Quantitative Policy Analysis of Innovation Activities: Application to Dynamic Structural Estimation*

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Abstract

This paper estimates a dynamic oligopoly model of product innovation and proposes an approach to evaluate an equilibrium effect of public policy on firm's innovation activities. The model considers a multi-agent Markov-Perfect Nash Equilibrium, allowing for firm's dynamic decision making on innovation activities, and its entry and exit. The estimation results obtained by use of Japanese firm-level data on product innovation identify net positive spillovers among firms' dynamic innovation activities.

Keywords: Product innovation; Spillovers; Dynamic oligopoly model; Markov perfect equilibrium; Subsidies; Innovation survey

JEL classification: C73; L13; O31; O38

I. Introduction

In view of tight state finances in many developed countries including Japan, more attentions have been placed upon private-sector innovation. In particular, product innovation is an important topic of policy discussion, as some of recent theoretical and empirical results show its economic significance.[1]

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[1] Recent studies on the endogenous growth theory (e.g. Grossman and Helpman, 1991, Aghion and Howitt, 1992, Klette and Kortum, 2004) position firm's product innovation as the engine for economic growth. Moreover, in literature on the product life cycle (PLC), Klepper (1996) shows that product innovation has a crucial role in the early stage of the PLC. As for empirical research, some of new econometric studies taking advantage of innovation surveys estimate the economic impact of firm's product innovation. For example, Crépon et al. (1998) and their variants indicate that sales of new products are associated with the firm's high productivity or profitability.

Since Arrow (1962), it has been pointed out that a firm cannot obtain full benefit from its new products or new processes due to technological spillovers in innovation, which leads to undersupply of private-sector innovation. In contrast, firm's innovation can also have a negative spillover effect if the innovation results in taking a customer away from its rival firms (Bloom et al., 2010). Moreover, firms' dynamic interdependence[2] is closely associated with the spillovers in innovation. An innovation achieved by a firm can act on its rivals' innovation activities, which changes their profit. In discussing innovation policy issues, we need a comprehensive analysis of firm's innovation activities by taking into consideration of these complexly entangled elements of innovation spillovers.

Our goal is to quantify the spillover effects of firm's product innovation activities by using Japanese firm-level data and to estimate the economic impact of an innovation-related policy based on the quantification. Specifically, we focus on public financial supports for firm's innovation activities in a form of subsidies. It is almost impossible to conduct a rigorous policy evaluation with a reduced form analysis (e.g. difference-in-differences analyses) in an environment like Japan where the government implements uniform policies throughout the country. We propose a two-step approach that overcomes this problem. First, we construct a dynamic oligopoly model of firm's decision making including that on product innovation, and estimate the primitive parameters of the model. This step enables us to quantify the net spillover effects of firm's product innovation. Second, we conduct simulation exercises to evaluate the effect of current public financial support with subsidies by considering the complex nature of innovation spillovers and of firms' dynamic interdependence. In this paper, we report the estimation results of the first step and present the simulation procedure of the second step.

The estimation results suggest that there exist technological spillovers in firm's product innovation, whose effects are estimated to be greater than those of negative spillovers due to increased competition in the product market. The existence of the net positive spillover effects is a necessary condition for the validity of public financial support.

The rest of this paper is organized as follows. Section II overviews the features of firm's product innovation with our data. Section III describes the dynamic oligopoly model used for the structural estimation, which is a variant of Ericson and Pakes (1995) or Doraszelski and Satterthwaite (2010). Section IV introduces our estimation procedure based on Bajari, Benkard and Levin (2007) and reports the estimation results. Section V presents the simulation procedure for the policy evaluation. Section VI concludes.

II. Firm's Product Innovation in Japan

This section reviews the current situation of firm's product innovation in Japan. Our

[2] Some of past empirical studies (e.g. Finger, 2008, Goettler and Gordon, 2011, Hashmi and Biesebroeck, 2010, Xu, 2006) stress dynamic and strategic properties of firm's innovation activities.

main data source is a Japanese innovation survey,[3] Japanese National Innovation Survey 2009 (hereafter JNIS2009) conducted by the National Institute of Science and Technology Policy (NISTEP) under the jurisdiction of the Ministry of Education, Culture, Sports, Science and Technology. This is a questionnaire survey targeting private firms in Japan on their activities for three years from April 1st 2006 to March 31th 2009. The study population is the group of 331,037 firms with more than ten employees in the agriculture, forestry and fisheries industry, the mining and manufacturing industry, the construction industry, and a part of the service industry. Of the population, 15,871 firms are selected with stratified sampling based on firm size and industry, and 4,579 firms of them answer the survey corresponding to a response rate of 30.3%.

JNIS2009 defines innovation activity as "firm's efforts including designing, R&D investment and market research intended to create innovative products or to develop new processes for business improvement," and regards product innovation and process innovation as its outcome. Product innovation, which is a focus of this paper, is also defined in JNIS2009 as follows.

Product innovation

Product innovation is defined as a release of new goods or new services. They include not only goods or services with new functions, performance, designing, primary materials, components and intended purposes, but also ones created by combining existing technologies or by advancing technologies used in existing goods or existing services. In this regard, however, product innovation excludes redesign of goods or services without changing their functioning or intended purposes, and sales or provision of other firms' goods or services.

We can compare the result of JNIS2009 with that of innovation surveys in other countries because JNIS2009 is conducted based on the Oslo Manual, which is the standardized guideline for innovation surveys. To begin with, we overview the current status of firm's product innovation in Japan from a global standpoint[4] by using *Innovation in Firms* (OECD, 2009).

We need to keep three points in mind in interpreting the results obtained from the international comparison. First, there are some variations in the survey period among countries. For most of countries participating in *Innovation in Firms*, international

[3] The Nordic Fund for Industrial Development proposed the development of standardized guidelines for surveying firm's innovation activities to the OECD in 1988, which was subsequently published as the Oslo Manual in 1992. The latest version of the Oslo Manual was published in 2005 (3rd edition). In parallel, the Eurostat developed normative survey techniques and survey sheets based on the Oslo Manual, many innovation surveys following them have been conducted so far in about 50 countries including those in EU, South America and Asia. See NISTEP (2010) for details of JNIS2009.

[4] See Nishikawa and Ohashi (2010) for detailed international comparison.

comparison rests on the result of CIS-4 (Community Innovation Survey-4) covering 2002-2004.[5] Since JNIS2009 targets later periods,FY2006-FY2008, we put down with the result of JNIS2003 covering 1999-2001. Second, it is difficult to eliminate subjective elements from measuring innovation, which is a common problem for innovation surveys based on the Oslo Manual. The word "innovation" can sound differently by each country.[6] Or the degree of technological progress can affect how innovation is recognized. Third, the distribution of firm size and industry in the sample varies by country. For this reason, we adjust the distribution with weighted sampling introduced in Little and Rubin (1986).

