frequent participation in these consortia increases research expenditure and research productivity. Also, Branstetter and Sakakibara (2002) uses the same dataset and finds that the outcomes of consortia are positively related to the level of potential spillovers within consortia and negatively related to the degree of product market competition among participating firms. There are also a number of studies that analyze the government involvements in pharmaceutical industry, and the examples include Okada et al. (2003) and Okada et al. (2006).[5]

This paper empirically analyzes the publicly sponsored consortia in the field of robot technology (RT). In the last two decades, RT has undergone dramatic technological development and attracted a lot of public attention, yet has been relatively neglected in the economic literature. To analyze these public consortia, we borrow the technique introduced by Branstetter and Sakakibara (1998) which uses the number of patents applied by firms as the proxy to measure innovation. Yet we extend the analysis into the following ways. First, instead of using the number of patents to measure innovation, we use indicators of quality of patents such as the number of claims and citations. This allows us to estimate the impact of public consortia on quality adjusted research productivity. Second, we look at the evolution of the design and organization of the government programs in RT and empirically analyze the effects of the evolution. Third, we take into account the fact that the government sponsored R&D consortia is one type of R&D collaboration and there also exists R&D collaboration among the firms without government involvement. Indeed, as indicated above, the theoretical justification of the government involvement in R&D activities owes to the industrial

[2] Other policy methods include special tax treatment on tax, subsidies, and the promotion of R&D activities in universities and public institutions.

[3] The example of these literature include Spence (1984), Katz (1986), and D'Aspremont and Jacquemin (1988).

[4] Indeed, there are a number of empirical studies that analyze the innovation policy based on case studies. Examples include Irwin and Klenow (1996), Link et al (2000), and Odagiri et al. (1997).

[5] Okada et al. (2006) examines the Japanese biomedical patents between 1991 and 2002 and find that patents fields by a corporation and joint applications by corporations are highly valued and, if a corporation is the first assignee, a patent with a government co-assignee is highly valued.

organization theories such as Spence (1984) and Katz (1986) which state the market failure can be mitigated by the R&D collaboration. In this paper, we define the government sponsored consortia as government coordinated R&D collaboration and define R&D collaboration in which firms are engaged without government involvement as market coordinated R&D collaboration. Then, we compare the respective impacts of these two types of R&D collaboration. We think the result of this comparison has potential important implication because some grounds to justify the government involvement would be lost, if the market can solve the market failure in R&D activities in the form collaboration among firms.

The results of this paper are summarized as follows. First, we find that the participation to the public R&D program has a positive impact on the quality of patents. We interpret this result in term of improvement of the "quality adjusted" research productivity. Second, if we divide the period of study into two sub-periods, respectively 1991-1997 and 1998-2004, we find that participation to public projects during the first sub-period has no impact on the quality of research but a positive impact during the second sub-period. We interpret this outcome as follows: it is resulted from the change in the orientation and structure of government programs in this field, which is briefly explained through a qualitative study. Third, we find that the impact of government-led R&D cooperation has more significant effects on the research quality than the market-led R&D collaboration.

The subsequent sections are organized as follows. The section 1 briefly overviews the theoretical and empirical literature on government sponsored R&D consortia. It also provides a brief description of RT related publicly funded consortia in Japan. The section 2 presents the dataset used in our analysis and specifies the definitions of the kind of patents used in the analysis. In the section 3, we specify our empirical models. The section 4 shows the results of our quantitative analysis and our interpretation of them.

1. Government sponsored consortia: a review of the literature and the case of the robot technology

1.1 Review on the literature on government sponsored R&D consortia

The theoretical explanation to justify government sponsored R&D can be found in the industrial organization theory on R&D collaboration. The seminal study by Spence (1984) clearly states that incomplete appropriability of the R&D results gives rise to market failure, and the equilibrium level of R&D is significantly lower than socially optimum level. The enhancement of intellectual property rights corrects the incentive problem of R&D but will create the duplication of R&D activities and hence excessive level of R&D. In this context, R&D collaboration can mitigate the tradeoff between the incentives for appropriation and the duplication of R&D and provides a solution to this dilemma.

Katz (1986), however, indicates that the incentive to form R&D collaboration can be affected by the states of the ex post market competition. If a firm tries to conduct R&D collaboration with a partner that competes in the market, part of the rent born out of the research can be lost in the subsequent market competition. Thus, if the market competition among collaborating firms is intense, the incentive to undertake R&D collaboration will be quite weak, which results in less R&D than optimal level.

The economic literature also identifies several potential channels through which government R&D projects have an impact on private R&D. For example, David et al. (2000) list the following three mechanisms through which government sponsored R&D stimulates complementary private R&D expenditures:

1) Publicly supported R&D generates learning effects which enhance the ability of private firms to obtain the latest scientific and technological knowledge. (*Absorptive capacity*)
2) Using public funds to enable the use of experimental facilities and research facilities and having the government assuming the fixed costs for establishing specific R&D projects allow private firms to start projects with low additional costs. This increases the expected return on R&D investment. (*Cost sharing*)
3) Commissioned R&D signals future demand in the public sector and demand for goods and services diverted to the private sector. Accordingly, this increases the expected return on R&D investments. (*Pump-priming effect*).

Another important channel that government projects benefit private R&D is the promotion of trust among collaborative R&D players (*institutional-building trust*), which enhances their social network for innovation. For example, Darby et al (2003) empirically analyzes the effect of Advance Technology Program (ATP) on firms' innovation and states that "the implicit design of ATP encourages firms to relax their boundaries and share knowledge. Firms participating in ATP gain from the project, learn from each other, and become better at innovating." (Darby et al: 2003, pp.5). The implicit institutional design that promotes the trust among participants includes:

(a) Third-party (ATP) monitoring of participants' behavior in Joint Ventures to ensure cooperation[6],
(b) Administrative structures and agreements such as intellectual property agreements, joint venture administrative structures to increase confidence in successful coordination[7] .

Compared to the large volume of theoretical literature that have been developed so far, little has been done to empirically test the validity of these theories using a relatively comprehensive dataset. There are, however, some exceptions. For example, Branstetter and Sakakibara (1998) uses the sample of 145 government sponsored R&D consortia in Japan and find the frequent participation in these consortia have positive impact on the level of research expenditure and research productivity. Also, Branstetter and Sakakibara (2002) use the same dataset and find that the outcomes of consortia

[6] See Zucker et al. (1996).
[7] See Das and Teng (1998).

are positively related to the level of potential spillovers within consortia and negatively related to the degree of product market competition among participating firms.

These empirical studies provide valuable insights on the effects of government sponsored consortia. Yet it is important to note that one can also find many cases of research collaboration between firms without government involvement. Thus, even if we find positive effects of government sponsored consortia to the level and the productivity of R&D, it does not necessarily justify the government involvement, as these government sponsored R&D collaboration could have been voluntarily realized by the decisions of private firms. Thus, in the later part of this paper, we conduct empirical analysis that compares the two types of R&D collaboration: government coordinated R&D collaboration (government sponsored consortia) and market coordinated R&D collaboration (R&D collaboration among firms without government involvement).

1.2 Overview of the robot technology related government sponsored R&D consortia

There have been a series of new movements in R&D and dramatic technological advances in robotics technology since the early 1990s. Namely, many firms have invested a lot of effort inventing service robots, which can be used outside factories like in households and public places, as well as new types of industrial robots characterized by more autonomy. These two types of robots have been categorized as “next generation robots”. R&D in these new RT technologies has actually attracted a great deal of public attention, and central and local governments support this industry in the form of the public projects and subsidies.

The RT related public projects have been extended to the domains of various ministries. Among these, only the Ministry of Economy, Trade, and Industry (METI) and Ministry of Internal Affairs and Communication (MIC) have had relatively comprehensive views on the industry-wide technological development and the biggest share of the budget of the RT related projects are assigned to METI. The projects in other ministries (Ministry of Education, Culture, Sports, Science and Technology, Ministry of Health Labor and Welfare, Ministry of Land, Infrastructure and Transport, Ministry of Agriculture, Forestry and Fisheries) are more focused on very specific issues which relates to RT.

Public Projects by METI. Most of the RT related public projects which are planned by METI are carried out by its R&D agency, NEDO. One can see the change in the nature of the involvement of METI and NEDO in RT in the later 1990s when the Humanoid Robotics Projects or HRP (1998-2002), which was the first comprehensive project, was implemented. In the pre-HRP period, METI had conducted various RT related projects which have very specific purposes, and there was no general strategy regarding the development of the industry. The projects that were carried out in this period include “R&D on the Micromachine Technology” (1991-2000), “Mobile Meal Delivery Robot for

Aged and Disabled People" (1995-1999), "The Surgery Support System for Brain Tumors" (1998-2000).

HRP project was the first comprehensive project which had an industry-wide strategic view, and the purpose of the project was to develop humanoid robots, which was thought to bring about a significant technological breakthrough and various commercial applications such as security service for plants, construction work, nursing care supports, management service for building or houses. Various manufacturing firms participated to this project, including Honda which was considered to be the leading firm in this field. A comprehensive hardware (HRP-2) and a comprehensive software (OpenHRP) are some of the outcomes of this project. Even though this project achieved some of its technological goals, it did not generate any commercial outcomes. Some criticize that the goal of the project was too vague, and there was not any clear views to connect the R&D to commercial applications.

