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Junichi Nishimura
and
Hiroyuki Okamuro

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Research Center for Interfirm Network
Institute of Economic Research, Hitotsubashi University
Naka 2-1, Kunitachi-city, Tokyo 186-8603, JAPAN
Tel: +81-42-580-9145
E-mail: hit-tdb-sec@ier.hit-u.ac.jp
http://www.ier.hit-u.ac.jp/ifn/

Knowledge and rent spillovers
through government-sponsored R&D consortia

Junichi Nishimura*
Institute of Innovation Research, Hitotsubashi University
Address: Naka 2-1, Kunitachi, Tokyo 186-8603, Japan
E-mail: b111086k@r.hit-u.ac.jp

Hiroyuki Okamuro
Graduate School of Economics, Hitotsubashi University
Address: Naka 2-1, Kunitachi, Tokyo 186-8601, Japan
E-mail: okamuro@econ.hit-u.ac.jp

Abstract
R&D consortia (collaborative R&D projects among private firms, universities, and public research institutes) have been attracting increasing attention as an effective means of promoting innovation. Especially for SMEs, such collaboration provides important opportunities to access and obtain advanced scientific knowledge generated by universities and public research institutes. It is expected that not only the participants in R&D consortia will enhance their performance, through direct knowledge spillovers, but also that the business partners of consortia members may enjoy indirect effects (rent spillovers), through their business transactions. This paper empirically examines the spillover effects through government-sponsored R&D consortia using firm-level data and the propensity score method. Focusing on a major support program for R&D consortia in Japan, the “Consortium R&D Project for Regional Revitalization” by METI, we confirm that there are both direct (knowledge) spillover effects from firms’ participation in this program and indirect (rent) spillover effects on the customer firms of the consortia members. Moreover, by comparing SMEs and large firms, we find that only SMEs obtain knowledge spillovers in R&D consortia, whereas, among their customers, only large firms enjoy rent spillovers.

Keywords: R&D consortia, business transaction, knowledge spillover, rent spillover, SME, policy evaluation
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* Corresponding author

1. Introduction

R&D consortia (collaborative R&D projects among private firms, universities, and public research institutes) have been attracting increasing attention worldwide, from both academics and practitioners, as an effective means of promoting innovation. Especially for small and medium sized enterprises (SMEs) that usually have limited business resources, such collaboration provides important opportunities to access and obtain advanced scientific knowledge generated by universities and public research institutes (Motohashi, 2005). In Japan, R&D consortia not only among large firms, but also those including small firms, have been promoted with public financial support. It is expected that not only the participants in R&D consortia increase their R&D productivity through direct knowledge spillovers, but also that the business partners of consortia members may enjoy indirect effects, through their business transactions.

The spillover effects are not confined to knowledge spillovers, but also include rent spillovers. Rent spillovers occur when economic benefits are transferred through business transactions, while knowledge spillovers arise when knowledge is transferred without a market transaction (Griliches, 1979). We argue that consortia members obtain knowledge spillovers, while customers of these member firms (especially those producing intermediate or capital goods) may benefit from rent spillovers. Therefore, the effect of R&D consortia would be underestimated if rent spillovers through business transactions would be ignored.

This paper examines the spillover effects through government-sponsored R&D consortia empirically, using firm-level data and the propensity score method. Focusing on a major support program for R&D consortia in Japan, the "Consortium R&D Project for Regional Revitalization" (hereafter the CRDP), supported by METI (the Ministry of Economy, Trade, and Industry), we examine the direct knowledge spillover effects from the firms' participation in the CRDP, and also the indirect rent spillover effects on firms who are customers of consortia members, through their business transactions. As such, the aim of this paper is to evaluate the effectiveness of public support for R&D consortia in Japan, taking indirect spillover effects into consideration.

Moreover, we pay special attention to a comparison of the effects of spillovers on SMEs and large firms. R&D consortia are often expected to have a larger impact on small firms that have limited resources and knowledge, and therefore, the METI project is also designed to support innovation by SMEs. Thus, another important aim of this study is to explicitly distinguish between SMEs and large firms in examining the spillover effects via publicly supported R&D consortia.

The remainder of this paper is organized as follows. In the next section, we provide our conceptual framework and a brief overview of previous empirical studies highlighting how we can contribute to the literature. Section 3 explains the method of empirical estimation. Section 4 describes our data and the sample used for the empirical analysis. Section 5 presents the empirical results and a discussion of them. Section 6 concludes this paper.

2. Conceptual background and previous studies

In this section, we explain our conceptual framework regarding spillover effects and R&D consortia. We first distinguish between knowledge and rent spillovers and then explain why R&D consortia may enhance spillover effects. Finally, we provide a brief overview of previous empirical studies and present our contribution to the literature.

2.1. Knowledge spillovers and rent spillovers

Previous studies indicate that the relevant spillover effects are not simply confined to knowledge spillovers, but also include rent spillovers (Terleckyj, 1974; Griliches, 1979; Jaffe, 1986; Clarke et al., 2006). According to Griliches (1979), knowledge has the characteristics of a public good: We can all consume it, without depleting it and so becoming rivals (non-rivalry). Additionally, knowledge can be freely consumed, to a certain extent without compensation (partial non-excludability). Furthermore, knowledge is subject to spillovers (positive externalities); knowledge (or ideas) created through R&D activity can be transferred to other agents without market transactions occurring. For example, imitation can lead to positive productivity effects elsewhere and idea creation processes can also be enhanced by knowledge flows.

Knowledge spillovers arise when knowledge is transferred without market dealings; however, rent spillovers occur when economic benefits are transferred through business transactions. Product or process innovations generate improved intermediate and capital inputs for customer businesses. If the prices of these inputs do not fully capture the changes in quality, part of the productivity gains made by the innovating industry, finally belongs to downstream industries (shifting rents from innovators to users) (Terleckyj, 1974; Goto and Suzuki, 1989; Verspagen, 1997; Crespi et al., 2007). This may occur because, due to severe competition or bargaining power inferiority, innovators are sometimes unable to set prices for new products that reflect the full quality increase relative to old products[1].

[1] If the innovator is a monopolist (e.g., a supplier of computers), they would have strong bargaining power to enforce a higher price, which completely reflects the increase in performance, being paid by user firms. There would be no rent spillovers at all, because the user firms do not obtain any benefit from the increase in productivity. The productivity gains (e.g., in terms of the number of calculations per unit of time) would be completely offset by the increase in computer price paid by the users. However, real markets are not completely concentrated and demand is to some extent elastic, which enables users to obtain rent spillovers.

Previous empirical studies provide some illustrating examples, including aircraft manufacturing and the airline industry (Terleckyj, 1974), and electronic components and NC machine tools (Goto and Suzuki, 1989) or computers (Verspagen, 1997). For example, Terleckyj (1974) argues that a substantial increase in airlines' productivity was achieved mainly because of the introduction of high quality aircrafts by manufacturers based on their R&D efforts. The price the airlines paid to aircraft manufacturers did not fully reflect the improvement in the quality of aircrafts, so part of the benefit of manufacturers' R&D efforts was captured by the buyers.

If the necessary information to produce an intermediate good is kept secret, other firms using this good in their production chain might profit from the technological progress through lower prices or higher quality. This would result in a typical case of rent spillovers, without the presence of knowledge spillovers. As a result, the productivity increases made in the innovating industry will be seen in industries purchasing the innovative products (Griliches, 1979; Los, 2000).

2.2. Spillover effects through R&D consortia

R&D consortia are defined as collaborative R&D projects formed by private firms, universities, and public research institutes, often with the support of the government. R&D consortia have been attracting increasing attention as an effective means of promoting innovation (e.g., Etzkowitz and Klofsten, 2005; Leydesdorff and Meyer, 2006).

Previous studies indicate that R&D consortia produce social benefits as they solve market failures by internalizing knowledge spillovers (thus increasing the private incentive for R&D) (Spence, 1984; Teece, 1986; Griliches, 1992) and reducing the inherent uncertainty of R&D (Malmberg et al., 1996); consortia achieve this through increasing coordination, risk sharing, and resource pooling. David et al. (2000) suggest potential conduits through which R&D consortia benefit private firms. R&D consortia enable participating firms to obtain advanced scientific knowledge due to intensive knowledge spillovers from other members of the consortia, including universities and public research institutes. R&D consortia with diverse and interdisciplinary partners such as universities, industry members, and the government may well enhance knowledge flows.

Moreover, R&D consortia enable experimental and research facilities to be shared amongst consortia members. This may allow private firms to start R&D projects at a reduced cost, which would increase their expected return on R&D investment and so their incentive for R&D investment. David et al. (2000) argue that public support for R&D consortia additionally increases participating firms' expected return on their R&D investments, because the government covers the fixed costs for establishing specific R&D projects[2].

Figure 1 summarizes our conceptual framework of spillover effects and R&D consortia. In this study, we use three measures of firms' performance: sales growth, labor productivity growth, and total factor productivity (TFP) growth. In the following section, we argue that consortia members obtain knowledge spillovers, while customers of firms in consortia (especially those producing intermediate or capital goods) will benefit from rent spillovers, which enhance the performance of these firms.

A firm in a consortium can access complementary assets owned by other cooperative organizations (suppliers, customers, rival firms, universities, the government, etc.), meanwhile the knowledge generated within an R&D consortium is shared among its members through various channels. For example, knowledge or information will be exchanged through face-to-face communication between consortium members, and the advanced skills or know-how embodied in a worker will be transferred through his/her mobility among members. In addition, access to new or cutting-edge research facilities and equipment provides the opportunity to acquire new knowledge or ideas through the training of researchers. Therefore, knowledge spillovers will positively affect the productivity of consortia firms, which may enable them to develop new products or processes and produce additional value. That is why sales growth, labor productivity growth, and TFP growth are expected to increase due to participation in an R&D consortium.