The left side of Figure 1 summarizes the share of firms with product innovation by country. Japan ranks 14th among 15 countries[7] with 20.3%, and it is hard to say that Japan is of a high level in terms of innovation achievement. However, the share modestly increased between JNIS2003 and JNIS2009.

The right side of Figure 1 shows the percentage of R&D expenditures financed by the government in each country. Here, we use the percentage for 2009 obtained from *Main Science and Technology Indicators* (OECD, 2012).[8] The percentage is relatively low in Japan, which implies that public sector involvement is limited.

Figure 1 indicates that there is much room for public support encouraging firm's product innovation activities from international perspectives. However, it is largely dependent on the existence of spillover effects of firm's innovation activities whether or not such policy intervention could work well. It is widely known that private firms undersupply innovation with positive spillovers in their product innovation. Hence, for justifying the policy intervention, we need to quantitatively show that product innovation supplied by the private sector is less than the social optimum.

In keeping with this argument, the rest of this section is organized as follows. Section II-1 discusses the existence of technological spillovers in innovation, which is implied by JNIS2009. Here, we also take a look at firm's strategic interdependence. Section II-2 reports the current state of public financial support for firm's innovation activities observed in JNIS2009. Finally, Section II-3 points out the limitations of discussing spillovers in innovation and policy issues only with these descriptive statistics. In the following sections, we propose a structural estimation approach overcoming these limitations.

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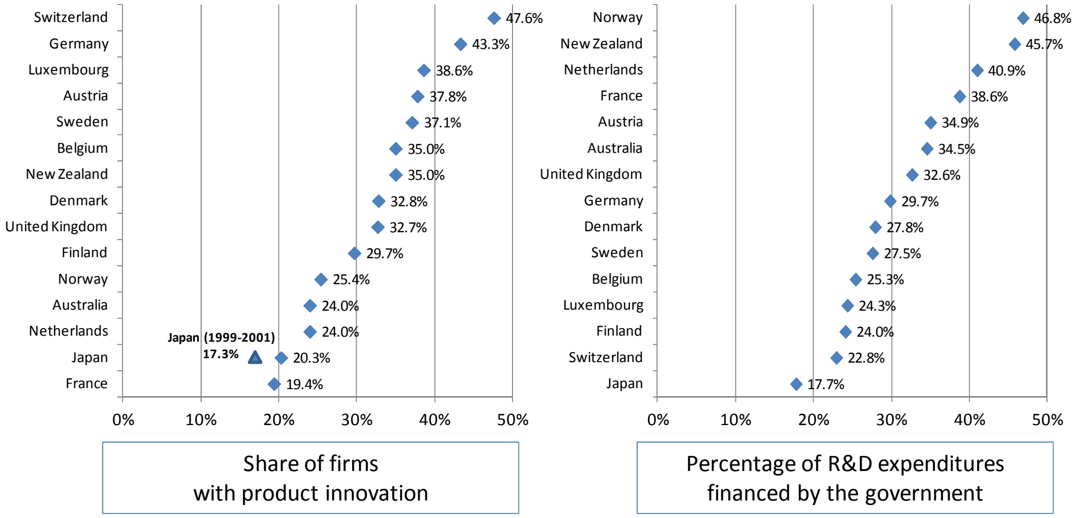
[5] The survey period is 2003-2005 in Switzerland and 2004-2005 in Australia and New Zealand. Germany has surveyed firm's innovation activities every year since 1993, which becomes the basis for a panel dataset.

[6] After JNIS2009, NISTEP conducts the comparative survey regarding the perception of "innovation" in Japan, USA and Germany, which shows that citizens of Japan are less likely to recognize concrete cases as innovation compared with those of USA and of Germany.

[7] Italy, Czech Republic and Brazil do not report the share while they participate in *Innovation in Firms*.

[8] For Australia and Switzerland, we use the share for 2008.

Figure 1
Product Innovation and Public Support



II-1. Spillovers in firm's product innovation

It has been a much-debated in economics both from a theoretical and empirical point of views whether there exist spillovers in innovation activities conducted by private firms. In particular, many researchers stemming from Arrow (1962) indicate the existence of technological spillovers, which means that technologies spilled out of an innovator benefit others, and there are huge quantities of empirical studies intended to estimate the economic impact of them qualitatively or quantitatively.[9] Here, by focusing on new-to-market product innovation,[10] we draw some implications about the technological spillovers from JNIS2009.

Figure 2 summarizes firm's technology provision and acquisition in JNIS2009. Circles in the figure represent the percentage of technology provision (or acquisition) for firms with new-to-market product innovation relative to that with new-to-firm product innovation by channel. On the other hand, snow marks in the figure do the percentage of technology provision (or acquisition) for firms with large-sales product innovation relative to that with small-sales product innovation.[11]

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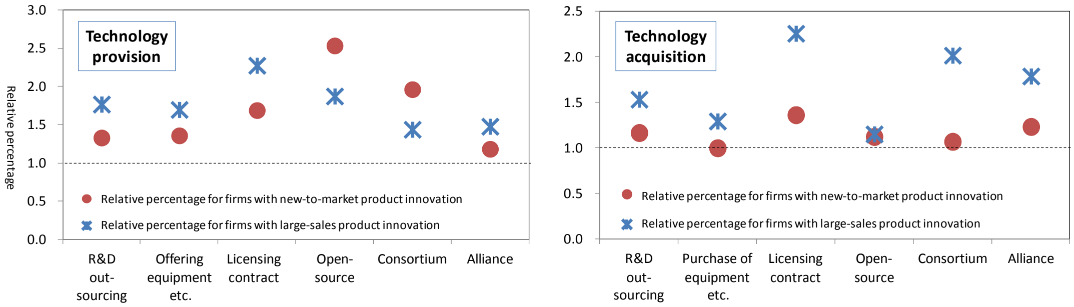
[9] Representative examples are studies estimating the social rate of return to R&D investment, which are discussed in Griliches (1992).

[10] OECD (1992, 1996, 2005) classifies firm's product innovation into two types, "the introduction of a product only new to the firm (new-to-firm product innovation)" and "the introduction of a product new to the market (new-to-market product innovation)." According to JNIS2009, 41.7% of product innovators achieve new-to-market product innovation.

[11] We define large-sales product innovation as the introduction of a new product whose sales exceed 168 million JPY, which is the median value of the sales. We also define small-sales product innovation vice versa.