The implementation of post-HRP projects has reflected these evaluations on the HRP project and was more focused on problem finding and solving and on practical uses of robot technologies. In 2002, the 21st Century Robot Challenge Program was established. It connected all the related robot projects (figure 1). The main aim of this program is to research on the common and basic technologies necessary for the development of robots. It includes "Humanoid Robot Project" (1998-2002), "Project for the practical application of Next generation robots" (2004-2005), "Development of a Software Infrastructure for robot system" ("RT Middleware project", 2002-2004).

=== Insert Figure 1 around here ===

In 2003, the first meeting of Robot Vision KONDANKAI (committee) was held, where important academic and business figures discuss the problems faced in this field.[8] In 2006, METI proposed New Industries Creation Strategy (NICS), and RT was selected as one of the priority industry. The recent RT projects have been carried out based on the proposals depicted by the committee reports and the action plan in the NICS. One characteristic of these public projects are the division of the technological themes. Currently, the themes in the whole projects are grouped into systematization technology, base technology, and elements technology, and the targets of each theme and the relation between them is clearly specified. The other characteristic is that users of the robots (such as securities companies) as well as the manufacturers are stimulated to take part. This is an attempt to integrate the user's point of view into the projects to realize practical applications out of the projects.

[8] Another committee for the RT related project (Robot Policy KENKYUKAI) was established in 2005.

Public Projects by MIC. MIC has been engaged in the public projects on network robots, which can provide high quality of services by using network. As it involves communication technologies, in which MIC has administrative authority, the public policies for the network robots at the central government level have been solely administrated by MIC. In 2004, MIC started a network robot related R&D project, "Network Robot where Ubiquitous Network Technologies and Robot Technologies". The target of this project is claimed to establish the necessary component technology to materialize network robot conducting the R&D on ICT by 2008.

MIC administers National Institute of Information and Communications Technology (NICT) as its incorporated administrative agency, and the robots related projects which were planned by MIC have been carried out by NICT.

Public Projects by MEXT (Ministry of Education, Culture, Sports, Science and Technology). There have two major projects funded by MEXT: "MEXT Special Project for Earthquake Disaster Mitigation in Urban Area" (DDT Project) and "Bio-Mimetic Control Research". DDT Project is aimed to promote R&D for the disaster mitigation in urban area, and one of its programs includes robotics related technology. This program was administrated by an NGO, IRS, and was carried out between 2002 and 2007. Bio-Mimetic Control Research was conducted by Riken, which is an Independent Administrative Institution (IAI) subordinated to MEXT. The main topics of this project include biological control system and biologically integrative sensors and the aim of the project to create advanced engineering systems such as soft human interactive robot. Also, some robotics related (small) research program has been funded through JST, a project-oriented funding agency (IAI) under MEXT.

Other Public Projects. Ministry of Land Infrastructure and Transport is conducting two projects which aim to apply robotics related technologies to construction and infrastructure building, and these two are "The Development of IT Construction System by Robotics" and "The Research on the Operation and Surveillance by Underwater Robots". Ministry of Health, Labour and Welfare (MHLW) funded a research grant, "R&D for Human Body Analysis, Support, and Substitution Instrument" (2003-2008), which aims to promote new medical instruments to substitute and support human body. The Ministry of Agriculture, Forestry and Fisheries (MAFF) funded "The Emergent Development of Next Generation Agricultural Machines Project", which aims to rapidly develop the high quality agricultural machines that will save energy, cost, and environmental damage by the cooperative research of firms, universities, and governmental agency such as Bio-oriented Technology Research Advancement Institution.

Inter-ministerial coordination. It is important to note that the public projects of each of these ministries have been planned and carried out independently, and there has been virtually no inter-ministerial coordination. However, in 2004, the Council for Science and Technology Policy (CSTP) decided to promote the cooperation among the ministries in the important technological fields, and RT was selected as one of the Cooperative Policy Groups. Based on this, four RT related public projects were carried out in 2004 and 2005 through the funding of MEXT to complement the existing projects. CSTP has recently launched a program that evaluates the technology policies of important technological fields among the ministries in an attempt to coordinate the various ministries in these fields. The actual administrative works for this program is commissioned to JST, and the coordination program for RT is led by Dr. Kazuo Tanie.

Characteristics of the firms that are involved with RT and RT related public projects. There are a variety of potential participating firms to the public project of RT, and it is possible to categorize them into at least three groups. One group is composed of the companies that are specialized in RT. They include large firms like Fanuc and Yaskawa and some start-up companies like Tmsuk. A second group is composed of very large companies in the machinery sector (including electrical machinery and car industries) like Hitachi, Toshiba or Mitsubishi Heavy Industries. They are often clients of the firms of the former group and they are engaged in RT in an attempt to diversify their activities. The third group is the potential users of service robots like SECOM, a security company. One can note a few characteristics of participants of the public projects. For example, some robot makers appear to be reluctant to be involved with government-sponsored consortia, for probably being unwilling to disclose some information. Generally speaking, participants are very big companies, but there is considerable heterogeneity in the participation frequency among firms. For example, for 17 commissioned programs between 1991 and 2005, the most frequent participating firms are Hitachi (7 participations), Toshiba (7), Mitsubishi Heavy Industries (6), whereas Toyota or Sony have never participated, despite the fact they are key players.

In the following sections, we empirically analyze the RT related government sponsored consortia. Yet, due to the lack of data especially in the patents that are assigned to the consortia, we do not cover all the RT related consortia but focus on 12 R&D consortia, which are listed in the appendix 1, including 9 projects by NEDO (METI) and 3 by NICT (MIC).

The questions that are asked in the empirical analysis are as follows.

1. Did participation to the government sponsored consortia lead to an increase of the research productivity of participating firms? Also, did the magnitude of the impact change as the organization of the public projects changed.
2. Did research productivity increase through the existence of spillovers?
3. Does the impact of the government sponsored R&D consortia on research productivity differ from the market coordinated type of R&D collaboration.

2. Data

In order to assess the RT related government projects, we use the information of patents that are applied out of the public projects and compared them with other patents. To do this, we first collected whole data of RT related patents and then identified the patents born out of the public projects within the whole data.

2.1 The dataset

We use two complementary data sources: Industrial Property Digital Library or IPDL ("Koho Text Kensaku") and Standardized Data ("Seiri-Hyojyunka Data"). The data of IPDL enable us to clearly classify 4 macro and 26 micro technological fields of RT (figure 2). However, for some reasons, JPO (Japan Patent Office) does not give information on 6 categories ("other robot", "modular structure", "attachment", "control unit to operate with a foot", "virtual reality", "and networking technology").[9] So we limit the analysis to 20 technological fields.[10] Moreover, IPDL only covers the patents from around 1991 and does not contain the information on citation. Contrary to this, Standardized Data include the information on citations. Yet we cannot clearly identify the RT related patents, and it covers patents until around 2001. Therefore we merged these two data sources to get a more complete dataset.

=== Insert Figure 2 around here ===

We collected 16,736 patent numbers through IPDL (12,863 patents of the total are matched with Standardized Data). Among these patents, we extracted patents applied by Japanese companies[11]. Then, we created unbalanced panel data by companies and years. We found, however, that many firms have small numbers of patents. It is difficult to assess the R&D productivity for small samples, so we extracted firms which have more than five patents. Finally, our sample includes 316 companies and 13,711 patents[12] and the sample period is 1991 - 2004.

2.2 Definition of G (G1 or G2) patents

For the next step, we identified the patents that were born out of the 12 projects by NEDO and NICT out of these 13,711 patents. We did this by referring to the official reports of these projects. We

[9] We did not receive a satisfying answer from JPO why they are not available. This is probably due to identification problems for theses six technologies.

[10] They are: 1)master-slave type, 2)mobile robots, 3) microrobots, 4) cartesian co-ordinate type, 5) cylinder/polar coordinates type, 6) multi-articulated arms, 7) chambers provided with manipulation devices, 8)gripping hands, 9)joints/wrists, 10)arms, 11)safety devices, 12)artificial intelligence, 13)control of mobile robots, 14)positioning control, 15)program control, 16)hand grip control means, 17)control stands, 18)teaching system, 19)image processing, 20)sound recognition (JPO, 2002)

[11] We checked inventors of all patents one by one, and created database on their affiliated companies using various search engines (see Lechevalier, Ikeda and Nishimura (2006) for more details).

[12] Among these patents, some patents overlap because there are collaborative patents.

define these patents as G1 patents and found that there are 94 such patents in the database. As the number is too small to compare with non-G1 patents (13,711-94=13,617), we borrowed the methodology used by Branstetter & Sakakibara (2002) and include the patents applied by the participating firms in the targeted technologies during and after consortiums as the outcomes of these consortiums. We define these patents as G2 patents and define the sum of the G1 and G2 patents as government (G) patents. One reason to include G2 patents as the outcome of consortia is that the strategy of the government on patents has changed over time. Branstetter & Sakakibara (1998: 213) points out "Prior to 1990, many if not most of the patents to directly emerge from the research undertaken within government sponsored research consortia were, by government directive, assigned not to the participating firms but instead to the research consortia themselves". Thus, the change of the government policy in the 1990s leads to an underestimation of the outcomes of the public projects if we define them strictly based on the G1 definition.