Especially for SMEs, which have limited business resources, R&D consortia provide important opportunities to obtain advanced scientific knowledge, generated by universities and public research institutes, and to access cutting-edge research facilities and equipment (Motohashi, 2005). Therefore, we expect that the effect of knowledge spillovers would appear more prominently in SMEs than in large firms.

Several previous studies suggest that public support for collaborative R&D projects may promote the formation of trust amongst the cooperating actors (institutional-building trust), which then intensifies their social network for innovation (Zucker, 1983; Zucker, 1986; Tripsas et al., 1995; Das and Teng, 1998; Zucker et al., 2001; Darby et al., 2004; Okamuro and Nishimura, 2011). Hence, government plays an important role in discouraging consortia members from behaving opportunistically by providing control mechanisms, such as contractual safeguards enforcing partnership agreements, through direct monitoring and its enforcement abilities, and by encouraging long-term relationships that discipline the future behavior of subsidized members. Therefore, knowledge flows may be increased in government-sponsored R&D consortia through a highly reliable networking environment being established among their

[2] This can be considered as an additional monetary effect of subsidy, aside from the knowledge spillovers. However, in our estimations we cannot estimate pure knowledge spillover effects excluding the monetary effects, which may induce upward bias into the estimated knowledge spillover effects.

members.

Regarding rent spillover effects, if, through participating in an R&D consortium, a firm develops a new product or process (or improves the quality of an existing product or process), customer firms of the subsidized firm also benefit from the technological progress generated by the firm's R&D investment. As already mentioned, it is often the case that due to competition and bargaining power inferiority, innovators (here, the consortia firms) are unable to set higher prices for new products that fully reflect the increase in their quality. Therefore, customer firms can enhance the quality of their products, or decrease their real manufacturing costs without reducing quality, by utilizing the new products or processes generated by R&D consortia as intermediate and capital inputs, which in turn will lead to growth in their sales. Moreover, customer firms can improve their labor productivity and TFP by creating products with greater added value and by decreasing the costs of intermediate goods. Therefore, we can expect productivity increases in an innovating industry to be transferred to industries purchasing the innovative products.

2.3. Previous empirical studies and our contribution

Several empirical studies investigate the determinants and effects of firms' participation in R&D consortia (George et al., 2002; Mohnen and Hoareau, 2003; Motohashi, 2005; Vergeleurs and Cassiman, 2005). There are also numerous studies on the effects of public support for R&D consortia, regarding the performance of subsidized firms (e.g., Irwin and Klenow, 1996; Branstetter and Sakakibara, 1998; Bayona-Saez and Garcia-Marco, 2010). However, as Klette et al. (2000) indicate, few empirical studies take rent spillovers, through business transactions, into consideration when examining the spillover effects through R&D consortia. However, the effect of R&D consortia might be underestimated if rent spillovers are ignored.

Several studies empirically examine the spillovers from suppliers to customers. Using industry-level data from Input-Output-Tables in Japan, Goto and Suzuki (1989) estimate that R&D efforts in customer and supplier industries have a considerably larger effect on firms' TFP growth than R&D efforts made in the same industry. Using industry-level panel data, Bartelsman et al. (1994) find a strong relationship between industry productivity and customers' activities from "within" estimates, and with suppliers' activities from "between" estimates. They interpret these results as suggesting that customer linkages are important in the short run, while supplier relationships increase industry productivity in the long run.

Some scholars have examined the spillovers between customers and suppliers using firm-level data. Focusing on the Japanese electrical machinery industry, Suzuki (1993) finds there is a substantial knowledge flow from core firms of vertical keiretsu groups to their suppliers and from other keiretsu groups. Branstetter (2000) also finds strong evidence that the vertical keiretsu relationship promotes knowledge spillovers between suppliers and customers. Crespi et al. (2008) find that the main sources of knowledge in these flows are competitors, suppliers, and plants of the same business group, and that these three flows together account for half of all TFP growth. Furthermore, a number of studies examine the spillovers from foreign plants to local suppliers through foreign direct investment (Javorcik, 2004; Branstetter, 2006; Kugler, 2006; Haskel et al., 2007; Motohashi and Yuan, 2010; Barrios et al., 2011). However, these previous studies have not addressed the effects of R&D consortia or R&D subsidies, and few studies have explicitly examined rent spillovers from suppliers to customers with a large sample of firms.

This study will be valuable from both an academic and a practical perspective, because of the following original contributions: First, this study not only explicitly addresses the spillover effects within R&D consortia, but also the effects through business transactions on major customer firms of consortia members, We also confirm that both types of effect are positive and significant. Thus, we estimate the economic effects of publicly supported R&D consortia more comprehensively than most previous studies do.

Second, we control for sample selection bias (as the probability of participation in R&D consortia is not random) by employing propensity score matching in our empirical analysis. Therefore, we estimate the effects of publicly supported R&D consortia more robustly than some previous studies do.

Third, this paper pays special attention to the effects of spillovers on SMEs as compared to large firms. In fact, we find that knowledge spillovers within publicly supported R&D consortia are positive and significant only for SMEs. However, with regard to rent spillover effects, through business transactions, we confirm that large firms receive greater benefits.

Last but not least, to the best of our knowledge, this is the first study to evaluate the effects of publicly supported R&D consortia in Japan using micro data. Under the Fourth Science and Technology Basic Plan, which began in 2011, the government needs and should promote science- and evidence-based science and technology policies; therefore, this empirical policy evaluation may also have considerable practical value.

3. Empirical strategy

We now explain our empirical framework. In order to accurately assess the effect of a treatment, we cannot simply compare the measured performance of the treated and the control firms, nor can we solely compare the values for treated firms before and after the treatment. Rather, we should consider the difference between treated firms' observed values and the unobservable values in the counterfactual situation, and so carefully estimate the average performance values that treated firms would have shown if they had not been treated.

We use propensity score matching (hereafter, PSM) to examine the improvement in firms' performance through publicly supported R&D consortia. PSM is a useful statistical tool in estimating the true effect of a treatment, policy, or other intervention, as it accounts for the covariates that predict receiving the treatment and so reduces the sample selection bias. This is because PSM can balance the observed differences between the treated and control firms, so that the matched samples have the same probability of assignment to treatment as under randomized selection.

In the first step, a firm's propensity to participate in publicly supported R&D consortia is estimated, conditional on some firm and regional characteristics that are observable before participation. In the second step, on the basis of the estimation results, each participant is matched with a control firm (a non-participant) that has a similar propensity score for participation in R&D consortia. Finally, we compare the ex-post performance of firms in the matched groups. We employ the same procedure to generate the matched sample of major customer firms of consortia members. In the following sub-sections, we describe our empirical procedures in more detail.

3.1. First step: Specification of a probit model

There may be significant differences in the characteristics of participants (treated firms) and non-participants (control firms), as we show for our sample in Section 4.2. The propensity to participate in R&D consortia is neither exogenous nor randomly given. Therefore, we should first control for such endogeneity, i.e., selection problems, when evaluating the effect of publicly supported R&D consortia on firm performance. Thus, using binary probit regression, we examine the determinants of participation in publicly supported R&D consortia and calculate the probability of such participation. The model for probit regression is specified as follows.

The propensity of a firm to participate in a publicly supported R&D consortium is estimated conditional on some firm and regional characteristics observable before participation. It is desirable to find the best conditioning variables; those that are expected to be causing an imbalance between the treated and the control firms. Moreover, these variables should also affect firms' performance, so that they can correct selection bias. Following Guo and Fraser (2009), we prepare for a range of variables which could affect firms' performance.

First, we control for firms' age, firms' size, R&D intensity, and ROA as the proxies for firms' capabilities. The age of a firm is an approximate measure of knowledge and experience accumulation. We use the number of employees as a proxy for firm size. We expect that a larger firm will own greater complementary assets and establish a broader network with related companies and universities. R&D intensity, calculated as the ratio of R&D expenditure to sales, is used to measure the degree of absorptive capacity of a firm. ROA measures how efficiently a firm's assets are being used to generate revenue. We expect that a firm's capability may contribute positively to the propensity of a firm to participate in R&D consortia.

Second, we also incorporate indicators of firms' growth potential into our models. It would cause estimation biases if we compared the treated firms with high (low) growth rates ex-ante and the control firms with low (high) growth rates ex-ante. Therefore, it is necessary to construct matched samples of treated and control firms with similar growth potential. We use sales growth, labor productivity growth, and TFP growth as proxies for firms' growth potential[3]. In our empirical analysis, firms' capability and growth potential are ex-ante variables and their average values for the years 2001 to 2003, before participation in R&D consortia, are taken (see Section 4.1).

Third, we introduce dummy variables for industry type, to control for differences across industries with regard to technological opportunity, the degree of competition, and economic fluctuations. Finally, prefectural dummies are included in the probit regression to capture the regional differences in the potential for research collaboration with universities and public research institutes.

3.2. Second step: Matching and performance comparison

In the second step, on the basis of the estimation results of the probit regressions, each participant is matched with a control firm (a non-participant) that has a similar propensity score for participation in publicly supported R&D consortia. Then, we compare the ex-post performance of firms in the matched groups to calculate the Average Treatment effect on the Treated (ATT), that is, the relative improvement in firm performance due to R&D consortia.