Figure 2
Technology Provision and Acquisition

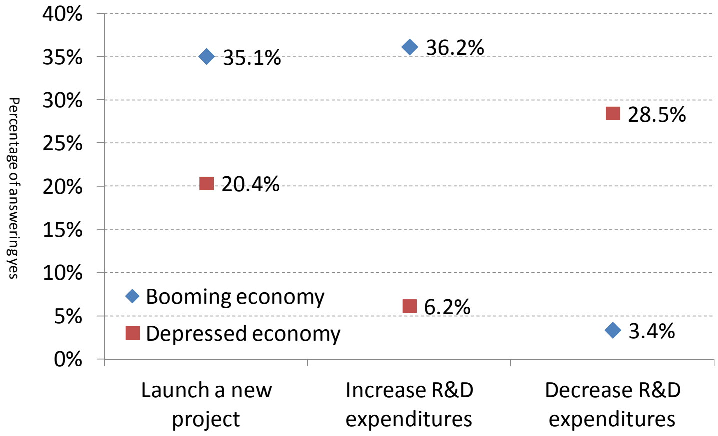


The left side of Figure 2 is for firm's technology provision. While large-sales product innovation is especially associated with licensing, new-to-market product innovation is more likely to bring technology provision through such as open sourcing or participation in consortia. It is typical of licensing that a technology provider can easily get paid for the technology that increases acquirer's profit. In other words, licensing enables the technology provider to internalize others' benefit from its technology with monetary consideration. In contrast, open sourcing or participation in consortia has a lower incidence of monetary consideration, which makes such internalization difficult. Therefore, the left side of Figure 2 may be said to show that new-to-market product innovation tends to produce technological spillovers less likely to be internalized.

The right side of Figure 2 is for firm's technology acquisition. New-to-market product innovation seems not to be linked to technology acquisition so much. On the other hand, firms with large-sales product innovation are more likely to acquire technology through licensing or participation in consortia. In particular, we can associate technology acquisition through consortia with technology provision. It is possible that a firm with new-to-market product innovation provide its technologies through channels such as open sourcing or consortia without the internalization, which in turn increase other firms' sales. This observation is consistent with the view that new-to-market product innovation produces positive spillovers in technology transactions.

Theoretically, it is pointed out the spillovers in firm's activities lead to its strategic decision making (Vives, 2009). In the context of this paper, it is possible that firm's decision on its innovation activities strongly depends on rivals' innovation achievement with some spillovers in product innovation. In fact, the result of JNIS2009 indicates the existence of such strategic interdependence of firms' innovation activities. JNIS2009 contains questions about how a firm would respond to its rival's achievement of product innovation. To be more precise, we focus on three questions about whether it would launch a new innovation project, whether it would increase R&D expenditures, and whether it would decrease R&D expenditures. Figure 3 shows the share of firms answering yes to each question depending on fictitious economic situations.

Figure 3
Response to Rival's Achievement of Product Innovation



In the case of booming economy, more than a third of firms launch a new innovation project and increase R&D expenditures whereas firms decreasing R&D expenditures are very few, 3.4%. Even though it is stated preference data, this result is consistent with the hypothesis that a firm aggressively conducts innovation activities in response to its rivals' innovation achievement for the purpose of enjoying technological spillovers. Note that the result for depressed economy is somewhat different. While the percentage of firms launching a new innovation project is not so low, 20.4%, that of firms decreasing R&D expenditures far exceeds that of increasing firms.[12]

II-2. Public financial support and firm's product innovation

It is well known that a private firm does not have an incentive to provide the socially optimal degree of product innovation with positive spillovers in firm's innovation activities. In response to this, policy intervention in private sector innovation, which tends to be undersupplied, can be justified. However, it is an empirical issue to be quantitatively examined whether current policies are optimally implemented, and if not, how they should be changed. Here, as a preliminary step for rigorous analyses based on the structural estimation discussed in the following sections, we examine the statistical relationship between public financial support and new-to-market product innovation.

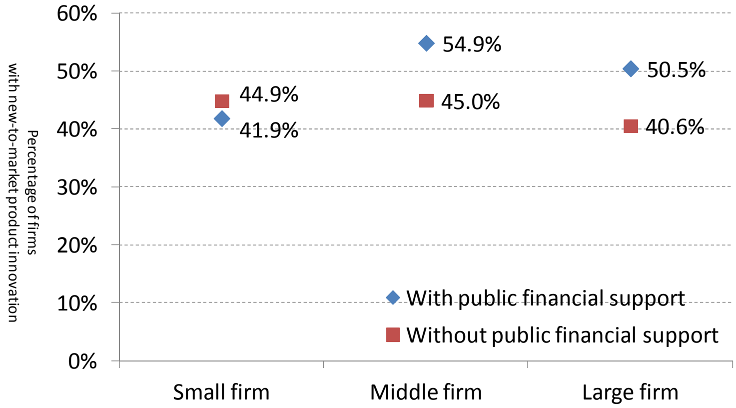
JNIS2009 defines public financial support as financing help provided by local

[12] This result might imply that a firm cannot enjoy positive spillovers during a time of economic recession. Ideally, we should take macro economic conditions into consideration in discussing innovation policy. In this paper, however, we make no further attempt to deal with this matter and leave it as a future challenge. In our estimation discussed in Section 4, we simply use the average percentage for booming economy and depressed economy.

governments[13] or by the central government[14] in the form of tax credits, subsidies, loan guarantees and so on. In particular, we pick up subsidies for firm's innovation activities in Section V.

Figure 4 shows the share of firms with new-to-market product innovation with and without public financial support by firm size.[15] Middle and large firms with public financial support are more likely to achieve new-to-market product innovation than ones without, which is interpreted that public intervention boosts the supply of new-to-market product innovation and resolve the undersupply problem in any way. On the other hand, we cannot find a positive correlation between public financial support and new-to-market product innovation for small firms.[16]

Figure 4
Public Financial Support and New-to-market Product Innovation



II-3. Structural estimation approach

In this section, we have overviewed some descriptive statistics consistent with the view that there are positive spillovers in firm's product innovation and public financial support

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[13] Local governments include prefectural and municipal governments and institutions taking on their duty.

[14] The central government includes government ministries and independent administrative institutions, government-affiliated corporations or authorized corporations taking on their duty such as the Japan Science and Technology Agency (JST), New Energy and Industrial Technology Development Organization (NEDO) and the Organization for Small & Medium Enterprises and Regional Innovation, JAPAN (SME Support, JAPAN).

[15] A small firm, a middle firm and a large firm are respectively defined as one with less than 50 employees, one with 50 or more but less than 250 employees and one with more than 250 employees.

[16] Nishikawa et al. (2010) point out that small firms seldom use information from universities and patent information in conducting innovation activities, which are important determinants of new-to-market product innovation. Hence, it is considered that such non-financial constraint prevents public financial support from creating new-to-market product innovation for small firms.

encourages firm's innovation activities except for small firms. However, we should not conclude that public financial support effectively complements private sector product innovation only with descriptive statistics. We identify three major issues.