We basically follow Branstetter & Sakakibara (2002) to identify public project related patents, but our criteria for the definition of G patents differ in the following two ways. First, in Branstetter and Sakakibara (2002), the public project related patents are defined as the number of patent applications by participating firms in the targeted technologies during the period that the firm participates to consortia. Yet we include the number of patent applications by participating firm in the targeted technologies during and after the period of participation. To put it differently, according to this definition, once a firm participates to a government program, all the patents it applies in the targeted technologies after the participating year are considered as G2 patents. Second, to classify the G2 patents, Branstetter & Sakakibara (2002) use the targeted technologies that are depicted in the official report, yet we use more quantitative criterion, utilizing the information of the technological fields of patents reported by JPO (2002). We first identified the technological fields of the 94 G1 patents (Table 1). Then, we count the number of patents for each technological field. For each project, the technological fields that have largest number of patents are defined as the target technologies of the project.

=== Insert Table 1 around here ===

For example, according to this criterion, the targeted technologies for "Humanoid robot project" are "master slave type", "mobile robots", "control of mobile robots", and "image processing" (respectively 15%, 33%, 10% and 13% of the 39 patents issued from this project). With this criterion, the number of targeted technologies varies from 5 (for "Mobil Meal Delivery Robot for Aged and Disabled People") to 0 ("R&D on Medical Welfare Machinery Technology").[13] The case for "Mobil Meal Delivery Robot for Aged and Disabled People" is ambiguous, in which the 8 patents are

[13] The official target of this last program is not RT and the technological fields of the 8 patents that were born out of this project are extended to 8 fields, thus we conclude that there is no target technology in this project.

distributed to 7 technological fields. Thus, we base the number of claims of these patents, instead of the number of patents, to determine the targeted technologies.

From this, it can be seen that “mobile robots” is the most frequently appeared as the targeted technological field in the government programs (11 times among 12 programs) while 11 technological fields are not defined as targeted technologies in any of the projects. Generally speaking, without surprise, the targeted technologies tend to be the technologies that are closely related to next generation robot (figure 2). There is only one exception, “artificial intelligence”, which has not been the focus of the commissioned type government program. This is not surprising, because this is the domain that universities are actively involved and the R&D in this technology is supported through subsidies from the MEXT (Lechevalier, Ikeda and Nishimura, 2006).

3 Empirical Models

This section specifies the three models we will use for our empirical analysis, and we follow the technique used by Branstetter and Sakakibara [1998] for our model building.

3.1. A Model of Research Productivity

We first specify the model of research productivity. We consider a knowledge production function and we assume that the productivity of the R&D activities is a function of firm level R&D spending and the intensity of participation to consortia:

$Ni = f(Ri, Ci)$

Where *Ni* is innovation (outcome), *Ri* is R&D spending (input), and *Ci* is intensity of participation to consortia. We assume that this relation is in the liner form.

(A) $N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 C_{it} + \mu_{it}$

One important problem to estimate this model is which proxy measures for the unobservable “innovation” will be used. Here we use two proxies: the number of claims and forward citations for patent[14]. The claims in the patent specification delineate the property rights protected by the patent. The larger the number of claims is, the broader and the greater the expected profitability of an innovation is. Forward citations are the number of times that a patent is cited by other patents in the

[14] Yet, as there are considerable citation lags in forward citations, we cannot have the data for them in the recent year. So, we mainly use the number of claims as a dependent variable and use the number of forward citations complementarily.

following years. Thus, the large number of forward citations means that the patent is highly evaluated by others.

These two variables are considered to be proxies to measure "quality-adjusted R&D productivity". Whereas the number of patents has been often used as a proxy for "innovation" (Sakakibara & Bransttter, 1998, 2002; Darby et al, 2003), these two indicators actually have been broadly used as "better" proxies than the number of patents.[15] For example, Tong and Frame (1994) compare the number of claims with the number of patent and found that patent claims appear to offer a better indicator of inventiveness than the number of patents. Likewise, Trajtenberg (1990) shows that there is a close relation between the number of patents weighted by forward citations and the social value of innovations in the computer tomography scanner industry.[16]

Concerning R&D spending, it would be desirable to collect data on R&D expenses in RT field by each firm. However, it is very difficult if not impossible to obtain this data. We may be able to use the total R&D expenses of each firm, but it appears to be not appropriate as the R&D activities in the RT area are often a very small part of the total R&D activities of the firms, especially in the case of large electrical machinery firms involved in the RT. In order to solve this problem, we make use of the number of inventors as a proxy for R&D expenses[17]. This variable is considered to be a proxy for the scale of a research project and the accumulation of human capital, as the larger the number of inventors of a patent is, the bigger the research project is. Goto et al (2006) and Mariani and Romanelli (2006) use the number of inventors as a proxy for R&D expenses and find that the coefficient of the variable is significantly positive on R&D productivity.

However, there is one important issue in estimating this model, which is the possibility of endogeneity of the second explanatory variable, C_{it}. It is natural to think that the selection of the participating firms is affected by multiple factors. Especially, METI officials are likely to assign projects to firms with high research quality (subjective or not). Accordingly, even if we find there is positive relation between research productivity and the intensity of participation, it may be high research productivity that leads to the higher participation intensity, rather than the other way around. The estimates of the model (A) would then be inappropriate (Branstetter & Sakakibara, 1998).

We thus estimate the following two models, instead of model (A), to deal with this problem. First, we assume that the unobserved "quality" of the firm *i* affects the intensity of the participation of firm *i*. In other words, there is an unobserved time constant firm effect which is correlated to the explanatory variable, C_{it}, that is,

[15] The number of citations has been available only recently in the case of Japanese patents. As for the number of claims, its identification for each patent is very time consuming. It may explain why the number of patents has been preferred in many studies as a proxy for the innovation outcome.

[16] Moreover, Lanjouw and Schankerman (2004) construct a composite index which includes claims, forward citations, backward citations and the family size. They indicate that the most important indicator for the quality of patents is the number of claims in most industries except drug industry.

[17] In the subsequent econometric analysis, we also use the number of patent applications as a proxy for R&D expenses on RT field. The correlation between the number of patent application and R&D expenses is high (0.982 in Japan, Tong and Frame, 1994). In fact, the estimation results do not change significantly when we use the number of applications, instead of the number of inventors.

(B) $N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 C_{it} + q_i + v_{it}$

where q_i is a time constant quality of firms and v_{it} is idiosyncratic errors. To estimate this model, we use fixed effects estimator which is consistent estimator if this is the case.

The other approach is to assume that the explanatory variable, C_{it} , is correlated with a time-variant unobserved effect, q_{it} . If this is the case, the fixed effects estimator is deem to be inconsistent, as the explanatory variable and disturbance are contemporaneously correlated. In order to solve this problem and conduct a consistent estimation, we conduct 2SLS estimation following Wooldridge (2002). This can be done by obtaining the predicted values of C_{it}, regressing against the instrument variables which are correlated with C_{it} but exogenous to the dependent variables.

(C) $\widehat{C}_{it} = \sum \theta_k Instruments_{it} + \varepsilon_{it}$

Then we estimate the original model using the predicted values of C_{it}, which were obtained by (C).

$$N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 \widehat{C}_{it} + w_{it}$$

The dependent variable of the models (the number of claims) is a count variable that takes on nonnegative integer values and its distribution does not follow normal distribution. Poisson Regression and Negative Binomial Regression models are the two common estimators for count data. One assumption of the Poisson Regression model is that its mean is equal to its variance. Looking at the characteristics of the data of the number of claims, the observed variance is greater than the mean (the sample average is 32.3 and the standard deviation is 91.6). The estimation of Poisson Regression model seems to lead to over-dispersion. Thus, we choose to use the Negative Binomial Regression model.

3.2 A Model to Estimate Spillover Effects

To see whether the impact on knowledge spillovers is one of the channels of the effects of consortia on the research productivity, we use the framework suggested by and Jaffe (1986).

Firms are usually engaged in research activities in various fields. Jaffe [1986] expresses the technological position of a firm in the vector which are composed of the portion of its R&D effort in each technological field

$F_i=(f_1 \cdot\cdot\cdot f_k)$

where each element of technological position vector represents the ratio of R&D resources used by firm *i* in each technological field. One way to calculate the technological position of the firm using the distribution of R&D spending in each field, yet it is quite difficult to obtain the portion of R&D spending across technological fields. Thus, we follow Jaffe [1986] and use the distribution of patents that firm apllies in each technological field. To calculate the technological position of firms we classify RT patents into twenty micro technological fields based on the classification of JPO (2002).

Further, Jaffe [1986] defines the "techonological distance" between the firm i and j using the their vector of technological position, which takes the form of

$$T_{ij} = \frac{F_i F_j'}{[(F_i F_i')(F_j F_j')]^{1/2}}$$

Here, technological distance *Tij* is an index to measure the magnitude of similarity in the patent portfolio between the firms and it approaches to 1 as the similarity of technological position become more similar. Following Jaffe [1986], we assume that the technological position and technological proximity are fixed in the short run.