ATT is the difference between the value actually observed for the consortia firms and the estimated value for the counterfactual situation: the average performance value that the participants (treated firms) would have shown if they had not been treated. Therefore, we regard positive values of the ATT as representing the impact of knowledge spillovers through participation in publicly supported R&D consortia. However, the counterfactual situation is never observable and has to be estimated. From among several methods to estimate the counterfactual (Imbens and Wooldridge, 2009), we employ three matching algorithms to check robustness: one-to-one nearest neighbor matching, nearest available Mahalanobis metric matching within calipers, and kernel matching.

[3] These variables, especially labor productivity growth and TFP growth, are often highly correlated with each other. Thus, later in the empirical estimation, we include these variables in the probit model interchangeably to check robustness. However, the estimation results do not differ much from those of the basic model.

One-to-one nearest neighbor matching is one of the most popular matching algorithms. We extract a control firm as a match for a treated firm if the absolute difference in their propensity scores is the smallest among all possible pairs of propensity scores of the treated and control firms. Then, the closest control firm and the treated firm are removed from the pool (without replacement) and the process repeats.

The nearest available Mahalanobis metric matching within calipers is a combination of Mahalanobis distance and nearest neighbor within caliper matching. Mahalanobis distance or Mahalanobis metric matching is based on a weighted distance between the matching variables of the treated and control firms (Cochran and Rubin, 1973; Rubin, 1976). In one-to-one nearest neighbor matching, no restriction is imposed on the distance between the propensity scores of the treated and control firms. Therefore, we only select a control firm as a match for a treated firm if the absolute distance between their scores is less than 0.1. According to Rosenbaum and Rubin (1985), this matching algorithm produces the best balance between the covariates of the two groups.

Kernel matching was developed from the non-parametric regression method (Heckman et al., 1997, 1998). This approach allows one-to-many matching, by calculating the weighted average of the outcome variable for all control firms and comparing this with the outcome for the treated firms. The weight assigned to a control firm is proportional to how close it is to a treated firm.

After the matching process, we compare firms' performance using three ex-post measures: sales growth, labor productivity growth, and total factor productivity (TFP) growth. Labor productivity is calculated by dividing the value added by the number of employees. Unfortunately, we cannot access information on total man-hours, which would include working hours dedicated to management and monitoring processes as well as the manufacturing processes. TFP is estimated by a basic Cobb–Douglas production function which defines total output (added value) as a function of capital input (tangible fixed assets), labor input (the number of employees), and TFP. In these comparative approaches, the control group is assumed to represent a good proxy for what the performance of an average participant would have been if it had not participated in publicly supported R&D consortia[4].

Additionally, we divide the whole sample into two sub-samples of SMEs and large firms (those with more than 300 employees) to compare the ATT between them. SMEs have limited business resources, so R&D consortia provide them with important opportunities to obtain advanced scientific knowledge generated by universities and public research institutes and access to cutting-edge research facilities and equipment. Therefore, we expect that the effect

[4] Actually, after PSM, we found no significant differences in the characteristics of the treated and control firms prior to participation in publicly supported R&D consortia (see Section 5 for more details).

of participating in R&D consortia will be greater for SMEs than for large firms[5].

In a similar respect, Monjon and Waelbroeck (2003) argue that spillovers from universities are only marginally beneficial to firms that are at the frontier of scientific knowledge. Rather, firms that are involved in incremental innovation benefit more from such spillovers. If larger firms are on average more likely than small local firms to be at the scientific frontier, we may observe that the latter benefit more than the former.

3.3 Propensity score matching of customer firms

Regarding the firms who are customers of consortia members, we employ the same procedure to generate a matched sample of major customer firms. If the characteristics of customer firms (treated firms) are substantially different from those of non-customer firms (control firms), then we have to construct a desirably matched sub-sample of control firms that represents the counterfactual situation, giving consideration to the covariates that would cause an imbalance between the treated and control firms. Then, the control group should provide the average performance values that the treated firms (customers) would have shown if they had not been treated.

Thus, in the first step, we use the same independent variables as described in Subsection 3.1 to calculate the propensity score of being a major customer of a consortium firm, and in the second step each customer is matched with a control firm (non-customer) that has a similar propensity score. Thus, the control firms (non-customers) have the same characteristics as the treated firms, except that the former have no business relationships with consortia firms. As before, we employ three matching algorithms to estimate the ATT. We then compare the customer firms' (treated firms') ex-post performance with that of the matched sample (control firms). Therefore, we regard positive values of the ATT as representing the effect of rent spillovers, occurring through business transactions with participants of publicly supported R&D consortia.

Regarding this, it is noteworthy that we are unable to consider the supplier structure (or the overall characteristics) of the customer firms when matching with the control firms, however, with which suppliers they transact may be important for their performance. We can identify major customers of consortia firms, but these customers may transact with many other suppliers. While information on the major suppliers of these customers is available, we cannot consider the major suppliers of several thousand other firms amongst which we select the control firms. Therefore, in the propensity score matching of customer firms, we implicitly assume that the suppliers of firms in the treated and control groups have the same characteristics

[5] The support program for R&D consortia by METI (the CRDP), on which we focus in our empirical analysis (see Section 4.1 for more details), mainly supports innovation in local SMEs who often act as project leaders. These characteristics may provide higher incentives for SMEs to participate than for large firms.

as a whole.

That we cannot sufficiently consider suppliers' characteristics would be a serious constraint if the value of the estimated ATT would be biased without doing so. For example, the customers of consortia firms may transact with suppliers in different industries or technology fields from those of control firms, which would incur differences in performance between the treated and control firms. More simply, innovative customers may be more likely to transact with innovative suppliers, and thus to engage consortia firms as their suppliers. However, we cope with these biases, at least partially, by including the variables regarding industry and innovativeness in our estimation of the propensity score of being a customer of a consortia firm. Therefore, we may assume that the possible bias that arises from not considering suppliers' characteristics will not be serious.

One may suspect that a positive value of the ATT would not only comprise rent spillovers, but also knowledge spillovers from suppliers to their customers. Knowledge spillovers may also occur between business partners through researchers' mobility or personal contacts. Previous studies that measure technological spillovers between customers and suppliers do not clearly distinguish between knowledge and rent spillovers (Goto and Suzuki, 1989; Bartelsman et al., 2004). However, as we show later, most of the consortia firms in our sample are manufacturers of parts and components for machinery industries, and thus their customers are mostly the assemblers of these parts and components. In such cases, rent spillovers are more likely to occur from suppliers to customers than knowledge spillovers, because the knowledge required to produce each component is but a small fraction of the knowledge required to produce the final product.

4. Data and sample characteristics

4.1. Consortium R&D Project for Regional Revitalization (CRDP)

Our sample is comprised of the firms that participated in the CRDP, supported by METI in Japan. The basic characteristics of the CRDP are summarized in Table 1. The CRDP aims to create new products, processes, and businesses for regional economic revitalization, by promoting university-industry-government collaboration. METI financially subsidizes R&D projects that are aiming for commercial success, utilizing the ideas or knowledge owned by universities, industry, or government (public research institutes). In order to be accepted into the CRDP and to obtain METI's grants, each R&D project has to include at least one university and one private firm. The grants range from 50 million to 150 million yen, the amount given depending on the characteristics of the research themes and the consortia members. This program started in 1997 when university-industry collaboration rapidly increased and intensified because of major changes to the national system for innovation[6]. Therefore, this program has been considered as playing an important role in promoting university-industry collaboration in Japan.

Furthermore, the CRDP aims to mainly support the innovation activities of local SMEs. The consortia typically include a large number of local universities and SMEs, and nearly half of the consortia are led by firms' representatives, while the rest are led by university professors. We find that SMEs act as project leaders in more than 80% of the CRDP consortia that are led by firms, although we recognize that large firms also actively participate in the CRDP, as shown below.

Another important feature of this program is that it targets applied research and development for commercialization, rather than basic research, although universities have to be included in consortia. As shown in Table 1, this program provides financial support for consortia for two years, with the goal that at least 30% of the supported consortia will achieve commercialization of innovation outcomes within three years following the funding period[7]. Thus, the program requires consortia members to promptly achieve commercialization, regardless of their commercial success.

Using the data on firms participating in this program, we can examine both the effects of knowledge spillovers on the participating firms and rent spillovers on their customer firms. Consortia members include private firms, universities, and public research institutes with various interdisciplinary research themes and skills, which may enhance knowledge spillovers among consortia members. Furthermore, the CRDP mainly supports the commercialization of new technology, which promotes rent spillovers from consortia members to their customers.

4.2. Sampling of the firms participating in the CRDP

We obtained a list of 1,550 firms that participated in the 666 R&D consortia supported by the CRDP between 2004 and 2008[8]. For 584 manufacturers, among these 1,550 firms, that could be matched with the COSMOS database provided by TDB (Teikoku Data Bank) we extracted financial and organizational information for fiscal years from 2000 to 2009. COSMOS is the most extensive corporate information database in Japan, which contains accurate and highly

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[6] Under the Science and Technology Basic Plan of 1996, the Ministry of Education, Culture, Sport, Science, and Technology (MEXT) has been giving financial support to promote the establishment of Technology Licensing Organizations (TLO), since 1998, and Intellectual Property (IP) Centers, since 2003, within Japanese universities, to manage and improve their collaboration with industry and the use of intellectual property. Backed by legal and institutional changes, including the Japanese Bayh-Dole Act of 1999 (that allowed national universities to retain their rights to IP produced using government research funds) and the reorganization of national universities into independent corporations in 2004, obtaining competitive research funding through collaboration with industry has become one of Japanese universities' most important strategies.