First, the discussion in this section does not fully include the complex nature of innovation spillovers. Whereas the result of Figure 2 indicates the existence of technological spillovers, we do not capture a negative spillover effect by taking a customer away from innovator's rivals. In addition, firms' strategic interdependence shown in Figure 3 is also connected to innovation spillovers. In order to justify public financial support, we have to identify *net* positive spillover effects including all these factors, which requires a comprehensive analysis of firm's innovation activities.

Second, some kind of comparative measure is required for a quantitative policy evaluation. For evaluating public financial support, we need to consider not only whether it encourages firm's innovation activities, but also whether it increases its economic value. It is necessary for such an analysis to identify economic incentives behind firm's innovation activities.

Third, it is unclear with what the current innovation policy is compared in this section. Figure 4 makes a comparison between firms with public financial support and ones without, which is an idea in common with program evaluation approaches (e.g. Almus and Czarnitzki, 2003, González et al., 2005). However, given the existence of spillovers and strategic interdependence in firms' innovation activities, such an approach is inappropriate because a firm without public financial support can be indirectly influenced by that. Therefore, a meaningful evaluation of public financial support requires, as a target for comparison, the hypothetical situation where no one receives the support.

In order to deal with all these issues, the following sections adopt a structural estimation approach. Section III presents a dynamic oligopoly model capturing innovation spillovers and firms' strategic interdependence. Then, Section IV estimates the model primitives for identifying economic incentives behind firm's innovation activities, which also enables us to quantify *net* positive spillover effects. Finally, Section V introduces a simulation procedure for evaluating the existing public financial support by considering the complex nature of innovation spillovers. We can simulate the counterfactual situation where no one gets public financial support, which is compared with the current one. A structural estimation approach has an advantage of being able to conduct this kind of policy analysis.

III. A Dynamic Model of Firm's Innovation Activities

This section describes a model used to explain firm's innovation activities. We take into consideration spillovers and strategic interdependence in the activities discussed in the previous section, and consider a multi-agent Markov-Perfect Nash Equilibrium. The model also incorporates firm's entry and exit for capturing the dynamic properties of its decision-making.

In what follows, Section III-1 shows the timing of the game introducing state variables and their transition in the model. In addition, we position our modeling of technological spillovers in the existing literature. We then discuss the detail of the model in the remaining sections.

III-1. Overview of the Model

This paper builds on a dynamic oligopoly model capturing spillovers and dynamic interdependence in firms' innovation activities that is a variant of Ericson and Pakes (1995) or Doraszelski and Satterthwaite (2010).

A market here is defined as a set of firms competing on a specific product.[17] There are M independent markets, denoted by m=1,…, M, each with $n_{m,t}$ incumbents at period t. We restrict a firm to behave independently across markets and drop subscript m in what follows. Each market is fully described by a vector of the commonly observed variables, s_t. This state vector includes the number of incumbents, n_t, and a vector of innovation achievement, I_t, whose i-th component is an indicator, $I_{i,t}$, taking the value of 1 if firm i achieves product innovation at period t.

At period t, given state s_t, each incumbent makes decisions on exit and on innovation activities. At the beginning, firm i obtains its per-period profit, $\pi_i(s_t)$, and observes its private subsidy status and its private scrap value. The subsidy status is denoted by an indicator, $sub_{i,t}$, taking the value of 1 if firm i receives public financial support for its innovation activities. On the other hand, the scrap value, $\sigma_\varepsilon\varepsilon_{i,t}$, represents a payoff that firm i receives if it exits from the market. Based on this set of information, firm i decides whether to exit from the market. The exit decision is denoted by $\chi_{i,t}$, which is an indicator taking the value of 1 if firm i exits.

If firm i decides to remain in the market at period t, it additionally observes its private innovation cost, $C(sub_i) + \sigma_v(sub_i)v_{i,t}$, which is incurred for its innovation activities.[18] We allow the distribution of the innovation cost to depend on firm's subsidy status because a subsidized firm is expected to incur less out-of-pocket expenditures for the same innovation activities. With this additional information, firm i decides whether to conduct innovation activities, denoted by an indicator, $d_{i,t}$, taking the value of 1 if firm i conducts innovation activities. It is assumed to take one period that innovation activities result in product innovation.[19] Innovation activities stochastically determine the following innovation achievement, $I_{i,t+1}$, and influence its per-period profit at the next period. Each

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[17] This definition is consistent with JNIS2009, which asks about firm's product innovation after specifying a product provided by the firm.

[18] Hashmi and Biesebroeck (2010) is a recent example of empirical studies considering such innovation cost.

[19] We set one period to three years reflecting the characteristics of firm's innovation activities in Japan. Fujimoto and Yasumoto (1998) estimate that average time between firm's product development and its release is 41.03 months.

firm compares this expected profit changes with its innovation cost in the decision-making.

We assume that the privately observed variables, $(sub_{i,t}, \varepsilon_{i,t}, v_{i,t})$, are drawn independently from each other and over time. This is because otherwise each firm would need to infer its rivals' private state by reference to their all past action and the number of state variables would drastically increase. In this regard, however, we allow the probability of subsidized to depend on its publicly observed state, $s_{i,t} \equiv (n_t, I_{i,t})$, which approximates a selection procedure of subsidy recipients by public institutions.[20]

At the same time, there is also a pool of ex-ante identical potential entrants. To enter a market, an entrant must incur time-independent stochastic entry cost, C^e_t. Given the market state, each potential entrant compares its expected entry value with the entry cost, and decides whether to become a new incumbent at the next period. Let e_t be the number of potential entrants that actually decide to enter the market. We assume that they do not conduct innovation activities upon entry.

Each incumbent and each potential entrant simultaneously makes decisions without knowing others' ones. In summary, the timing of the game at period t is as follows.

1. Each incumbent obtains its per-period profit, $\pi_i(s_t)$.
2. Each incumbent privately observes its subsidy status, $sub_{i,t}$, and an idiosyncratic scrap value, $\sigma_\varepsilon \varepsilon_{i,t}$. It decides whether to exit from the market, and receives the scrap value if it exits.
3. If not exiting, an incumbent then privately observes its innovation cost, $C(sub_{i,t}) + \sigma_v(sub_{i,t})v_{i,t}$, and decides whether to conduct innovation activities. It incurs the innovation cost if it conducts innovation activities.
4. Each potential entrant observes stochastic entry cost, C^e_t. and decides whether to enter the market.
5. The number of incumbents changes due to entry and exit. Furthermore, the following innovation achievement for each of new incumbent, $I_{i,t+1}$, is determined. While a remaining incumbent achieves product innovation based on its innovation activities at period t, a potential entrant deciding to enter the market becomes a new incumbent j with $I_{j,t+1}=0$.