We can then calculate potential spillover pool of each firm using the index of technological distance. The idea behind this is that spillover effects for firm *i* will be bigger as its technological position become more similar to the firm *j*. The spillover pool for the firm *i* in time *t* is formularized as

$$K_{it} = \sum_{i \neq j} T_{ij} R_{jt}$$

where *Rj* is the number of patent application of firm *j*. It can be thought as the sum of knowledge stock of other firms weighed by the technological distance to the firm *j*.

We assume that a higher intensity of participation leads to a higher absorptive capacity to utilize potential spillover pool; in other words, frequent participation will yield higher research productivity elasticity. Thus, the research productivity function will be

$N_i = f\,(R_i, (K_i\ C_i))$

We assume the function takes the linear form

(D) $N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 C_{it} * K_{it} + \mu_{it}$

where *Nit* is innovation, *Rit* is R&D spending, *Cit* is intensity of participation, and μ_{it} is a error term with fixed effects and random errors.

3.3 Impact of Two Types of Collaboration on Spillover Effects

We define the government sponsored consortium as one type of collaborative R&D activities or government coordinated collaboration as opposed to the collaborative research among firms or market coordinated collaboration. We hypothesize that these two types of collaboration affect knowledge spillovers and test the following equation which is based on the equation (D) and allows for the impact of collaboration among firms.

$N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 K_{it} * CP_{it} + \beta_3 K_{it} * CG_{it} + \mu_{it}$

Where CG_{it} is the frequency of participation to the government sponsored consortia for firm *i* in time *t* and CP_{it} is the frequency of collaboration with other firms for firm *i* in time *t.*

One problem of conducting this estimation is that the information on the cooperation among firms is not readily available, as the firms are usually reluctant to disclose the relevant information. We therefore identify the collaborative R&D among firms by looking at the information on the inventors of each patent. If the affiliated firms to inventors for a patent include more than two firms, we define that patent as “collaborative patents”, and we use “collaborative patents” as a proxy for the number of collaborative R&D among firms. An invention is defined as the outcome of “collective R&D” if more than one inventors who belong to different organizations are mentioned in the bibliography of the patent.[18]

We use two kinds of variables for CG_{it} and CP_{it}. One is the accumulated number of G1 and collaborative patents applied by the firm *i* before time *t*, in order to see the impact of past involvement in collaboration on the research productivity. This is actually the data commonly used for an indicator of the stock of knowledge. Thus, we assume that some of the knowledge becomes obsolete over time, which is common assumption to measure the stock of knowledge, and assume that the rate to be obsolete (depreciation rate) is 10% per year[19]. The other variable is the number of G1 patents and collaborative patens which are applied by firm *i* in time *t*. This variable is used to see the impact of collaboration activities on the productivity of contemporary R&D activities.

4. Results

4.1. Basic Statistics of G and NG Firms

Table (2) shows the basic characteristics of patents applied by the firms that has participated to public projects (G firms) and firms that have never participated the public projects (Non-G firms). First, we note that the average number of patents per firm is much higher for G Firms than Non-G firms. The number of patents can be regarded as a measure for the scale of R&D activities for RT by firm. Thus, the data show that the G firms tend to have been involved with R&D in much larger scale than Non-G firms. Second, the average number of collaborative patents is larger for G firms than Non-G firms. The participants in the public projects tend to be more involved with collaborative R&D outside of the public project than non-participants.

=== Insert Table 2 around here ===

Table (3) gives the data of five indicators of patents quality. The average number of each indicator is a little higher for G firms than Non-G firms. To see if these indicators are statistically different between G firms and Non-G firms, we calculated two sample mean comparison tests. We find that the numbers of claims, inventors, and technological fields are statistically significantly higher

[18] It is important to note that the collaborative patents are a subset of actual incidents of collaborative R&D, as not all the R&D activities would lead to the patent application. Also, to look at the both type of collaboration at the same level, we use the number of patents generated by the participating firms out of consortium (G1 patent defined in section 2.2) for estimating the impact of government sponsored consortia, instead of the number of actual participation. Using G1 patents as an indicator of participation to public consortia is much more restrictive way than using the number of actual incidents of the participation.

[19] We cannot identify the correct depreciation rate in RT fields. So, we also conduct the estimations in the case of 20% depreciation rate and without depreciation rate. The results do not change if we use either 10% or 20% depreciation rate.

for G firms than Non G firms at 1 per cent significance rate. Yet the numbers of forward and backward citations are not significantly different between G firms and Non-G firms. This may indicates that the research productivity of G firms is intrinsically higher than Non-G firms. Thus, we cannot reject the possibility that firms with higher research productivity tend to be selected as the participants of the public projects, which would cause an endogeneity problem in our models. It confirms the necessity to solve this problem in using an adequate estimation procedure.

=== Insert Table 3 around here ===

We also conduct the χ square test which investigates whether the technological fields of patents applied by G firms and Non-G firms differ. The data show that both groups have the similar tendency in patents application in terms of technological fields. It appears to be no problem to use Non-G firms as a control group in terms of technological specialty.

4.2. Research Productivity Function

We first conduct an empirical analysis to test the hypothesis that an increase in the intensity of participation is associated with an increase in the quality adjusted productivity of the firms' R&D activities. The equation we estimate is based on the model (A) and is in the form of

$$N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 C_{it} + \beta_3 Sc_{it} + \mu_{it}$$

N_{it} is the number of claims of patents generated by firm i in time t . R_{it} is the number of inventors for the patent. C_{it} is the accumulated number of consortia in which a firm i has been involved before year t.[20] Sc_{it} is the number of patents in the "science based" technologies among the sub-types of RT technologies. We include this variable as a control variable as it seems to be related to the productivity of technology or the number of claims (Lechevalier et alii, 2007).

The Table (4) presents the results of the estimation using fixed effects and random effects. As discussed earlier, the intensity of participation is likely to be associated with the unobserved research quality of each firm. Thus, random effects model appears to be inconsistent and the fixed effects model, which controls unobserved time invariant effects, appear to be more appropriate. This is confirmed by a Hausman specification test.

=== Insert Table 4 around here ===

[20] Alternatively, accumulated years of participation to the consortia can be used as explanatory variable, yet the conclusion is almost the same in this case too. See the Table A1 in the Appendix.

The results show the term of intensity of participation is positive and statistically significant, indicating that the participation of an additional consortium in the past has a positive impact on the quality of the R&D activity of firms. However, using the coefficient estimated by the fixed model, the number of claim of patents generated by a firm in time *t* averagely increases 2.3% (= [exp(0.1547)-1]×0.14) by additional participation in the past. Obviously, this figure is not so large.

One thing we have to note is that there may be a sampling bias if we include the non-participating firms into the dataset, as the data do not show how much the magnitude of the impact would be if non-participants are involved with the projects. As there are relatively large number of non-participating firms in the dataset (there are many cases that explanatory variables takes the number of 0s), this may lead to the under-evaluation of the impact of the explanatory variable. Therefore, we also estimate the same model using the data which include only the participating firms in order to get more robustness for our estimation. The results of this estimation are presented in the Table A2 of the appendix. The results of this test show that impact of the participation to consortia has a positive and significant effect on the research productivity. The result shows that the number of claim of patents generated by a firm in time *t* averagely increases 13% by additional participation in the past.

As already noted earlier, there may be the problem of endogeneity for C_{it}[21]. Government decides which companies take part in which projects, and this assignment is not random. The governmental officials tend to select firms whose R&D productivities are high and who have participated to the projects more frequently.

In order to solve this problem and check the robustness of the model, we conduct 2SLS in the following way.

$$\widehat{C}_{it} = \theta_0 + \theta_1 R_{it} + \theta_2 PCP_{it} + \theta_3 Sc_{it} + \theta_4 C_{i,t-k} + \sum \theta_d Y_{id} + \varepsilon_{it}$$

$$N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 \widehat{C}_{it} + \sum \theta_d Y_{id} + w_{it}$$

where R_{it} and Sc_{it}, are same definitions as before. PCP_{it} is the accumulated number of collaborative patents for firm *i* applied before time *t* with depreciation rate 10%. C_{it-k} is the k-lagged values of C_{it} and Y_{it} is the year dummy variable.

We expect that the larger companies tend to participate in government sponsored projects more often, and if firms have more experiences in collaborative R&D in the past, they tend to be more willing to take part in projects. Also, most of targeted technologies of projects include science based technologies, which are more related to next-generation robots. Thus, the companies which have the higher ratio of science based technologies related patents to total RT patents tend to participate in

[21] We conduct Hausman-Wu Test for the problem of endogeneity and null hypothesis is rejected, that is, C_{it} appear to be endogeneous to the model.

projects more often. Furthermore, concerning the k-lagged variable $C_{it-k,}$ as suggested in Branstetter and Sakakibara [1998], we suppose that there is some "bureaucratic" inertia to the selection process. Firms which were frequently selected as the participants of the projects in the past are more likely to be selected in the projects given their research quality[22].

The Table (5) shows the result of fixed effects IV estimation. In the table, the model 1 shows the results of first stage within regression. In this model, we include the lag (3), lag (4) and lag (5) variables of C_{it}. The result shows that the size of companies, the degree of science orientation in technology have significant impact on intensity of participation, while the past experiences of collaborative R&D do not affect.