[7] However, according to METI, the actual rate of commercialization is 24%. Hence, this program has not yet achieved its goal.

[8] We are very grateful for the support of a METI staff who constructed the list of participating firms.

reliable corporate information gathered through corporate credit research. Around 1,700 field researchers are involved in all parts of the country, visiting companies to obtain corporate information in every industrial category and location. COSMOS now stores data on approximately 2 million companies nationwide. Therefore, COSMOS is useful for constructing panel data of corporate information.

Table 2 shows the distribution by manufacturing industry (defined by TDB, 2-digit industry classification) of participating firms in the CRDP (treatment group: 584 firms) and non-participating firms (control group: 39,952 firms). We find that there are no significant differences between the distributions of the treated and control groups, although the ratio of treated firms in chemical and electrical machinery industries is relatively higher than that of the control firms.

Figure 2 presents the distribution of the treated and control firms by firm size, measured as the average number of employees between 2001 and 2003. We find that the treated group is biased towards larger firms relative to the control group. This is because a considerable number of smaller firms (startups) participating in the CRDP are dropped from our sample, as they are not included in the COSMOS database because it is difficult to track the establishment of young startups.

Table 3 summarizes the characteristics and performance indicators of the treated and control firms, taking the average values between 2001 and 2003. We conducted a Wilcoxon rank-sum test to compare the mean values between the treated and the control firms. Table 3 clearly shows the differences between the groups. The treated firms are on average older, larger, more R&D intensive, and more profitable than the control firms, while the latter have higher potential for sales growth, labor productivity growth, and total factor productivity (TFP) growth before participating in the CRDP. These differences suggest the importance of utilizing the propensity score matching method to create balanced sub-samples of treated and control firms, to enable us to correctly compare their performance.

4.3. Sampling of the customer firms of the consortia firms

In order to analyze rent spillover effects, we also collected business transaction data from COSMOS for the three largest customer firms of each of the 584 manufacturers participating in the CRDP, as of 2007. COSMOS does not continually provide information on business transactions and we only have access to transaction data for 2007. Thus, we assume that the largest customer firms do not frequently or drastically change. Furthermore, we use performance measures for the years 2007 and 2008 to compare the treated with the control firms, assuming that the business transaction data is suitable information for the analysis.

We identified 1,210 customer firms of the 584 manufacturers. Among these customer firms, 485 belong to the manufacturing sector, while 392 are wholesale firms. In this paper, we focus on the 485 customer firms in the manufacturing sector, because the mechanisms of producing additional value may differ significantly between the manufacturing and wholesale sectors[9]. We collected financial data for these 485 firms to examine rent spillover effects due to the CRDP.

Table 4 presents a matrix by manufacturing industry of the number of business transactions between the CRDP participants (suppliers) and their customers. There are several cases where a CRDP participant has more than one business transaction (multiple transactions) within the 485 customers. In Table 4, we can see which manufacturing industries have business transactions with which other industries. For example, among the 46 CRDP participants (suppliers) in food processing, 14 suppliers have business transactions with firms in the same industry, while 2 suppliers sell their products to customers in the chemical industry. The remaining suppliers in the food processing industry have business transactions with wholesale firms. In sum, the suppliers in the food processing and chemical industries are more likely to have transactions in the same industry, while those in the ceramic, stone and clay products, steel, nonferrous metal, metal products, general machinery, electrical machinery, transportation equipment, and precision and medical instrument industries are more likely to have diverse connections with other industries. Table 4 shows that CRDP participants play a significant role supplying intermediary goods to customers in a variety of manufacturing sectors.

Figure 3 shows the distribution of customer firms by firm size, measured as the average number of employees between 2001 and 2003. Most customers are large firms with more than 300 employees. Therefore, Figure 3 suggests that the CRDP participants tend to supply intermediary goods to larger firms.

Table 5 summarizes the characteristics and performance indicators of the customer firms (treated firms) and the non-customer firms (control firms) measured as the average values between 2001 and 2003. Again, we conducted a Wilcoxon rank-sum test to compare the mean values of the treated and the control firms. Similarly, we find that the treated firms are on average older, larger, more R&D intensive, and more profitable than the control firms before beginning the CRDP, while the latter have higher growth potential in sales, labor productivity, and TFP. Table 5 again suggests the importance of balancing the sub-samples of treated and control firms in order to diminish sampling biases.

5. Estimation results

[9]To check robustness, we conducted the same analyses on the 392 wholesale firms as for the manufacturers. The results are presented in Appendix 1. In sum, the significance levels of the estimators reduced overall, and rent spillovers did not affect labor productivity and TFP growth in the wholesale industry, which implies that there are different mechanisms to create additional value in the manufacturing and wholesale sectors.

5.1. Results of probit regressions

Table 6 shows the estimation results from probit regressions in the first step. We have estimated the probability of participation in the CRDP in Model (1), in which the treated firms are the participants in the CRDP, and the probability of having business transactions with at least one CRDP participant is estimated in Model (2), in which the treated firms are major customer firms of consortia members. As mentioned above, the independent variables used are firm age, the number of employees (in units of 100), the ratio of R&D to sales, ROA, sales growth, labor productivity growth, TFP growth, and industry and regional (prefectural) dummies. These are ex-ante variables for which we take the average values over the period 2001 to 2003, i.e., the period before participation in the CRDP.

The results of the probit regression show that all covariates regarding firm capability have a positive and significant sign in both Models (1) and (2), meaning that older and larger firms and those with higher R&D intensity and ROA have a higher propensity to enter the CRDP and to become customer firms of consortia members. Moreover, we find that technological opportunities (represented by industry dummies) and the regional potential for university-industry research collaboration (represented by prefectural dummies) also affect these propensities. These results are consistent with theoretical predictions. Specifically, as Branstetter and Sakakibara (1998) indicate, we find that the effect of R&D intensity (absorptive capacity) is larger than that of other factors. For example, a 1% increase in the ratio of R&D to sales leads to a 6.5% increase in the probability of participation in the CRDP in Model (1).

In contrast, the variables regarding a firm’s growth potential do not significantly contribute to the propensities, with the exception of labor productivity growth in Model (2). Therefore, we can assume that a firm’s growth potential does not matter in determining whether it participates in the CRDP or has business transactions with consortia members.

The goodness-of-fit indices for the binary probit model are as follows: The Chi-square test of all coefficients (Wald chi2) suggests that all the covariates’ coefficients are significantly different from zero. The Hosmer-Lemeshow goodness-of-fit test supports the appropriateness of the specifications of the probit regressions.

5.2. Test of matching accuracy

Table 7 presents the summary statistics following the matching procedures. Panel A shows the summary statistics of the participants (treated firms) and non-participants (control firms), while Panel B presents the summary statistics of the customers (treated firms) and non-customers (control firms). As mentioned above, we have used three matching algorithms: one-to-one nearest neighbor matching, nearest available Mahalanobis metric matching within calipers, and kernel matching.

This table (Panels A and B) clearly shows that nearest available Mahalanobis metric matching within calipers is the most desirable matching procedure for our sample. As seen in Tables 3 and 5, we find significant differences in the ex-ante characteristics of the treated and the control firms, these, however, totally disappear after the nearest available Mahalanobis metric matching within calipers procedure. In this sense, we have obtained desirably balanced sub-samples through this matching procedure. In contrast, one-to-one nearest neighbor matching and kernel matching are not useful for constructing the matched sample. For example, following kernel matching, firm age, the number of employees, the ratio of R&D to sales, and ROA in Panel A, and firm age and the number of employees in Panel B, are significantly different between the two groups.

Based on these results, we mainly report estimation results using nearest available Mahalanobis metric matching within calipers. It is noteworthy that Table 7 uses PSM for the comparison of sales growth, but we find that nearest available Mahalanobis metric matching within calipers provides a desirably matched sample for the other performance measures.

5.3. Post-matching analysis: Performance comparison

5.3.1. The effects on participants in the CRDP: Knowledge spillovers

Following the matching procedures, we have estimated the ATT with regard to ex-post sales growth, labor productivity growth, and TFP growth in 2007 and 2008. Table 8 summarizes the estimation results of the ATT regarding participants (treated firms) vs. non-participants (control firms). We present the results of estimation based on the three matching algorithms for each performance measure. We first show the results of estimation using the entire sample, and then those from using the sub-samples of SMEs and large firms (those with more than 300 employees).

With regard to participation in the CRDP, we obtain positive and significant signs for almost all variables even with the different matching methods for the entire sample (1). Under nearest available Mahalanobis metric matching within calipers, the value of the ATT for sales growth is 0.032 in 2007 and 0.026 in 2008, meaning that the sales growth of the participants (treated firms) is on average 3.2% (2.6%) higher than that of non-participants (control firms) in 2007 (2008). Furthermore, with regard to labor productivity growth, we find that the participants had on average improved their labor productivity by 7.3% in 2007 and 3.2% in 2008 compared to non-participants. Finally, the participants' TFP growth was also enhanced through their participation in the CRDP. In 2007 (2008) the TFP growth of the participants is on average 8.6% (5.2%) higher than that of the non-participants. The estimation results based on the other matching algorithms also support these effects of the CRDP, but the ATT values are overestimated compared to those found with nearest available Mahalanobis metric matching within calipers. This is because the matching accuracies are not satisfied in one-to-one nearest neighbor matching and kernel matching (Table 7).