III-1-1. Relationship between innovation activity and product innovation in this paper

This paper distinguishes between firm's innovation activities, $d_{i,t}$, and the achievement of product innovation, $I_{i,t}$. On firm's innovation activities is firm's decision to be made, and product innovation is the stochastic outcome of that. Because of a time lag between

[20] It is perfectly possible that firm's characteristics other than its publicly observed state here also affect the probability of subsidized. In order to check whether this omission affects the result of this paper, we additionally estimate the model with subsamples created by dividing the original sample based on firm's characteristics such as firm size and age. These results are not qualitatively different from that of this paper.

innovation activity and innovation achievement, this paper does not directly associate firm's innovation activities with its product innovation in the same time period, which is the survey period of JNIS2009. In other words, firm's observed innovation activities are assumed to be conducted not for product innovation captured in JNIS2009 but for future product innovation.[21]

In our model, firm's innovation activities are linked to its product innovation from two aspects. One is the effect of firm's product innovation already achieved on its (additional) innovation activities. The model includes firm's own innovation achievement as one of state variables, and incumbent's policy function is a mapping from the achievement to its innovation activities in a Markov-Perfect Nash Equilibrium, which is discussed in Section III-4. Hence, the two things are naturally related from the aspect of firm's decision making. In estimation, we associate firm's observed product innovation with its innovation activities, which derives its policy function as we discuss in Section IV-1-2 (1).

Another one is the success probability of product innovation, which determines whether a firm conducting innovation activities can achieve product innovation at the following period. Because it is hard to imagine that all firms conducting innovation activities achieve innovation,[22] the success probability plays a significant role in determining the transition of state variables in a dynamic environment. We have to capture the relationship between firm's innovation activities and its *future* product innovation in estimating the success probability, which is discussed in Section IV-1-2(2).

The derived policy function and the derived success probability are also used in simulation exercises in Section V. Note that the result of this paper is robust to changes of a measure of firm's innovation activities. While JNIS2009 can, if not perfectly, identify firm's innovation activities especially targeting product innovation, the result of analyses based on this information is nearly-unchanged.

III-1-2. Technological spillovers in this paper

In our model, technological spillovers mean firm's increased profit in the product market due to its rivals' achievement of product innovation. Here, we position this approach in existing studies.

Many researchers have tried to quantify technological spillovers in firm's innovation from a viewpoint of its R&D expenditures. However, they do not necessarily adopt the same approach in constructing their estimation models. The technological spillovers in the models can be viewed from two different perspectives, that is, inflow and outflow.

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[21] In fact, JNIS2009 asks about firm's innovation activities and about its product innovation respectively in different sections.

[22] The result of JNIS2009 indicates that 13.1% of firms answer that they stop their innovation activities on the way. Furthermore, the approach here is consistent with many of past empirical studies including Xu (2006) that assume that firm's R&D expenditures stochastically influence state variables.

As for inflow, most studies assume that the outcome of past R&D investment creates the technological spillovers. This assumption is based on the view that the sum of others' *knowledge*,[23] which is typically measured by R&D stock, benefits the firm. Hence, our approach focusing on the *outcome* of others' innovation activities shares similarities with past studies considering spillovers from the *outcome* of R&D investment from others.

As for outflow, on the other hand, there are two lines of approaches for modeling. One is adopted in studies estimating the social rate of return to R&D investment, which are discussed in Griliches (1992). They pick up firm's productivity increase thanks to others' knowledge. In contrast, the other supposes that others' knowledge has an influence on firm's knowledge production. This approach, which is adopted in recent empirical studies based on a dynamic model (e.g. Xu, 2006) or on a two-stage model (e.g. Bloom et al., 2010), places emphasis on firm's knowledge accumulation fostered by technological spillovers. Here, the spillovers improve firm's economic value not by directly boosting its current profit but by increasing its future benefit due to the fostered knowledge accumulation.

This paper supposing that technological spillovers directly affect firm's profit is more closely related to the former approach. Even though we do not focus on firm's productivity in specific, the productivity improvement usually results in increasing firm's profit. While our approach cannot precisely capture the future benefit by technological spillovers, we relieve this problem by setting one period to three years, which is a relatively long time span.

III-2. Incumbent's Problem

III-2-1. Per-period profit

As described in Section III-1, an incumbent obtains its per-period profit, $\pi_i(s_t)$. We assume that $\pi_i(s_t)$ is the equilibrium profit in a variant of static Cournot competition.[24] Specifically, it is quantity competition with vertical quality differentiation supposing that product innovation increases the quality of firm's product, which enables us to incorporate positive and negative spillovers into our model in a natural way. We omit subscript t temporarily for notational simplicity.

We formulate an inverse demand function faced by firm i in a market that is shifted by its own product innovation, I_i, and the number of its rivals with product innovation, $I_{-i} \equiv \Sigma_{j \neq i}\, q_j$, as below.

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[23] Practically, many works calculate the weighted sum of knowledge, whose weight is set in proportion as the technological distance between an innovator and another firm enjoying the spillovers. This paper uses weight taking the value of 1 if they compete in the same market and taking the value of 0 otherwise.

[24] This profit function has the same properties with that in Finger (2008).

$$p_i = A(I_i,I_{-i}) - \alpha\Sigma_j\, q_j, \quad (1)$$

where $A(I_i,I_{-i}) = A_0 + A_1 I_i + A_2 I_{-i}$,

where A_0 is a constant term of the function, A_1 represents the effect of its own product innovation, A_2 does that of its rivals' product innovation and α is a parameter capturing the relationship between price and quantity. Here, technological spillovers can be captured with A_2. If its rivals' technologies accompanying their innovation boost firm's profit, A_2 should be estimated positive. On the other hand, its rivals' larger production decreases firm's profit in Cournot competition. Rivals' product innovation has a negative effect on its profit because it is expected to shift their inverse demand functions upward and to raise their output with positive A_1. Thus, the modeling here captures both positive and negative spillovers.

As for firm i's production cost, we assume constant returns to scale as below.

$$c(I_i) = c_0 + c_1 I_i,$$

where c_1 is additional production cost for supplying a new product. Since I_i is a binary variable, this functional form makes no further assumption.