=== Insert Table 5 around here ===

The model 2 in the table (5) shows the result of 2SLS which uses the result of the model 1. The coefficient of C_{it} *n* is significantly positive on the quality-adjusted R&D productivity. These results indicate that the intensity of participation affects the R&D productivity even after the model is adjusted to the endogeneity issue.

However, it should be noted that this result depend on the robustness of the result of model 1 where we conclude that lag (3), lag(4) and lag(5) of C_{it} is exogenous to the R&D productivity. When the longer lagged variables, from lag 6 to 8, are included in the first stage of the 2SLS model, we cannot conclude if intensity of participation has positive impact on the R&D productivity because the coefficient of C_{it} *n* is not significant. We also estimated the same model using only the participants of project as the sample. In this case, the result is almost same as the previous case (but the coefficient of C_{it} is larger, about 31). However, if we take the longer lagged variables (from 6) as instruments in this estimation, the coefficients of those variables in the first stage are not significant (or 10% significant). Thus, there may be a problem of weak instruments for these longer lagged variables and they are not appropriate as instruments[23].

4.3 Impact on the Spillover Effects

We then conduct an empirical test to examine if the impact of consortia on the research productivity includes the augmentation of knowledge spillover effects. The equation we estimate is

$$N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \gamma_1 K_{it} * C_{it} + \beta_2 Sc_{it} + \mu_{it}$$

[22] If we exclude the variables of CP_{it} and $Sc_{it,}$ the results do not change.

[23] We have three indicators to measure the intensity of participation, accumulated numbers of participated projects (C), accumulated years that the firm participated (*CY*), and the number of projects the firm participate at the time *t* (*CC*). We also used CY and CC to estimate the 2SLS model. In the case that we use *CY*, the result is almost same as the case of using *C*. In the case that we use *CC*, the coefficient of *CC* is positively significant if we take longer lagged variables (from 6) as instruments.

which is based on the model (D). The coefficient of the interaction term, K_{it} *$C_{it,}$ represents the magnitude of the change in innovation productivity elasticity to the participation for a given level of potential knowledge spillovers. In other words, the coefficient measures the impact of participation on the absorptive capacity of firm in terms of utilizing the knowledge outside of the firm.[24]

The results in the table (6) show that the interaction term is positive and statistically significant, indicating the participation increases the knowledge spillovers. The p-value of the Hausman specification test is on the order of 0.00, indicating that the random effect is not appropriate model. However, we cannot see much difference in the coefficients between fixed and random models, thus the selection of estimation methods between them does not give bias on the estimation.

=== Insert Table 6 around here ===

The results suggest that the impact of participation to consortia on the research productivity include the channel of raising incoming spillovers of the participating firms. Using the coefficient estimated by the fixed model, the number of claim of patents generated by a firm in time *t* averagely increases 1.6% (= [exp(0.0002)-1]×80.76) by additional participation in the past for a given potential spillover level. Here again, this number is apparently relatively small.

As in the case of research production function, we also estimate the same model using the data which include only the participating firms to get more robustness for our estimation. The results of this estimation are presented in the Table A4 of the appendix. The results show that impact of the participation to consortia has positive and significant effect on the research productivity through the knowledge spillover augmenting effects. The result shows that the number of claim of patents generated by a firm in time *t* averagely increases 9.5% by additional participation in the past.

4.4 Impact of the evolution of the program

As mentioned earlier, one commonly used indicator for quality adjusted R&D productivity is the number of citation for patents. We estimate the same model using the number of forward citation as the dependent variable but cannot find any positive relation between the intensity of participation and research productivity. It may be, however, due to the fact that the model with forward citation includes the data only up to 1997 for the lack of data on forward citation and there may be a structural change in 1998.

To test the hypothesis that there is a structural break in 1998, we first regress the number of claims again to estimate the same model but with the sample of data up to 1997 and we cannot find

24 We used the accumulated number of consortia for K_{it}* *Cit*. Alternatively, accumulated years of participation to the consortia (*CY*) can be used for variable K_{it}* *Cit*.; the conclusion is almost the same. See the Table A3 in the Appendix. We does not include *Cit* as an explanatory variable, for the observed existence of multicollinearity with the interaction term *Kit *Cit*.

any positive relation between the participation and research productivity as indicated in Table (7). Also, we use the dummies for 1991-1997 and 1998-2004 to estimate the following model

$$N_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 C_{it} *(Dummy1991\text{-}1997) + \beta_2 C_{it} *(Dummy1998\text{-}2004) + \mu_{it}$$

where N_{it} is the number of claims and here C_{it} is a number of consortia the firm *i* participated in time *t* (not the accumulated number). We find that the participation term with 1998-2004 dummy has significant positive impact on N_{it} while the term with 1991-1997 dummy is insignificant. Thus, we can infer that the involvement in the public project began to have impact on the research productivity only after 1998.

=== Insert Table 7 around here ===

These results strongly suggest that there is a structural break in 1997/1998. Indeed, year 1998 was the time the HRP project has started. The HRP was the first project which covered relatively comprehensive technologies, and since this period METI has started to be strategically involved in the research on RT in order to create a new market for service robots. The estimation results may indicate that the public projects became more appropriate since 1998 as the government become more active and strategic in the research of RT

4.5 Government Coordinated Consortium and Market Coordinated Collaborative Research

As discussed earlier, government sponsored consortia can be thought as one kind of collaborative research. We estimate the impact of both government sponsored consortia (or government coordinated collaboration) and collaborative research among firms (or market coordinated collaboration) on research productivity.

We first estimate the following equation to test if the involvement of two types of collaborative R&D increases the research productivity.

$$N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \beta_2 CG_{it} + \beta_3 CP_{it} + \beta_4 Sc_{it} + \mu_{it}$$

N_{it} is the number of claims of patents generated by each firm per year as the indicator of research productivity.

We use two kinds of variables for CG_{it} and CP_{it} . One of them is the stock data of G1 and collaborative patents (with depreciation rate 10%) to see the impact of involvement in collaboration in the past on the research productivity. We name these variables as PCG_{it} and PCP_{it} respectively. The other is the number of G patents and collaborative patens in the same year to see the impact of collaboration activities on the productivity of contemporary R&D actvities. We name these variables as KCG_{it} and KCP_{it} respectively. We do not include the two types of variables into the same equation due to the observed existence of multicollinearity.

Thus, we conduct two estimations X1 and X2 where

X1: $N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \beta_2\, PCG_{it} + \beta_3\, PCP_{it} + \beta_4 Sc_{it} + \mu_{it}$

X2: $N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \beta_2\, KCG_{it} + \beta_3\, KCP_{it} + \beta_4 Sc_{it} + \mu_{it}$

PCG_{it} = the accumulated number of G1 patents for firm *i* applied before time *t* with depreciation rate 10%.

PCP_{it} = the accumulated number of collaborative patents for firm *i* applied before time *t* with depreciation rate 10%.

KCG_{it} = the number of G1 patents for firm *i* in time *t*

KCP_{it} = the number of collaborative patents for firm *i* in time *t*

We then test if the collaborative R&Ds increases research productivity through the spillover augmenting effects by estimating the following equation.

$$N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \gamma_1 K_{it} * CG_{it} + \gamma_2 K_{it} * CP_{it} + \mu_{it}$$

We also estimate two equations X3 and X4 where

X3: $N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \gamma_1 K_{it} * PCG_{it} + \gamma_2 K_{it} * PCP_{it} + \mu_{it}$

X4: $N_{it} = \beta_0 + \beta_1 R_{it} + \gamma_0 K_{it} + \gamma_1 K_{it} * KCG_{it} + \gamma_2 K_{it} * KCP_{it} + \mu_{it}$

For all the estimations, the Hausman specification test suggests that the random effect models are not appropriate, so we present the results of fixed effects models. The estimation results are presented in Table (8), and statistical implications based on the estimations are summarized in Table (9). The results show that the variables that are related to the participation to government projects are positive and significant for all the models. This implies that, even with this restrictive definition of participation (G1 patent), the participation to the public projects both at the present and in the past positively affects the quality of patents, and one channel of the impact is the spillover augmenting effects.

=== Insert Tables 8 & 9 around here ===

On the other hand, market coordinated collaboration appears to be only significantly affect the productivity of firms contemporary R&D activities (the past experiences of collaboration do not affect the productivity of research). Also, there is no evidence of spillover augmenting effects.

These results indicate that the impact of market coordinated collaborative research on the research productivity is relatively limited compared to the government coordinated collaboration. This result is basically consistent with the finding of Lechevalier et, al (2007), where they find the evidence of positive impact of current collaborative R&D on the quality of patents, but cannot find the evidence of positive impact of past collaborative R&D.

As in the previous cases, we also estimate the same models using the data which include only the participating firms to get more robustness for our estimation. The results are summarized in the table (10). With these estimations some of the variables we found previously significant become insignificant. The variables that are related to collaborative patents are insignificant in all the models, indicating that there is no impact of market coordinated collaboration on research productivity in any way. Also, the participation of public projects in the past seems not to affect the research productivity whereas the current involvement still has the impact on it.