These results suggest that participation in the CRDP does improve firms' performance to a larger extent than non-participation. Participants can access the complementary assets owned by other cooperative organizations, such as, rival firms, universities, and public research institutes, through participation in the CRDP, and knowledge generated in the CRDP can be shared among members of the consortia. Knowledge spillovers positively affect the productivity of participants and outcomes produced in the consortia lead to growth in their sales.

By separating the entire sample into sub-samples of SMEs (2) and large firms (3), we find interesting differences between them. All ATT values for SMEs are positive and significant, whereas almost none have significant signs for large firms. Thus, the effect of participating in the CRDP is only clearly confirmed for SMEs[10]. This result is consistent with the policy's aim of supporting innovation by SMEs. One reason that SMEs often become leaders of R&D consortia supported by the CRDP may be that an SME's incentive for and commitment to innovation within R&D consortia is likely to be higher than that of large firms. Another is that the sales growth and productivity growth of large firms may depend on a variety of business divisions, and thus, as the CRDP only relates to a segment of their business it may have a negligible effect on the overall performance of large, diversified firms. Finally, relying on Monjon and Waelbroeck (2003), we also expect that among consortia members large firms tend to be at the scientific frontier, so only marginally benefit, if at all, from knowledge spillovers from local universities.

However, based on these results, we would not suggest that large firms' participation is not necessary in the CRDP, because SMEs may obtain benefits (knowledge spillovers) from interacting with large firms in the consortia. It may seem strange that such large firms participate in R&D consortia, even though they do not obtain significant benefits from spillovers. A possible explanation is that they participate in research consortia in order to maintain good relationships with local universities and public authorities (in the case of publicly funded consortia) for the future.

5.3.2. The effects on customers of consortia firms: Rent spillovers

Table 9 summarizes the ATT estimation results regarding the comparison of the major customers

[10] In Section 3.2 (Figure 2), we find that our population of participants (treated firms) is biased towards larger firms compared to non-participants (control firms). However, this bias will not be a serious problem for our empirical results, because we find that the effect of participation in the CRDP is positive and significant only for smaller consortia members, which suggests downward rather than upward bias in our estimation results.

(treated firms) of consortia firms with the non-customers (control firms). As indicated in Table 7, the matching accuracies of one-to-one nearest neighbor matching and kernel matching are insufficient, and thus the values of the ATT are upwardly biased relative to those with nearest available Mahalanobis metric matching within calipers. Thus, in Table 9, we report the estimation results using nearest available Mahalanobis metric matching within calipers. Regarding the entire sample (1), we again find that almost all values of the ATT are positive and significant: the ex-post growth in sales, labor productivity, and TFP growth of the customer firms are higher than those of the control firms. On average the customer firms have sales growth 3.8% higher in 2007 and 3.1% higher in 2008 than the non-customers. The labor productivity growth of customers is on average 7.6% higher than that of non-customers in 2007. Finally, the TFP growth of customers is on average 7.4% higher than that of non-customers in 2007.

Estimating the ATT for the sub-samples of SMEs (2) and large firms (3), we find that the results differ significantly with firm size. Contrary to the results for the consortia firms, as in Table 8, our results show that the improvement in the performance of customer firms is not confined to SMEs. Rather, we find that large customers receive greater benefits from business transactions with consortia firms. For example, the sales growth of large customers is on average 2.2% (2.1%) higher than that of large non-customers in 2007 (2008). Large customers on average have labor productivity growth 4.7% higher in 2007 and 5.5% higher in 2008, and their TFP growth is greater by 5.2% in 2007 and 4.0% in 2008, compared to large non-customers.

These estimates suggest that the magnitude of spillover effects on firms outside the CRDP is considerable. Our results reported in Tables 8 and 9 imply that the knowledge spillover effects from the CRDP are restricted to SMEs, which then play an important role in generating rent spillovers to business partners[11]. This is because SMEs have a significant role in the production chain of larger firms that use their products as intermediate goods. The degree of rent spillovers may depend on the relative bargaining power between consortia firms and their business customers. In general, we may assume that large customers can obtain better intermediate goods with lower prices, by exerting their stronger bargaining power, than smaller customers. Therefore, the rent spillover effects from the consortia firms are striking as demonstrated by the ATT for large customers. The results also suggest that spillovers from suppliers to customers are mostly constituted of rent spillovers rather than knowledge spillovers; the values of the ATT for SMEs would be significantly positive if knowledge

[11] Using the same procedure (nearest available Mahalanobis metric matching within calipers), we estimated the ATT of the customers transacting with small consortia firms and those transacting with large consortia firms, as compared to non-customers. The estimation results are shown in Appendix 2: we find that the first type of customers receives benefits from rent spillovers, whereas the latter does not.

spillovers were considerable.

5.4. Additional analyses

In this sub-section, we conduct some additional analyses of spillover effects. First, we examine rent spillover effects considering customers' bargaining power and the number of their business transactions. Then, we analyze further (second-tier) rent spillover effects on the customers of the 485 customers firms of the consortia members. Finally, we estimate the cost performance of the CRDP using the empirical results presented in Tables 8 and 9.

5.4.1. Customers' Bargaining power and multiple transactions

Verspagen (1997) expects that rent spillovers may be related not only to the magnitude of trade flows, but also to the market structure in supplying and purchasing industries. Therefore, rent spillover effects may vary according to the relative bargaining power between the consortia firms (suppliers) and their customers. The stronger the bargaining power of a customer firm relative to its supplier, the lower the price of the supplier's product with enhanced quality, and thus the greater rent spillovers the customer may obtain. Moreover, the rent spillover effects on a customer may depend on the number of that customer's suppliers that participate in R&D consortia. The more suppliers participating in R&D consortia and obtaining the associated knowledge spillovers, the greater the rent spillovers a customer of these suppliers may expect from their business transactions.

To examine these ideas empirically, we construct sub-samples of 1) customers with a strong vs. weak bargaining power, and 2) customers transacting with multiple suppliers vs. a single supplier participating in R&D consortia. To identify the customers with strong bargaining power, we first calculate the relative firm size by dividing the number of a customer's employees by the number of its supplier's employees. Then, we define strong (weak) customers as those whose relative firm size is larger (smaller) than the median of the entire sample.

We again use PSM to estimate the ATT using nearest available Mahalanobis metric matching within calipers. These estimation results are shown in Table 10. Regarding bargaining power, the ATT of customers with strong bargaining power are positive and significant, thus they may purchase better intermediate goods with relatively lower prices than other customers, by exerting their stronger bargaining power. In contrast, almost all of the ATT with respect to customers transacting with multiple consortia firms are not significant. Therefore, customer firms' performance does not differ significantly with the number of their suppliers participating in R&D consortia. Not all CRDP participants are successful in developing new products or processes, Failure projects would not generate rent spillover effects for customers. Moreover, we may assume that the structure (e.g. the length and the concentration) of business transactions has more influence on rent spillovers than the number of suppliers engaged in business transactions (Verspagen, 1997).

5.4.2. Rent spillover effects on the second tier

In our sample, we consider 485 major customers of the 584 consortia firms in the manufacturing sector. Some of these 485 (first-tier) customers sell their intermediary goods to other firms in downstream industries (second-tier customers). These second-tier customers may also receive some benefits from rent spillovers generated through the CRDP. That is, CRDP participants produce new products (intermediary goods) that are purchased by the first-tier customers, and the latter increase the quality of their products (intermediary goods) without accordingly enhancing product prices, this then enhances the performance of the second-tier customers of these products. In order to examine the second-tier rent spillover effects, we identify 220 second-tier customers who are the top customers of the 485 first-tier customers in the manufacturing sector. We again adopt PSM to estimate the ATT of second-tier customers (treated firms) compared to non-customers (control firms) using nearest available Mahalanobis metric matching within calipers.

Table 11 presents the ATT estimation results. We find that almost all of the ATT are not significant, which means that there are no rent spillover effects on the second tier. There may be a certain time lag between the participation of a supplier firm in the CRDP and second-tier rent spillovers occurring. Moreover, first-tier customers may adjust prices for new products to fully reflect quality increases; if so, part of the productivity gains made by the innovating industry will not be further transferred to second-tier customers. The rent generated by participation in the CRDP would therefore be shared by the CRDP participants and their customers, according to their bargaining powers.

5.4.3. Cost-benefit analysis

As presented in Tables 8 and 9, we find that the CRDP enhances the performance of its participants and their customers. Using these results, we estimate the impact of the CRDP on the value added by estimating the counterfactual value added that the treated firms would have created if they had not been treated. In addition, we have obtained information on the size of the grants given to each consortium supported by the CRDP. Therefore, we can conduct a cost-benefit analysis based on our estimation. In order to estimate the counterfactual values, we have selected 273 consortia supported by the CRDP for which we have information on the performance of all participating firms (manufacturers). Additionally, we have extracted the information on their customers. Our estimation results suggest that the performance of SMEs participating in the CRDP and their large customers is enhanced. Thus, the final sample we use to evaluate the counterfactual values comprises 100 (104) SMEs participating in R&D consortia supported by the CRDP in 2007 (2008) and 101 (107) of their large customers in 2007 (2008).