In this setting, the equilibrium production by firm i is written as below.[25]

$$q_i(s_t) = \alpha^{-1}(n+1)^{-1}\{A_0\text{-}c_0\text{+}(A_1\text{-}c_1)(nI_i\text{-}I_{-i})\text{+}A_2(2I_{-i}\text{-}(n\text{-}1)I_i\},$$

and the equilibrium profit is

$$\begin{aligned}\pi_i(s_t) &= \alpha^{-1}(n+1)^{-2}\{A_0\text{-}c_0\text{+}(A_1\text{-}c_1)(nI_i\text{-}I_{-i})\text{+}A_2(2I_{-i}\text{-}(n\text{-}1)I_i\}^2 \\ &= (n+1)^{-2}\{\tilde{A}_0\text{+}\tilde{A}_1(nI_i\text{-}I_{-i})\text{+}\tilde{A}_2(2I_{-i}\text{-}(n\text{-}1)I_i\}^2 \equiv \pi(n,I_i,I_{-i}|\theta_\pi),\end{aligned}$$

where $\tilde{A}_0 \equiv \alpha^{-1/2}(A_0\text{-}c_0)$, $\tilde{A}_1 \equiv \alpha^{-1/2}(A_1\text{-}c_1)$, $\tilde{A}_2 \equiv \alpha^{-1/2}A_2$ and $\theta_\pi \equiv (\tilde{A}_0, \tilde{A}_1, \tilde{A}_2)$.

We cannot identify $(A_0,A_1,A_2,\alpha,c_0,c_1)$ separately. Instead, we set our goal to estimate θ_π, which contains enough information for quantifying the economic impact of product innovation. $\tilde{A}_1$ corresponds to the difference between increased price and additional cost by introducing a new product, which is interpreted as changes in firm's profit margin due to its own product innovation. $\tilde{A}_2$ captures the direct effect of rivals' product innovation on its demand, or technological spillovers. All the parameters are normalized by α.

III-2-2. Innovation activities and product innovation

Firm i's innovation activities, $d_{i,t}$, determine its following innovation achievement, $I_{i,t+1}$.

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[25] We assume a symmetric equilibrium. While we only introduce an internal solution for notational simplicity here, we consider corner solutions in estimation.

To be more precise, $I_{i,t+1}$ stochastically takes the value of 1 if and only if firm i conducts innovation activities at period t as below.

$$\Pr(I_{i,t+1} = 1 \mid d_{i,t}) = d_{i,t} * \Pr(I_{i,t+1} = 1 \mid d_{i,t} = 1). \quad (2)$$

III-2-3. Value function

Given the discussion above, firm i's expected continuation value conditional on $(n_t, I_{i,t}, I_{-i,t}, sub_{i,t})$ is written as

$$V^c(n_t, I_{i,t}, I_{-i,t}, sub_{i,t}) = \mathrm{E}_v[\max_{d_{i,t}\in\{0,1\}} - d_{i,t}*(C(sub_{i,t}) + \sigma_v(sub_{i,t})v_{i,t}) + \beta \mathrm{E}[V^c(\mathrm{n}_{t+1}, I_{i,t+1}, I_{-i,t+1}, sub_{i,t+1}) \mid n_t, I_{i,t}, I_{-i,t}, d_{i,t}]], \quad (3)$$

where the expectation operator $\mathrm{E}_v[\cdot]$ is taken over $v_{i,t}$, which is a stochastic part of innovation cost. Let $C(sub_{i,t})$ be the location parameter and $\sigma_v(sub_{i,t})$ be the scale parameters of the innovation cost allowing them to differ depending on firm's subsidy status. We assume that $v_{i,t}$ follows the standard logistic distribution for computational tractability. Each firm discounts its future payoff with a common discount factor, β. For the purpose of our estimation, we set the discount factor equal to 0.95.

Similarly, firm i's expected value at the beginning of period t is written as

$$V(n_t, I_{i,t}, I_{-i,t}, sub_{i,t}) = \pi(n_t, I_{i,t}, I_{-i,t} \mid \theta_\pi) + \mathrm{E}_\varepsilon[\max_{\chi_{i,t}\in\{0,1\}} (1-\chi_{i,t})*V^c(n_t, I_{i,t}, I_{-i,t}, sub_{i,t}) + \chi_{i,t}*\sigma_\varepsilon\varepsilon_{i,t}], \quad (4)$$

where the expectation operator $\mathrm{E}_\varepsilon[\cdot]$ is taken over $\varepsilon_{i,t}$, which is a stochastic part of scrap value. Let σ_ε be the scale parameter of the scrap value. We assume that $\varepsilon_{i,t}$ follows the standard logistic distribution for computational tractability again. This assumes that the mean of scrap value is normalized to zero. This is a necessary assumption for our estimation because we could not identify the location of parameters otherwise.

III-3. Entrant's Problem

We suppose that there are an infinite countable number of ex-ante identical potential entrants in each market. Given stochastic entry cost, C^e_t, each potential entrant decides whether to enter the market. In addition, we assume that market state variables observed by a potential entrant is limited to the number of incumbents, n_t.[26] Since a potential entrant does not conduct innovation activities upon entry, entrant i becomes a new incumbent with

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[26] While this is an unavoidable assumption to estimate entry cost parameters with our data, we can interpret it in association with information asymmetry between an incumbent and a potential entrant.

$I_{i,t+1} = 0$ at the next period. Hence, letting the number of actual entrants be e_t, entry value expected at period t can be written as $\beta E[V(n_{t+1}, 0, I_{-i,t+1}) | n_t, e_t]$. Each potential entrant enters the market as long as this expected entry value is greater than the entry cost, which leads to the following free entry condition.

$$\begin{cases} \beta E[V(n_{t+1}, 0, I_{-i,t+1}, sub_{i,t+1}) \mid n_t, e_t = e+1] < C^e_t \\ \qquad\qquad < \beta E[V(n_{t+1}, 0, I_{-i,t+1}, sub_{i,t+1}) \mid n_t, e_t = e] & \text{if} \quad e_t > 0, \\ \beta E[V(n_{t+1}, 0, I_{-i,t+1}, sub_{i,t+1}) \mid n_t, e_t = 1] < C^e_t & \text{if} \quad e_t = 0. \end{cases} \tag{5}$$

We assume that C^e_t is drawn independently over time from a normal distribution, $N(\mu_e, \sigma_e^2)$.

III-4. Equilibrium

Following Maskin and Tirole (1988, 2001), we consider a Markov perfect Nash Equilibrium (hereafter MPNE). Because the Markovian assumption allows us to abstract from calendar time, we omit subscript t hereafter unless it is necessary. Furthermore, we restrict our attention to a pure-strategy equilibrium, which Doraszelski and Satterthwaite (2010) proves to exist in their dynamic oligopoly model similar to ours. In addition, we assume that the same equilibrium is played across markets.