=== Insert Table 10 around here ===

These results indicate that the impact of government coordinated collaborative research on the research productivity is more significant compared to the market coordinated collaboration. This result is basically consistent with the finding of Lechevalier et, al (2007), who find the evidence of positive impact of current collaborative R&D on the quality of patents, but cannot find the evidence of positive impact of past collaborative R&D.

It is possible to think of several potential reasons for the observed difference in the impact between two types of collaborative research. First, governments tend to picks up the R&D theme which are close to the technological frontier, and the goals of government project tend to be quite ambitious. Indeed, science-based technologies such as mobile robot, control of mobile robot, image processing are often picked up as targeted technologies by public projects. These kinds of R&D projects are potentially more risky, but the benefits and learning effects of it tend to be bigger. Even if such highly risky R&D cannot be undertaken by the private firms, the firms may be able to engage in that R&D if it is a public project as the publicly sponsored projects signal future demand and increase the expected return on R&D investment (*Pump-Priming effect*). Also, the public funds expended for the projects will decrease firms' cost for R&D and increase firms' incentive to participate (*Cost Sharing*).

Second, as the participation to public projects goes with *ex ante* agreement on the ownership of research output, there is little chance of opportunistic behavior and necessity of bargaining over the research outcome. The monitoring and evaluation by the public institution also promote cooperation among the participants. Accordingly the participants can be more eager to collaborate with other participants, which will promote knowledge sharing and more knowledge spillovers (*institutional-building trust*).

Third, the difference in relative scale of research between the two might have affected their relative impact. As depicted in the Appendix 1, a relatively large number of firms participate for the public projects whereas the R&D collaboration among firms are undertaken by only two partners in most cases. If the number of participating firms is larger, the accumulated level of knowledge of the participants is likely to be larger, and there are more chances for each participating firm to access to the complementary technology; thus, the spillover effects tend to be larger.

Finally, government involvement may have decreased the coordination costs which were necessary to form R&D collaboration. The coordination costs include the search costs to find proper partner, the cost of negotiation on the allocation of the research results, and the management costs for the projects. These costs will become larger as the number of participants becomes larger. The government might have played a role of coordinator, who bears these costs and helps to realize larger scale R&D collaboration that cannot be undertaken by the coordination by markets.

Conclusion

In this article, we have proposed an evaluation of government-supported R&D consortia based on the methodology developed by Sakakibara & Branstetter (1998). We focus on the case of robot technology, which has rarely been the object of the analysis from this point of view. Our main methological contribution is the use of indicators of quality of patents (numbers of claims and citations) instead of number of patents as indicators of the outcomes of the programs. It allows us to provide an estimation of quality adjusted research productivity.

Our findings can be summarized as follows. First, participation in the government sponsored R&D consortia tends to lead to the increase in quality adjusted research productivity of participating firms. Yet the impact of consortia on the research productivity seem to begin to appear only after 1998 when the METI started to actively and strategically involved with the RT. Second, the channel through which the consortia affect research productivity includes the increase of incoming spillovers, or firm's absorptive capacity to utilize the knowledge outside of the firm. Third, if we divide the collaborative R&D into government coordinated collaboration and market coordinated collaboration, the latter appear to have limited impact on the research productivity, whereas the former seem to have non-negligible impact.

Finally, this study can be complemented by further research especially in the following points. At a general level, it is important to check whether our main result - the positive impact of participation to government consortia on R&D productivity – is resulted from the characteristic of the robot technology or industry. The positive impact of government coordination on private R&D may be resulted from the nature of the robot technology - which requires a high level of collaboration as an assembling technology - as well as the current state of the industry - characterized by a high degree of uncertainty. At a more specific level, it is necessary to provide more direct tests whether government-led collaboration is complementary or substitute to market-led collaboration. In this paper, we only conducted an indirect test by comparing these two types of collaboration. The significant impact of the participation to government consortia may not enough be to justify government participation in this field.

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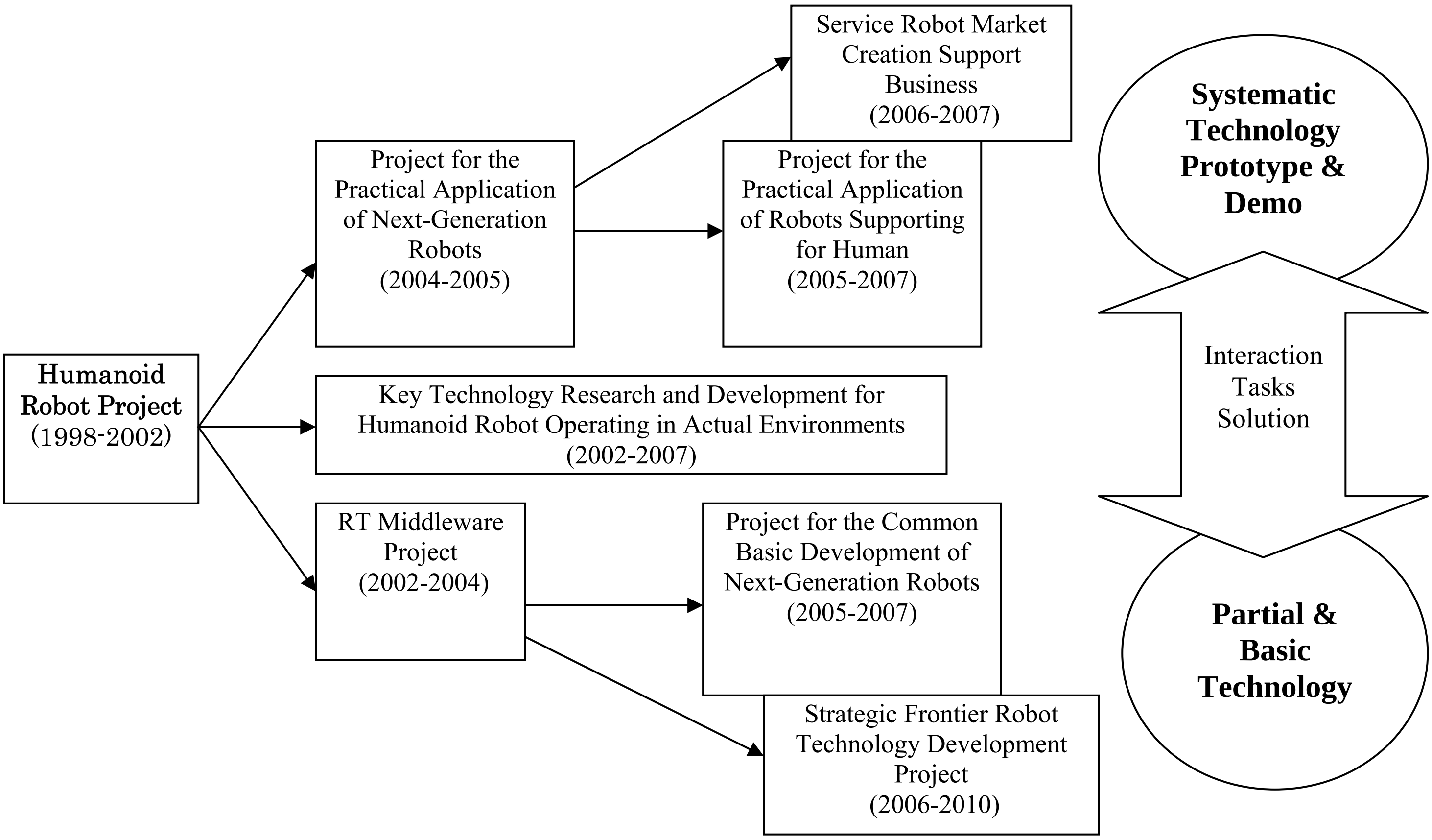
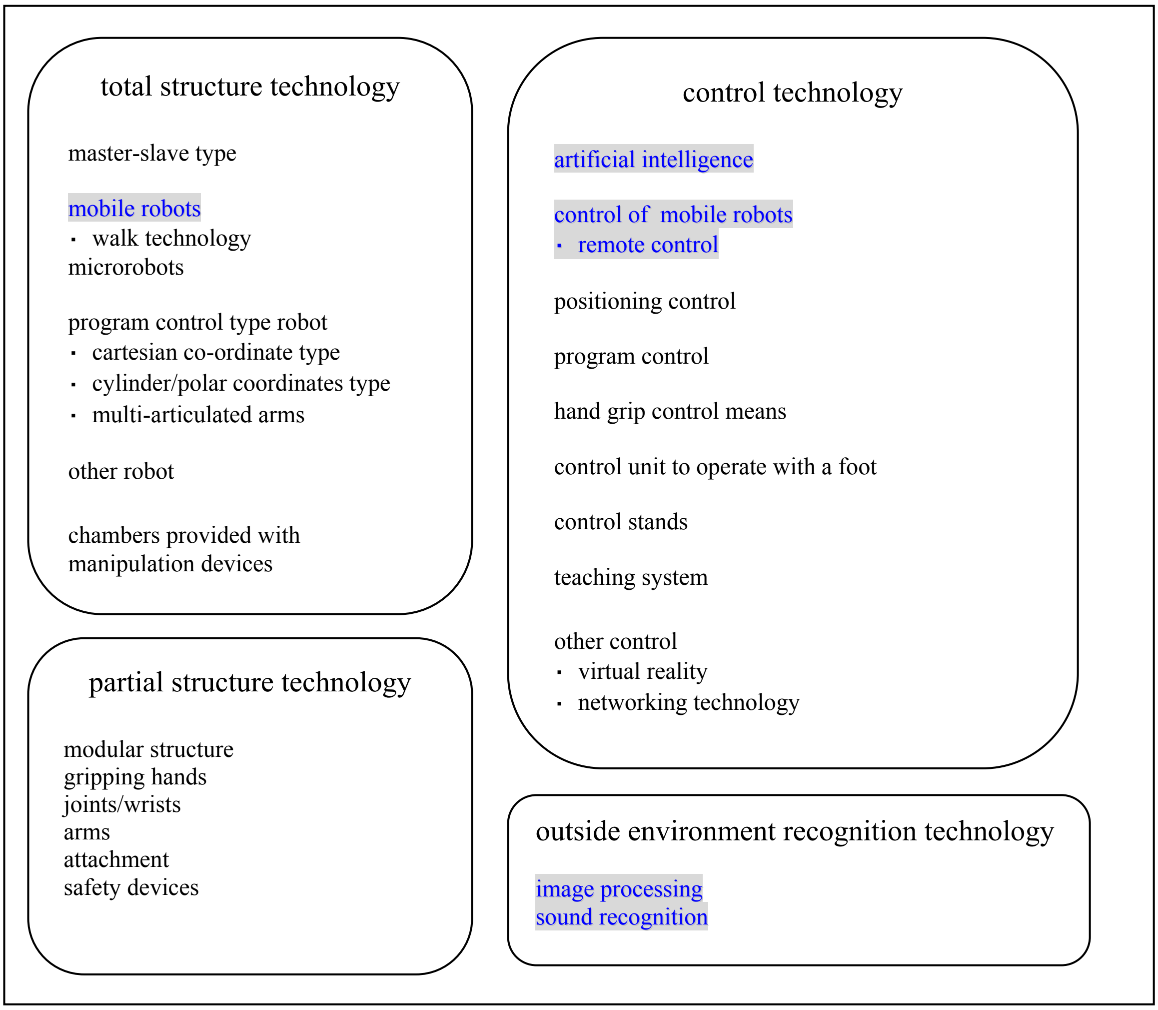
Figures & tables