Table 12 presents our estimates of the impact of the CRDP. We calculate the counterfactual value added of the SMEs participating in the CRDP (PANEL A) and their large customers (PANEL B). Row (1) shows the average values per firm that were actually observed, Row (2) shows the calculated counterfactual average values per firm based on the estimation results, Row (3) shows the difference between the observed and counterfactual values (i.e., the average impact of the CRDP per firm), Row (4) shows the number of sample firms, and Row (5) shows the total impact of the CRDP. We know that the total sum given in grants to these 273 consortia is 20,948 million yen, while we find that the impact of the CRDP amounts to 7,110 million yen for consortia firms and 162,101 million yen for their customer firms. These results demonstrate that the overall spillover effects from the CRDP are substantial relative to its budget. Thus, our findings show that the CRDP created much larger rent spillovers to firms that are customers of its participants than knowledge spillovers to its participants. The CRDP is cost effective only if we consider the rent spillover effects on the customers of the consortia firms. Hence, we might seriously underestimate the impact of public support for R&D consortia if we ignore rent spillovers from consortia firms through business transactions.

6. Conclusions

This paper examines the spillover effects through government-sponsored R&D consortia empirically using firm-level data and the propensity score method. Focusing on a major public support program for R&D consortia in Japan, we confirm the effectiveness of R&D consortia in improving the performance of participating firms and their customers, although the knowledge spillover effect on participants is limited to SMEs. Previous empirical studies of government-sponsored R&D consortia have ignored the rent spillovers to business partners of consortia members, whereas our results suggest that R&D consortia generate extensive spillover effects benefitting related manufacturing industries. Therefore, it would be problematic to evaluate public R&D support programs, including government-sponsored R&D consortia, without considering rent spillover effects occurring through business transactions.

Several policy implications can be derived from this study. For policymakers, it would be important to take into account the potential rent spillover effects through business transactions of consortia firms when determining which research proposals (or consortia members) should be approved for public support, and when evaluating the outcomes of supported projects. Specifically, policymakers should pay particular attention to the types of customers consortia firms have business relationships with, the kinds of products they plan to develop in the consortia, and who will use the developed products. Doing so would enhance the effect on the productivity of firms outside the R&D consortia[12].

Furthermore, our findings indicate that the effects of knowledge spillovers from R&D consortia are restricted to SMEs, while rent spillovers through business transactions are mainly obtained by large customers with strong bargaining power. This is because SMEs often undertake a significant role in the production chain of larger firms, which use their products as intermediate goods. Therefore, it is beneficial to promote R&D consortia involving SMEs in order to increase the productivity effects on related downstream industries.

To finish this paper, we now mention some of its limitations that future research should address more explicitly. First, we do not examine the effect of R&D consortia on the research performance of universities and public institutes. We expect that university researchers may also receive valuable knowledge flows from research partners, including those in private firms. For example, through collaboration with firms, university researchers would acquire information or ideas regarding the commercial possibilities for their scientific ideas. Therefore, we may have underestimated the effect of R&D consortia as we have ignored the performance of university researchers.

Second, our data may be insufficient to estimate the full effect of the CRDP on firms' performance because of a time lag between participation in the CRDP and the improvement in performance. Our sample period includes the years from 2004 to 2008 due to data constraints. However, as mentioned in Section 4.1, this program provides financial support for R&D consortia for two years, with the goal that at least 30% of the supported consortia achieve commercialization within three years following the funding period. Therefore, we may need data on participation in the CRDP from earlier years in order to comprehensively estimate its effects on firms' performance[13].

Third, we cannot access detailed information on the structure of business transactions. The effect of rent spillovers may depend on the length and concentration of business transactions. For example, the longer a firm has a business transaction with a certain customer, and the more concentrated the firm's business transactions are on that customer, the more likely it is that the firm's investment becomes customer-specific. Hence, the business structure of a firm may affect its bargaining power with its customers, and thus the flow of rent spillovers. Further analysis should more explicitly consider and highlight these limitations. Moreover, as we made clear in Section 3.3, we identify the customers of consortia firms and match them with

[12] As indicated in Griliches (1992), rent spillovers do not mean externalities, because productivity gains are transferred from suppliers to customers through business transactions.

[13] We conducted a robustness check using sub-samples of participating firms in the CRDP between 2004 and 2006 and their customers, thus excluding the participants in 2007 and 2008. We used the same procedures to estimate the ATT. The results are not significantly different from those found using the entire sample between 2004 and 2008. These results are available from the authors upon request.

control firms from the viewpoint of suppliers. Thus, we cannot consider the characteristics of the supplier networks of each customer in the matching procedure.

Last but not least, growth in the sales or productivity of customer firms, relative to control firms, may be partially attributed to knowledge spillovers rather than rent spillovers, if knowledge is transferred from suppliers to customers through mechanisms other than business transactions, such as the personal contacts of researchers. Hence, it might be misleading to regard the entire ATT of customer firms as rent spillover effects. However, it is important for us to estimate the spillovers from consortia firms to their customers, which would mostly comprise rent spillovers.

Despite these limitations, our study contributes to the literature by examining the effect of publicly supported R&D consortia on the performance of both participating firms, through knowledge spillovers, and their major customers, through rent spillovers. Moreover, we consider the factors determining participation in publicly supported R&D consortia and eliminate estimation bias using propensity score matching. More importantly, few empirical studies explicitly compare the spillover effects through R&D consortia on SMEs and large firms, although the former may be expected to benefit more from R&D consortia than the latter. Therefore, the comparison between SMEs and large firms, regarding the spillover effects from R&D consortia, is another of this paper’s contributions.

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Figure 1: Conceptual framework of spillover effects and R&D consortia

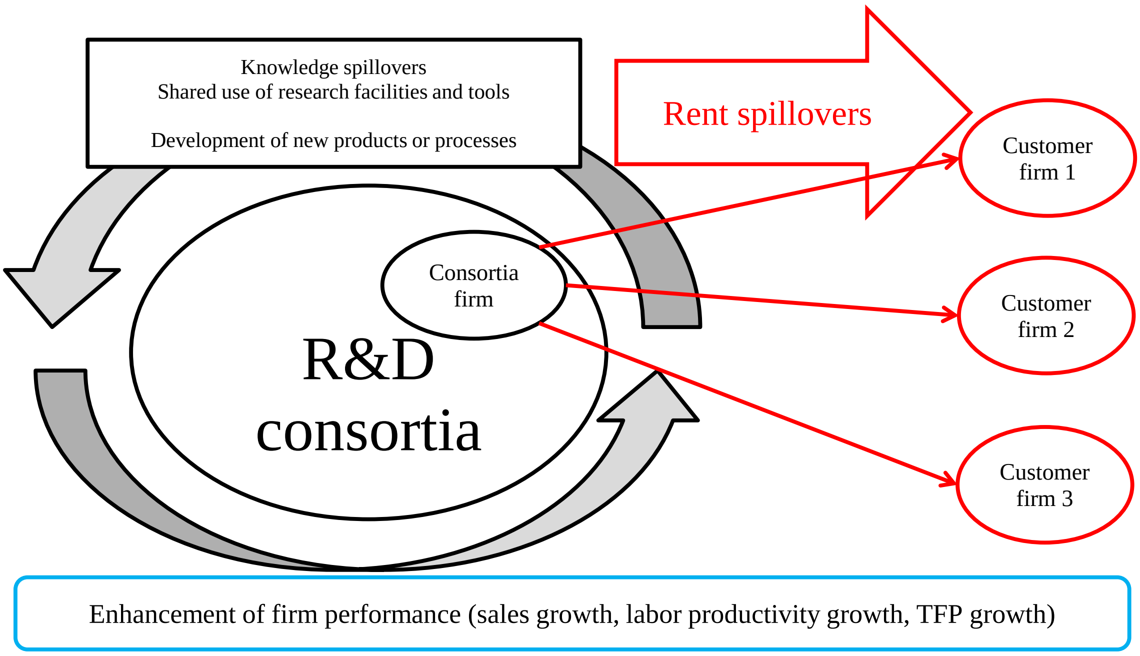

Figure 2: Distribution of participants and non-participants by firm size (the number of employees)

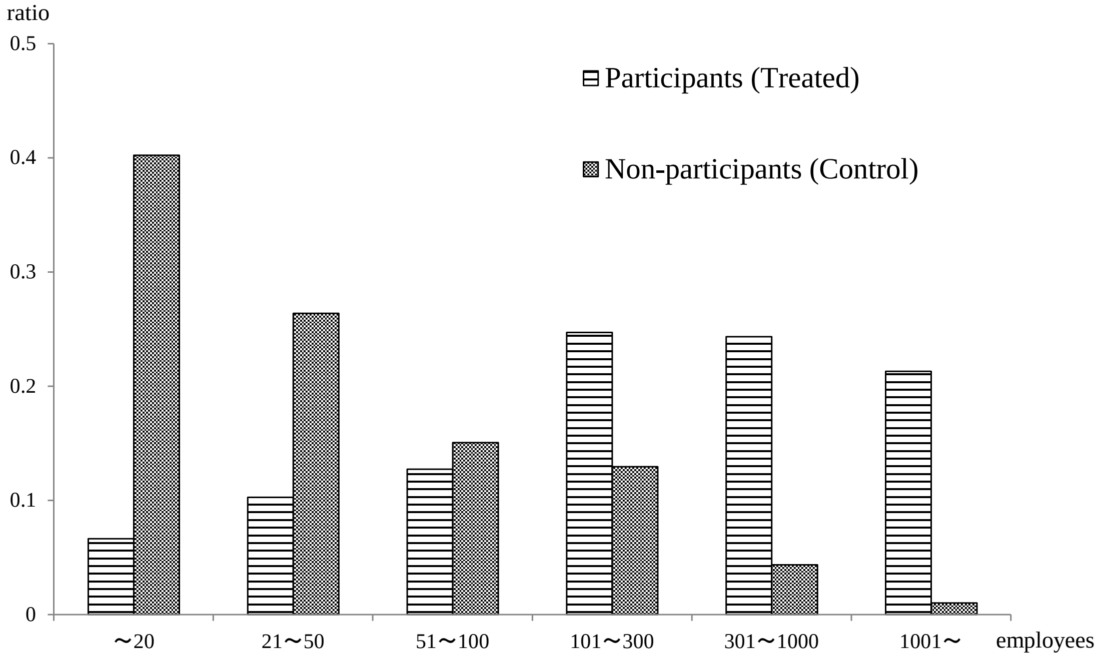

Figure 3: Distribution of customer firms by firm size (the number of employees)