The equilibrium is characterized by incumbent's policy function denoted by $\tilde{A} \equiv \{\tilde{A}_\chi, \tilde{A}_d\}$ and the free entry condition in equation (5). The incumbent's policy is a mapping from state variables to its decision.

$$\tilde{A}_\chi : (n, I_i, I_{-i}, sub_i, \varepsilon_i) \rightarrow \chi_i, \; \tilde{A}_d : (n, I_i, I_{-i}, sub_i, \varepsilon_i, v_i) \rightarrow d_i. \tag{6}$$

III-4-1. Restriction on incumbent's policy

Due to data limitation, we impose a functional restriction on the incumbent's policy. Since our data only contains binary information on rivals' innovation achievement, we need to assign a binary value depending on I_{-i}. Hence, we construct an indicator function, $\Delta(n, I_{-i})$, taking the value of 1 if I_{-i} exceeds a critical value, $\bar{I}(n)$.

$$\Delta(n, I_{-i}) = \begin{cases} 1 & \text{if} \quad I_{-i} \geqq \bar{I}(n), \\ 0 & \text{if} \quad I_{-i} < \bar{I}(n). \end{cases} \tag{7}$$

As the baseline, we use the following critical value.[27]

[27] We also use a simpler critical value, $\bar{I}(n) = (n-1)/2$, and confirm that our estimation results do not change qualitatively.

$$\bar{I}(n) = F^{-1}{}_{bino}(1-p;\, n-1,\, p), \tag{8}$$

where $p = \Pr(I_j=1|n)$ and $F^{-1}{}_{bino}(x;n-1,p)$ is the inverse CDF of a binomial distribution with parameters $(n-1,p)$. This setting means that $\Pr(\Delta(n,I_{-i}) = 1|n) = \Pr(I_j = 1|n)$, or in other words, the probability of $\Delta(n,I_{-i}) = 1$ equals to that of a rival's innovation achievement.

Supposing that I_{-i} plays a role in firm's decision making only through $\Delta(n,I_{-i})$, its policy function in equation (6) can be rewritten as $A \equiv \{A_\chi,A_d\}$ with

$$A_\chi : (n, I_i, \Delta(n, I_{-i}), sub_i, \varepsilon_i) \rightarrow \chi_i\,,\ A_d : (n, I_i, \Delta(n, I_{-i}), sub_i, \varepsilon_i, v_i) \rightarrow d_i. \tag{9}$$

IV. Estimation

This section describes our estimation procedure based on the model introduced in Section III and reports the estimation results. Our main data source is JNIS2009 overviewed in Section II. We restrict our sample to firms bringing its products only to domestic markets because it is likely that domestic competition is somewhat different from global one.[28] Although this restriction comes into question if firm's export status, showing whether or not a firm exports its products, changes in time, some of past empirical studies (e.g. Kasahara and Lapham, 2008) point out that the export status is persistent. Our resulting sample size is 1,418.[29]

Primitives to be estimated include ones determining the distribution of innovation cost, $\theta_{IC} \equiv (C(\cdot),\sigma_v(\cdot))$, ones determining incumbent's per-period profit and scrap value, $\theta \equiv (\tilde{A}_0,\tilde{A}_1,\tilde{A}_2,\sigma_\varepsilon)$, and ones determining the distribution of entry cost, $\theta_e \equiv (\mu_e,\sigma_e)$. In what follows, Section IV-1 describes our estimation procedure. Then, Section IV-2 checks the fitness of our model and Section IV-3 reports the estimation results.

IV-1. Estimation Procedure

Our estimation procedure can be divided into three steps as below.[30]

[1] Estimate primitive parameters determining the distribution of innovation cost, θ_{IC}, based on a variant of the Tobit model.[31]

[28] The difference of competitive pressure between a domestic market and a foreign one is widely discussed from a theoretical and empirical perspective especially in trade literature. For example, Melitz (2003) constructs a theoretical model where only a firm with high productivity exports its products.

[29] The exclusion of firms exporting their products decreases the sample size from 4,579 to 2,235. Then, we omit 817 firms from that because some of their variables discussed in Section 3 are not observed.

[30] We follow a bootstrap procedure for estimating the standard errors of all the estimates. We set the number of bootstrap trials to 50.

[31] It is impossible to estimate innovation cost parameters at the same time as the other incumbent's

[2] Estimate primitive parameters determining incumbent's per-period profit and scrap value, θ, with a method presented in Bajari, Benkard, and Levin (2007, hereafter BBL).

[3] Estimate primitive parameters determining the distribution of entry cost, θ_e, based on the maximum likelihood estimation (MLE) similar to that in Berry and Waldfogel (1999).

In what follows, we give details of Step [1] and [2].[32]

IV-1-1. Primitive parameters determining the distribution of innovation cost

By approximating innovation costs by R&D expenditures, we can use observed firm's R&D expenditures for estimating the distribution of innovation cost. More specifically, we construct the proxy by subtracting firm's research expenditures financed by public institutions from all its R&D expenditures. Since JNIS2009 does not contain information on research expenditures publicly financed, we merge the survey with Survey of Research and Development 2008 (SRD2008) conducted by Statistics Bureau, Ministry of Internal Affairs and Communications.[33]

For estimating innovation cost parameters with this observed "innovation cost," we need to deal with the truncation problem that we can observe the realized value of innovation cost only if a firm conducts innovation activities. Since it is naturally expected that lower innovation costs encourage firm's innovation activities, the distribution of observed innovation cost lies below its underlying distribution. Hence, we estimate innovation cost parameters based on a variant of the Tobit model.

To be more precise, we assume that the observed innovation cost, c_i, is determined as follows.

$$c_i^* \sim \text{Logistic}(C(sub_i),\sigma_v(sub_i)), \tag{10}$$
$$c_i = \begin{cases} c_i^*, & \text{if} \quad B(s_i) - c_i^* > 0 \quad \text{i.e. } d_i = 1, \\ 0. & \text{if} \quad B(s_i) - c_i^* < 0 \quad \text{i.e. } d_i = 0, \end{cases}$$

where $B(s_i)$ approximates firm's additional benefit obtained by conducting innovation activities. Equation (10) means that innovation cost is realized if and only if the additional

parameters. Because our model only includes discrete choices in firm's decision making, we need to normalize the scale of all parameters in estimation.

[32] As for step [3], all we have to do is to calculate the likelihood of the number of actual entrants using the free entry condition in equation (5) and to maximize the likelihood under the assumption that C^e_t follows a normal distribution.

[33] We choose SRD2008 because it covers FY2007, the middle of the survey period of JNIS2009. After subtracting firm's research expenditures financed by public institutions from all its R&D expenditures, we multiply them with three because we set one period to three years.

benefit exceeds the innovation cost drawn from a logistic distribution and the firm conducts innovation activities. This setting is consistent with our structural model presented in Section III.