Figure 1: 21st Robot Challenge Program and Action Plan (NICS) －History, Linkage and Hierarchy of the Public Policy by METI



Source : METI (2005a,b)

Figure 2: Four macro classifications and twenty micro classifications of RT



Source: JPO (2002)

Note: The technologies shaded are closely related to the technology of next generation robots

Table (1) The distribution of G1 patents by 12 public projects and 20 micro technological fields (percentage)

Project No.	master-slave type	mobile robots	microrobots	cartesian co-ordinate type	cylinder/polar coordinates type	multi-articulated arms	chambers provided with manipulation devices	gripping heads	joints/wrists	arms	safety devices
1		0.125							0.125		0.250
2	0.200		0.400						0.200	0.200	
3	0.154	0.333						0.026	0.026		0.077
4	0.750					0.125			0.125		
5											
6	0.048	0.714							0.048		
7		0.667									0.333
8	0.029	0.324	0.324			0.029		0.059	0.059		
9	0.125		0.125	0.125		0.125			0.125		0.125
10		0.571									
11		0.182								0.091	
12		0.500									
Non-G1	0.016	0.154	0.014	0.015	0.006	0.053	0.004	0.213	0.053	0.017	0.034
Total	0.017	0.156	0.014	0.014	0.006	0.052	0.004	0.211	0.053	0.017	0.034

Project No.	artificial intelligence	control of mobile robots	positioning control	program control	hand grip control means	control stands	teaching system	image processing	sound recognition	Total
1		0.125	0.125					0.125	0.125	1
2										1
3		0.103		0.051	0.077	0.026		0.128		1
4										1
5		1								1
6	0.048				0.048		0.048	0.048		1
7										1
8		0.059	0.059					0.059		1
9							0.125	0.125		1
10								0.143	0.286	1
11	0.364							0.273	0.091	1
12		0.500								1
Non-G1	0.019	0.055	0.078	0.032	0.008	0.009	0.063	0.131	0.028	1
Total	0.019	0.055	0.078	0.032	0.008	0.009	0.062	0.131	0.028	1

Note: This figure is created by our original patent database. Concerning the 12 public projects, see the appendix.

Table (2): Basic Characteristics of G Firms & Non-G Firms

Firm Types		Total	Average per firm
G Firms (36 firms)	***Trend of patents***		
	Total RT patents	5488	152.444
	G1 patents	94	2.611
	G patents (G1 or G2 patents)	1281	35.583
	Collaborative patents(exc.G1 patents)	528	14.667
	Collaborative patents(exc.G patents)	419	11.639
	% of collaborative patents(exc.G patents)	7.635	-
	Trend of Participation in Projects		
	Cumulative numbers of projects	44	1.222
	Cumulative years of projects	265	7.361
Non-G Firms (280 firms)	***Trend of patents***		
	Total RT patents	8223	29.368
	Collaborative patents	1186	4.236
	% of collaborative patents	14.423	-

Table (3): R&D Productivity in terms of Quality of Patents -Comparison between G Firms & Non-G Firms

Firm Types		Total	Average	SE
G Firms (36 firms)	***Total RT patents***	5488		
	Quality per patent			
	Claims	5.599	5.803***	0.221
	Forward Citations	0.509	0.511	0.041
	Backward Citations	1.199	1.217	1.199
	The number of Inventors	2.473	2.478***	0.080
	The number of Technological Fields	1.397	1.353***	0.017
Non-G Firms (280 firms)	***Total RT patents***	8223	8223	8223
	Quality per patent			
	Claims	5.411	4.636	0.085
	Forward Citations	0.450	0.480	0.029
	Backward Citations	1.137	1.122	0.043
	The number of Inventors	2.163	2.177	0.029
	The number of Technological Fields	1.315	1.246	0.009

Table (4) : Estimation of Research Productivity Function
(Standard errors in parentheses)

Variable	Dependent variable: ***N (number of claims)*** Fixed Effects	Random Effects
R	0.0102*** (0.0003)	0.0106*** (0.0003)
C	0.1547*** (0.0368)	0.1860*** (0.0335)
Sc	0.0483 (0.0482)	0.0824 (0.0451)
constant	0.0802 (0.0801)	0.0647 (0.0797)
Year Dummies	yes	yes
Number of samples	2324	2329
Number of groups	311	316
Log likelihood	-6998.2243	-8760.8442
Hausman Specification test	chi2(16) = 75.37	Prob>chi2 = 0.0000

*Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table (5) : Fixed Effects IV Estimation (Standard errors in parentheses)

	C	*N (number of claims)*
	1	2
	coefficients standard errors	coefficients standard errors
C		22.5252*** (8.2094)
R	0.001*** (0.0003)	3.7101*** (0.0665)
PCP	0.0019 (0.002)	
Sc	0.0378** (0.019)	
C (lag3)	0.3826*** (0.0436)	
C (lag4)	0.2198*** (0.0553)	
C (lag5)	0.2118*** (0.0367)	
constant	0.0300* (0.0159)	-12.4379*** (4.0488)
year dummies	yes	yes
Number of samples	1450	1450
Number of groups	301	301
R. sq		
Within	0.4242	0.7428
Between	0.9147	0.7378
Overall	0.8614	0.7452

Notes: The model 1 is the first-stage within regression. In the model 2, instrumented variable is *C and* instrument variables are *inventors, CP, Sc, C(lag3), C(lag4), C(lag5) and year dummy variables*

Table (6) : Estimation of Spillovers Model (Standard errors in parentheses)

Variable Names	Dependent variable: ***N (number of claims)***	
	Fixed Effects	Random Effects
R	0.0101***	0.0105***
	(0.0003)	(0.0003)
K	0.0007***	0.0008***
	(0.0002)	(0.0003)
*K*C*	0.0002***	0.0003***
	(0.0001)	(0.00006)
Sc	0.0523	0.0821
	(0.0479)	(0.0448)
Constant	-0.1945*	-0.2279**
	(0.117)	(0.1069)
Year dummies	yes	yes
Number of samples	2324	2329
Number of groups	311	316
Log likelihood	-6995.5744	-8755.0481
Hausman Specification test	chi2(17) = 80.63	Prob>chi2 = 0.0000

*Significant at the 10% level

** Significant at the 5% level

*** Significant at the 1% level

Table (7) : Estimation to check for a structural change (Standard errors in parentheses)

	N(number of forward citations)	***N (number of claims)***	***N (number of claims)***
	1	2	3
	coefficients standard errors	coefficients standard errors	coefficients standard errors
R	0.0117*** (0.0011)	0.0130*** (0.0007)	0.0094*** (0.0004)
K	0.0018*** (0.0006)	0.0001 (0.0003)	0.0008*** (0.0002)
C	-0.2807** (0.1362)	-0.1753* (0.1048)	
C(until1997)*			-0.0329 (0.0642)
C(from1998)*			0.1002*** (0.0477)
KCG			0.0791*** (0.0226)
KCP			0.0189*** (0.0064)
Sc			0.0602 (0.0477)
constant	0.1955 (0.285)	0.3534** (0.1551)	-0.2152* (0.1162)
Year Dummies	yes	yes	yes
Number of samples	1091	1207	2324
Number of groups	225	268	311
Sample periods	1991-1997	1991-1997	1991-2004
Log likelihood	-1335.8153	-2948.755	-6984.5685
Hausman specification test	chi2(9)=67.18 (prob>chi2=0.00)	chi2(9)=63.42 (prob>chi2=0.00)	chi2(20)=64.31 (prob>chi2=0.00)