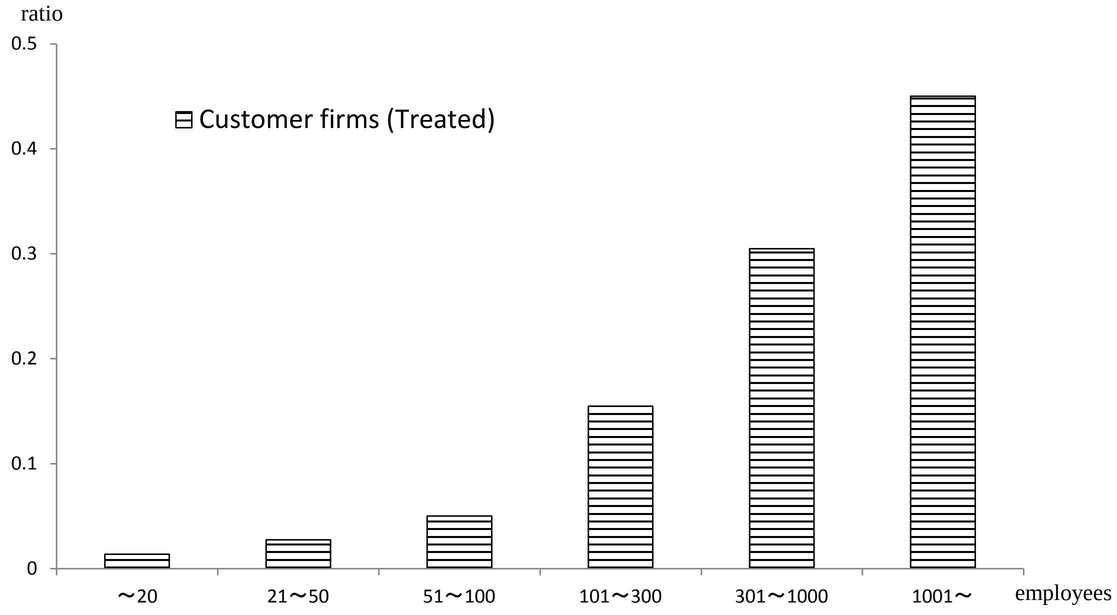

Table 1: Outline of the “Consortium R&D Project for Regional Revitalization” (CRDP)

Program initiator	Ministry of Economy, Trade and Industry (METI)
Concept	CRDP aims at creating new products, processes and businesses for regional economic revitalization, by promoting university-industry-government collaboration.
Support content	METI financially subsidizes R&D projects which aim at creating new products, processes and business services, utilizing the seeds or knowledge owned by university-industry-government.
Subsidized member	University-industry-government R&D consotia: in order to obtain the public subsidy, the R&D consortia have to include at least a university and a firm.
Grant size	50－150 million yen
Support period	Two years
Program goal	At least 30% of the consortia achieve commercialization within three years after the support period.

Table 2: Distribution of the participants and non-participants by manufacturing industry

	Participants (Treated)		Non-participants (Control)	
Manufacturing industries	Freq.	Percent	Freq.	Percent
Weapon manufacture	1	0.00	0	0.00
Food processing	46	0.08	3946	0.10
Tabacco	0	0.00	1	0.00
Textile, except clothing	18	0.03	875	0.02
Clothing and miscellaneous textile products	7	0.01	1174	0.03
Lumber and wood products, except furniture	6	0.01	1283	0.03
Furniture and equipment	5	0.01	1289	0.03
Pulp, paper and paper products	7	0.01	1019	0.03
Publishing, printing and related industries	4	0.01	2359	0.06
Chemical industry	63	0.11	1524	0.04
Petroleum and coal products	2	0.00	177	0.00
Rubber products	9	0.02	403	0.01
Leather, leather products and fur	1	0.00	154	0.00
Ceramic, stone and clay products	26	0.04	2643	0.07
Steel industry and nonferrous metal	36	0.06	1553	0.04
Metallic products	36	0.06	5419	0.14
General machinery	117	0.20	6213	0.16
Electrical machinery and equipment	118	0.20	4065	0.10
Transportation equipment	25	0.04	1281	0.03
Precision instrument and medical instrument	36	0.06	724	0.02
Miscellaneous manufacturing industries	21	0.04	3850	0.10
Total	584	1.00	39952	1.00

Table 3: Summary statistics for participants and non-participants prior to matching

	Participants: Treated			Non-participants: Control			Wilcoxon rank-sum test
	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	
Firm age	584	46.748	21.935	39467	32.845	16.698	***
Employees (100 persons)	526	15.157	46.935	28622	0.882	2.802	***
R&D ratio to sales	412	0.017	0.035	23314	0.003	0.057	***
ROA	526	0.026	0.066	28622	0.018	0.201	***
Sales growth	507	0.049	0.526	23236	0.075	2.963	***
Labor productivity growth	492	0.394	2.174	22101	0.792	19.924	***
TFP growth	492	0.331	2.141	22101	0.742	21.836	***

Note 1: Level of significance: ***1%.

Table 4: Matrix of the numbers of business transactions between consortia participants (suppliers) and their customers classified by manufacturing industry

		Manufacturing sector: Customers																			
Codes	Manufacturing industries: Participants (Suppliers)	20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Total
19	Weapon manufacture															3					3
20	Food processing	14							2												16
21	Tabacco																				
22	Textile, except clothing		5					1	4									1			11
23	Clothing and miscellaneous textile products			1		1			1												3
24	Lumber and wood products, except furniture				1	1												1			3
25	Furniture and equipment				1																1
26	Pulp, paper and paper products						2		1												3
27	Publishing, printing and related industries							2					1				1				4
28	Chemical industry	6					3	1	39	2	1		3	3			2	1	1	3	65
29	Petroleum and coal products																				
30	Rubber products								1		1			2		3	2	6		1	16
31	Leather, leather products and fur											1						1			2
32	Ceramic, stone and clay products				1				4		1		4	8	2	3	7	2	1	1	34
33	Steel industry and nonferrous metal												1	11	4	7	9	11	1	1	45
34	Metallic products								1		1		1	2	7	12	19	7	2	2	54
35	General machinery	3	3						17		1		8	5	11	41	41	16	5	3	154
36	Electrical machinery and equipment	2							6				2		4	20	76	16	3	1	130
37	Transportation equipment								1		3		1	1	1	5		41	1		54
38	Precision instrument and medical instrument								1					1	1	4	11	1	14		33
39	Miscellaneous manufacturing industries	1							4						1	7	11	1	1	3	29

Table 5: Summary statistics for customers and non-customers before matching

	Customers: Treated			Non-customers: Control			Wilcoxon rank-sum test
	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	
Firm age	485	52.973	21.452	39467	32.845	16.698	***
Employees (100 persons)	440	23.316	54.903	28622	0.882	2.802	***
R&D ratio to sales	355	0.020	0.032	23310	0.002	0.019	***
ROA	440	0.032	0.046	28619	0.019	0.102	***
Sales growth	422	0.017	0.127	23236	0.075	2.963	**
Labor productivity growth	414	0.275	1.296	22101	0.792	19.924	***
TFP growth	414	0.200	1.027	22101	0.742	21.836	*

Note 1: Level of significance: ***1%, **5%, *10%.

Table 6: Estimation results of probit regressions in the first step

	(1) Treated: Participants		(2) Treated: Customers	
	Marginal effect	Robust S.E.	Marginal effect	Robust S.E.
Firm age	0.0003***	0.0000	0.0003***	0.0000
Employees (100 persons)	0.0010***	0.0001	0.0008***	0.0001
R&D ratio to sales	0.0650***	0.0185	0.0414***	0.0132
ROA	0.0171*	0.0101	0.0192**	0.0078
Sales growth	−0.0000	0.0000	0.0000	0.0001
Labor productivity growth	0.0001	0.0001	0.0002**	0.0001
TFP growth	−0.0001	0.0001	−0.0004	0.0003
industry dummy	yes		yes	
regional dummy	yes		yes	
N	18766		17209	
Wald chi2 (68)	480.08 (p = 0.000)		570.09 (p = 0.000)	
Pseudo R2	0.241		0.383	
Hosmer-Lemeshow chi2(8)	Number of groups =10 12.19 (p = 0.142)		Number of groups =10 12.81 (p = 0.119)	

Note 1: Level of significance: ***1%, **5%, *10%.