Note: KCG_{it} = the number of G1 patents for firm *i* in time *t*
KCP_{it} = the number of collaborative patents by two or more firms for firm *i* in time *t*

Table (8) : Fixed Effects Negative Binomial Regression (Standard errors in parentheses)

	Dependent variable: *N (number of claims)*			
	X1	X2	X3	X4
R	0.0101*** (0.0004)	0.0094*** (0.0004)	0.0101*** (0.0004)	0.0097*** (0.0004)
K	0.0008*** (0.0002)	0.0008*** (0.0002)	0.0008*** (0.0002)	0.0007*** (0.0002)
PCG	0.0449*** (0.0205)			
PCP	-0.0004 (0.0035)			
KCG		0.1062*** (0.0211)		
KCP		0.0171* (0.0066)		
*K*PCG*			0.00008*** (0.00003)	
*K*PCP*			0.0000 (0.0000)	
*K*KCG*				0.0002 *** (0.00005)
*K*KCP*				0.0000 (0.00001)
Sc	0.0575 (0.0478)	0.0620 (0.0480)	0.0590 (0.0478)	0.0637 (0.0477)
Constant	-0.2415** (0.1163)	-0.2082* (0.1163)	-0.2465** (0.1172)	-0.2054* (0.1171)
Year dummies	Yes	Yes	Yes	Yes
Number of samples	2324	2324	2324	2324
Number of groups	311	311	311	311
Log likelihood	-6992.978	-6988.2725	-6996.9958	-6991.4481
Hausman specification test	chi2(18)=89.77 (prob>chi2=0.00)	chi2(18)=56.71 (prob>chi2=0.01)	chi2(16)= 98.63 (prob>chi2=0.00)	chi2(17)=57.99 (prob>chi2=0.00)

Table (9) Summary of estimation results (Whole Sample)

	Model 1	***Model 2***	***Model 3***	***Model 4***
	Test if past participation affect R&D productivity	Test if present participation affect R&D productivity	Test if past participation affect R&D productivity through spillover effects	Test if present participation affect R&D productivity through spillover effects
Government Collaboration	Significant (1%)	Significant (1%)	Significant (1%)	Significant (1%)
Elasticity	0.44	0.45	7.62	0.44
Market Collaboration	Insignificant	Significant (10%)	Insignificant	Insignificant
Elasticity		1.19		

Table (10) Summary of estimation results (Only Participants)

	Model 1	***Model 2***	***Model 3***	***Model 4***
	Test if past participation affect R&D productivity	Test if present participation affect R&D productivity	Test if past participation affect R&D productivity through spillover effects	Test if present participation affect R&D productivity through spillover effects
Government Collaboration	Insignificant	Significant (1%)	Insignificant	Significant (1%)
Market Collaboration	Insignificant	Insignificant	Insignificant	Insignificant

Appendix 1: List of the 12 government projects related to the robot industry studied in this paper

Name of the program	Period	Participants (firms)	Budget (million yen)	Number of patents (G1)	Targeted technologies
1) R&D on the Micromachine Technology	1991－2000	Around 30 firms (the participants changed over time), including Mitsubishi Electric, Yasukawa, Fanuc, Toshiba, Hitachi	25,000	26 (34)	Mobile Robots, Microrobots
2) Mobil Meal Delivery Robot for Aged and Disabled People	1994 － 1998	2 (Yasukawa & Fujitsu)	563.4	4 (8)	Mobile Robots, Safety Devices, Positioning Control, Image Processing, Sound Recognition
3) The Surgery Support System for Brain Tumors	1995 － 1999	3 (Hitachi, Toshiba, NHK Engineering Services)	931.9	4 (5)	Microrobots
4) Humanoid Robot Project	1998 － 2002	12 (including ALSOK, Hitachi, Kawasaki Heavy Industries, Yaskawa Electric, Kawada Industries, Honda, Fanuc) in collaboration with universities and AIST	4,573	23 (39)	Master-slave type, Mobile Robots, Control of Mobile Robots, Image Processing
5) Advanced support system for endoscopic and other minimally invasive surgery	2000 － 2004	2 (Toshiba & Asahi Optical)	About 850	7 (8)	Master-slave type
6) Development of a Software Infrastructure for Robot System (RT Middleware Project)	2002 － 2004	1 (Matsushita Electric Works) in collaboration with AIST and JARA	267	1 (1)	Control of Mobile Robots

7) Key Technology Research and Development for Humanoid Robot Operationg in Actual Environments	2002 — 2007	2 (Kawada Industries, Kawasaki Heavy Industries) in collaboration with AIST	No data	16 (21)	Mobile robots
8) Project for the Practical Application of Next-Generation Robots	2004 — 2005	Around 40 (including Matsushita Electric Works, Mitsubishi Heavy Industry, ALSOK, tmsuk, NEC) in collaboration with many universities	About 4,000	2 (3)	Mobile Robots, Safety Devices
9) R&D on Medical Welfare Machinery Technology	1999 — 2003	6 (including Hitachi, Yaskawa Electric, Daihen Tec, Sanyo Electric)	No data	6 (8)	No Targeted Technologies
10) Epigenetic Interface for Appropriating Social Communication Skills	2002 — 2004	1 (ATR) in collaboration with universities	No data	4 (7)	Mobile Robots
11) R&D on Human Information Communication	2002 — 2006	1 (ATR) in collaboration with universities	No data	7 (11)	Mobile Robots, Artificial Intelligence, Image Processing
12) R&D on Network Human Interface (Network Robot)	2004 — 2008	5 (ATR, Toshiba, NTT, Mitsubishi Heavy Industries, Matsushita Electric Industries)	No data	1 (2)	Mobile Robots, Control of Mobile Robots

Source: Compilation of public reports by the authors
Note 1: Programs 1 to 9 are organized by NEDO (METI); programs 10 to 12 are organized by NICT (MIC)
Note 2: In the column "number of patents", the first figure is the absolute number of G1 patents, while the figure into parenthesis is the number calculated by firms: a collaborative patent is therefore counted as many times as there are different partners.

Appendix 2: complementary tables

Table A1 : Estimation of Research Productivity Function (Standard errors in parentheses)

Variables	Dependent variable: *N (number of claims)* Fixed Effects	Random Effects
R	0.0101***	0.0105***
	(0.0003)	(0.00032)
C	0.0196***	0.0250***
	0.0066	0.0061
Sc	0.0535	0.0877
	(0.0482)	(0.0451)
Constant	0.0713	0.0553
	(0.0801)	(0.0797)
Year dummies	yes	yes
Number of samples	2324	2329
Number of groups	311	316
Log likelihood	-7001.3634	-8767.8197
Hausman Specification test	chi2(16) = 152.23	Prob>chi2 = 0.0000

*Significant at the 10% level

** Significant at the 5% level

*** Significant at the 1% level

Table A2 : Estimation of Research Productivity Function using the data of participating firms only - Fixed Effects
(Standard errors in parentheses)

Dependent variable: *N (number of claims)*	
R	0.01245***
	(0.0006)
C	0.1541395 ***
	(0.0460)
Sc	0.0705
	(0.1216)
Constant	0.0842
	(0.1594)
Year dummies	yes
Number of samples	393
Number of groups	36
Log likelihood	-1544.5051
Hausman Specification test	chi2(16) = 122.38 Prob>chi2 = 0.0000

*Significant at the 10% level

** Significant at the 5% level

*** Significant at the 1% level

Table A3 : Estimation of Spillovers Model (Standard errors in parentheses)

Variable Names	Dependent variable: *N (number of claims)*	
	Fixed Effects	Random Effects
R	0.0101***	0.0105***
	(0.0003)	(0.0003)
K	0.0008***	0.0008***
	(0.0002)	(0.0002)
CY	0.00003**	0.00004***
	(0.00001)	(0.00001)
Sc	0.0550	0.0852
	(0.00001)	(0.0448)
Constant	-0.2179**	-0.2540**
	(0.1162)	(0.1065)
Year dummies	yes	yes
Number of samples	2324	2329
Number of groups	311	316
Log likelihood	-6996.4237	-8757.1316
Hausman Specification test	chi2(16) =76.05	Prob>chi2 = 0.0000

Table A4 : Estimation of Spillovers Model using the data of participating firms only - Fixed Effects (Standard errors in parentheses)

Dependent variable: *N (number of claims)*	
R	0.0123***
	(0.0007)
K	0.00036***
	(0.0005)
C	0.0002***
	(0.00008)
Sc	0.0484
	(0.1222)
Constant	-0.0568
	(0.2710)
Year dummies	yes
Number of samples	393
Number of groups	36
Log likelihood	-1545.9585
Hausman Specification test	chi2(17) = 80.63

*Significant at the 10% level

** Significant at the 5% level

*** Significant at the 1% level