Table 7: Summary statistics after matching

PANEL A	*Nearest available Mahalanobis metric matching within calipers*			*one-to-one nearest neighbor matching*			*Kernel matching*		
Treated: Participants	Mean value			Mean value			Mean value		
Variable	Treated	Control	p value	Treated	Control	p value	Treated	Control	p value
Firm age	49.356	49.089	0.882	49.651	48.720	0.555	50.424	43.042	0.000
Employees (100 persons)	6.742	5.900	0.256	11.280	9.405	0.237	20.341	10.867	0.004
R&D ratio to sales	0.010	0.009	0.781	0.017	0.027	0.189	0.017	0.041	0.027
ROA	0.029	0.030	0.849	0.028	0.019	0.215	0.026	0.008	0.025
Sales growth	0.019	0.011	0.303	0.025	0.013	0.222	0.023	0.045	0.622
Labor productivity growth	0.202	0.161	0.507	0.377	0.473	0.626	0.375	0.451	0.892
TFP growth	0.152	0.124	0.629	0.305	0.311	0.967	0.306	0.411	0.856

PANEL B	*Nearest available Mahalanobis metric matching within calipers*			*one-to-one nearest neighbor matching*			*Kernel matching*		
Treated: Customers	Mean value			Mean value			Mean value		
Variable	Treated	Control	p value	Treated	Control	p value	Treated	Control	p value
Firm age	52.493	52.467	0.988	59.422	60.731	0.392	59.610	52.700	0.000
Employees (100 persons)	6.761	6.635	0.874	19.747	18.381	0.500	27.961	17.491	0.005
R&D ratio to sales	0.006	0.006	0.765	0.020	0.034	0.068	0.021	0.021	0.958
ROA	0.026	0.026	0.925	0.032	0.024	0.151	0.032	0.031	0.640
Sales growth	0.004	0.004	0.997	0.018	0.004	0.130	0.018	0.034	0.722
Labor productivity growth	0.134	0.111	0.705	0.232	0.132	0.158	0.229	0.482	0.643
TFP growth	0.092	0.081	0.840	0.144	0.086	0.232	0.143	0.377	0.663

Table 8: Estimation results of the ATT in the second step: Participants (treated firms) vs. non-participants (control firms)

	(1) entire sample		(2) SMEs		(3) large firms	
	ATT	S.E.	ATT	S.E.	ATT	S.E.
Sales growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.032**	0.012	0.034*	0.019	0.017	0.016
2008	0.026**	0.012	0.038**	0.019	−0.002	0.014
one-to-one nearest neighbor matching						
2007	0.057**	0.020	0.025*	0.013	0.026	0.021
2008	0.057**	0.019	0.048***	0.015	0.036*	0.022
Kernel matching						
2007	0.038***	0.008	0.033**	0.012	0.014	
2008	0.068***	0.010	0.052***	0.014	0.028*	0.015
Labor productivity growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.073**	0.030	0.077*	0.044	0.059	0.043
2008	0.032*	0.018	0.140**	0.070	−0.038	0.043
one-to-one nearest neighbor matching						
2007	0.105***	0.031	0.126**	0.048	0.019	0.047
2008	0.050*	0.035	0.118*	0.063	−0.026	0.050
Kernel matching						
2007	0.072**	0.032	0.125***	0.040	0.053	0.048
2008	0.052*	0.034	0.103*	0.057	0.025	0.043
TFP growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.086***	0.028	0.060*	0.039	0.023	0.106
2008	0.052*	0.027	0.098**	0.038	−0.008	0.045
one-to-one nearest neighbor matching						
2007	0.030	0.031	0.111**	0.045	−0.013	0.043
2008	0.046*	0.026	0.123***	0.036	0.043	0.039
Kernel matching						
2007	0.083***	0.026	0.110**	0.038	−0.014	0.415
2008	0.065**	0.023	0.085**	0.029	0.045	0.034

Note 1: Level of significance: ***1%, **5%, *10%.

Table 9: Estimation results of the ATT in the second step: Customers (treated firms) vs. non-customers (control firms)

	(1) entire sample		(2) SMEs		(3) large firms	
	ATT	S.E.	ATT	S.E.	ATT	S.E.
Sales growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.038**	0.016	0.024	0.037	0.022**	0.010
2008	0.031**	0.015	0.036*	0.021	0.021*	0.013
one-to-one nearest neighbor matching						
2007	0.083***	0.016	0.034	0.027	0.083***	0.018
2008	0.086***	0.014	−0.018	0.024	0.115***	0.019
Kernel matching						
2007	0.074***	0.013	0.031*	0.019	0.074***	0.014
2008	0.064***	0.011	0.030*	0.018	0.124***	0.015
Labor productivity growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.076**	0.027	−0.118	0.102	0.047*	0.030
2008	0.027	0.031	−0.002	0.098	0.055*	0.035
one-to-one nearest neighbor matching						
2007	0.133***	0.040	0.074	0.061	0.125**	0.049
2008	0.043*	0.029	−0.011	0.068	0.066*	0.034
Kernel matching						
2007	0.111***	0.034	0.057	0.047	0.107**	0.045
2008	0.028	0.301	−0.039	0.046	0.076**	0.032
TFP growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.074***	0.023	0.003	0.082	0.052*	0.034
2008	0.030	0.029	0.090	0.092	0.040**	0.017
one-to-one nearest neighbor matching						
2007	0.102**	0.035	0.056	0.051	0.122***	0.034
2008	0.029	0.030	0.037	0.048	0.038	0.030
Kernel matching						
2007	0.096***	0.029	0.060*	0.043	0.104***	0.030
2008	0.018	0.025	0.020	0.045	0.046*	0.026

Note 1: Level of significance: ***1%, **5%, *10%.

Table 10: Estimation results of the ATT regarding bargaining power and multiple transactions

	customers with strong bargaining power vs. customers with weak bargaining power		customers with multiple transactions vs. customers with a single transaction	
	ATT	S.E.	ATT	S.E.
Sales growth				
2007	0.071***	0.023	0.042*	0.026
2008	0.032*	0.019	−0.020	0.016
Labor productivity growth				
2007	0.113**	0.056	−0.016	0.065
2008	0.031	0.048	−0.101	0.072
TFP growth				
2007	0.111**	0.053	−0.064	0.060
2008	0.051	0.049	−0.081	0.078

Note 1: Level of significance: ***1%, **5%, *10%.

Table 11: Estimation results of the ATT regarding second-tier rent spillover effects

	second-tier rent spillover effects on the top customer of 485 customers	
	ATT	S.E.
Sales growth		
2007	0.038*	0.023
2008	−0.005	0.012
Labor productivity growth		
2007	0.488	0.433
2008	−0.157	0.116
TFP growth		
2007	0.456	0.467
2008	−0.192	0.216

Note 1: Level of significance: *10%.

Table 12: Estimates of the impact of the CRDP (million yen)

PANEL A: SMEs participants	Value added		
	2007	2008	Total
(1) Observed average value per firm	331	318	648
(2) Counterfactual average value per firm	307	271	578
(3) Average impact of the CRDP per firm ((1)−(2))	24	46	70
(4) Numbers of sample firms	104	100	—
(5) Total impact of the CRDP ((3)×(4))	2477	4633	7110

PANEL B: Large customers	Value added		
	2007	2008	Total
(1) Observed average value per firm	15484	15219	30703
(2) Counterfactual average value per firm	14779	14360	29139
(3) Average impact of the CRDP per firm ((1)−(2))	704	859	1563
(4) Numbers of sample firms	107	101	—
(5) Total impact of the CRDP ((3)×(4))	75369	86732	162101

Appendix 1: Estimation results of the ATT in the wholesale sector: Customers (treated firms) vs. non-customers (control firms)

	(1) entire sample		(2) SMEs		(3) large firms	
	ATT	S.E.	ATT	S.E.	ATT	S.E.
Sales growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.030**	0.013	0.036*	0.019	0.030**	0.013
2008	0.025*	0.015	0.032	0.027	0.021*	0.013
one-to-one nearest neighbor matching						
2007	0.033*	0.019	0.037*	0.021	0.038**	0.016
2008	0.007	0.016	0.024	0.026	0.021	0.022
Kernel matching						
2007	0.019*	0.012	0.011	0.014	0.028*	0.015
2008	0.013	0.011	0.011	0.015	0.006	0.015
Labor productivity growth						
Nearest available Mahalanobis metric matching within calipers						
2007	0.061*	0.039	0.124*	0.069	0.005	0.037
2008	−0.113	0.158	−0.014	0.044	0.020	0.036
one-to-one nearest neighbor matching						
2007	0.068*	0.035	0.085	0.080	0.024	0.040
2008	−1.627	1.223	−0.053	0.113	−0.386	0.423
Kernel matching						
2007	0.036*	0.023	0.062	0.056	0.007	0.033
2008	−1.340	3.714	−1.562	1.094	−0.394	0.416
TFP growth						
Nearest available Mahalanobis metric matching within calipers						
2007	−0.156	0.527	0.736	0.524	−0.097	0.134
2008	−0.100	0.159	0.009	0.079	0.088	0.092
one-to-one nearest neighbor matching						
2007	−0.241	0.504	0.607	0.461	−0.396	0.330
2008	−1.317	1.221	0.058	0.085	−0.360	0.410
Kernel matching						
2007	−0.226	0.299	0.161	0.465	−0.254	0.297
2008	−1/138	3.608	−1.487	1.063	−0.211	0.403

Note 1: Level of significance: **5%, *10%.

Appendix 2: Estimation results of the ATT: Customers transacting with small consortia firms and those transacting with large consortia firms, compared to non-customers

	Customers transacting with small consortia firms		Customers transacting with large consortia firms	
	ATT	S.E.	ATT	S.E.
Sales growth				
2007	0.035**	0.017	0.021	0.018
2008	0.027*	0.017	0.018	0.018
Labor productivity growth				
2007	0.135***	0.038	0.064	0.046
2008	0.019	0.036	−0.001	0.048
TFP growth				
2007	0.118**	0.048	0.053	0.060
2008	0.039	0.035	−0.015	0.098

Note 1: Level of significance: ***1%, **5%, *10%.