Since equation (10) is a variation of Type 2 Tobit model with a logistic distribution, we can estimate the innovation cost parameters, θ_{IC}, with an MLE procedure.[34] Table 1 reports the estimated innovation cost parameters depending on firm's subsidy status. A firm with subsidies tends to incur lower and less varying innovation cost. The smaller variation may reflect the fact that a firm conducting high-cost innovation activities tends to receive massive subsidies.[35]

Table 1
Estimation Results of Innovation Cost Parameters (in million JPY)

	Without subsidies	With subsidies
$C(\cdot)$	2313.7	2271.06
$\sigma_V(\cdot)$	3949.16	2419.9
Obs.	92	21

IV-1-2. Primitive parameters determining incumbent's per-period profit and scrap value

We estimate the other incumbent parameters, θ, by following BBL, which can be divided into two steps. In the first step, we derive firm's policy functions and state transition probabilities by using its observed decision and state. Then, in the second step, we recover the target parameters θ, which is set to make firm's policy functions obtained in the first step to be optimal. This is because firm's policy functions observed should be optimal under a MPNE with true parameters. For checking the optimality condition, we estimate firm's value by using a forward simulation procedure introduced in BBL.

(1) Derive firm's policy function

In the model in Section III, an incumbent makes decisions on exit and on innovation activities every period. Under the assumption of MPNE, it should act optimally subject to its state, and its policy function is represented by a mapping from the state variables to its decision as in equation (9).

Firm i exits from the market if and only if its scrap value exceeds its expected continuation value. Hence, policy function A_χ can be written as

[34] We formulate $B(s_i) = b_0 + b_1 n + b_2 I_i$. Note that s_i includes information on the number of incumbents and firm's own product innovation, which is defined in Section 3.1. Hence, equation (10) endogenizes a selection procedure of subsidy recipients by public institutions in the same fashion as our structural model.

[35] In fact, the result of SRD2008 shows a positive correlation between firm's total R&D expenditures and those financed by public institutions.

$$A_\chi(n, I_i, \Delta(n,I_{-i}), sub_i, \varepsilon_i) = 1\{\sigma_\varepsilon\varepsilon_i > V^c(n, I_i, I_{-i}, sub_i)\}. \tag{11}$$

On the other hand, firm i continues and conducts innovation activities if and only if equation (11) is unsatisfied and its continuation value with innovation activities exceeds that without. With writing the deterministic part of firm i's continuation value with innovation activities as $V_1^c(n,I_i,I_{-i},sub_i)$ and that without innovation activities as $V_0^c(n,I_i,I_{-i},sub_i)$, A_d can be represented as

$$A_d(n, I_i, \Delta(n,I_{-i}), sub_i, \varepsilon_i, v_i)$$
$$= 1\{\sigma_\varepsilon\varepsilon_i < V^c(n, I_i, I_{-i}, sub_i)\} * 1\{V_1^c(n, I_i, I_{-i}, sub_i) + \sigma_v v_i > V_0^c(n, I_i, I_{-i}, sub_i)\}. \tag{12}$$

A significant practical problem in using equation (11) and (12) is the impossibility of observing firm's continuation value included there. In this regard, it is widely known that this kind of policy function can be rewritten with firm's conditional choice probabilities as discussed in Hotz and Miller (1993). Since both ε_i and v_i are assumed to follow the standard logistic distribution, equation (11) and (12) can be written explicitly with its conditional probability of exit, $\Pr(\chi_i=1|n,I_i,\Delta(n,I_{-i}),sub_i,)$, and that of innovation activities, $\Pr(d_i=1|n,I_i,\Delta(n,I_{-i}),sub_i,)$. Therefore, all we have to obtain for deriving firm's policy function are these conditional choice probabilities, which are usually estimated associating its observed action,[36] (χ_i,d_i), with observed state variables, $(n,I_i,sub_i,)$.

Although we cannot directly observe rivals' product innovation, which is captured with $\Delta(n,I_{-i})$ in our model, we can use questions about firm's response to rivals' innovation achievement for identification as we see in Section II-1. To be more precise, by focusing on two questions about whether a firm would launch a new innovation project and about whether a firm would exit from the market, we estimate firm's probability of exit and of innovation activities conditional on rivals' achievement of product innovation.[37] As a result, we can identify the effect of rivals' product innovation on firm's decision-making even though we are not able to directly observe rivals' state.[38]

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[36] Because JNIS2009 does not contain enough information on firm's exit decision, we use Basic Survey of Japanese Business Structure and Activities (BSJBSA) conducted by Minister of Economy, Trade and Industry. This survey is conducted each fiscal year and we can easily construct a corresponding panel dataset by using permanent firm ID as introduced in Matsuura and Kiyota (2004). Here, after merging JNIS2009 with BSJBSA2009, we additionally merge BSJBSA2010 with it. Then, we can obtain information on firm's exit by checking whether a firm observed in BSJBSA2009 is also found in BSJBSA2010. Since our model sets one period to three years, we calculate firm's three-year (or one-period) exit probability by transforming one-year one.

[37] We can also derive the probabilities conditional on rivals' *non*-achievement of product innovation.

[38] This approach has an advantage that we can avoid a spurious correlation between firm's action and rivals' innovation caused by market characteristics. The conditional choice probabilities are usually estimated by associating firm's observed action with rival's observed achievement of product innovation. However, such an approach cannot separate the effect of rivals' innovation on firm's action from a mere correlation of incumbents' action and state in the same market.

(2) Derive state transition probabilities

We need to estimate the transition probabilities of state variables, $(n,I_i,sub_i,)$, for running forward simulations.

The number of incumbents, n, transits due to incumbents' exit and entry of potential entrants. Since JNIS2009 contains information on changes in the number of incumbents, Δn_t, we can directly estimate the transition probability of the number. In addition, combining this with information on firm's exit yields the probability distribution of the number of entrants.

As for the achievement of product innovation, our model requires the success probability of product innovation, $\Pr(I_{i,t+1}=1|d_{i,t}=1)$. Since firm's innovation activities and product innovation only have a cross sectional variation in JNIS2009, we assume stationarity of the share of firms with product innovation for estimating the success probability as below.

$$\Pr(I_{i,t+1}=1|d_{i,t}=1)$$
$$= \Pr(I_{i,t+1}=1 \text{ and } d_{i,t}=1) / \Pr(d_{i,t}=1) = \Pr(I_{i,t+1}=1) / \Pr(d_{i,t}=1) = \Pr(I_{i,t}=1) / \Pr(d_{i,t}=1).$$

Lastly, we estimate the probability of subsidized. We allow this probability depend on firm's publicly observed state, $s_i \equiv (n,I_i)$, which approximates a selection of subsidy recipients by public institutions. Connecting firm's observed subsidy status, sub_i, with the publicly observed state, s_i, yields the probability of subsidized.

(3) Run forward simulations

By using the estimated policy function and state transition probabilities, we conduct forward simulations for evaluating firm's value as follows.

[1] (Initial state) Set firm i's initial state, (n,I_i,I_{-i},sub_i). In addition, for n-1 rivals in the market, assign their subsidy status randomly based on the probability of subsidized.

[2] (Incumbent's decision) For all incumbents in the market, generate random numbers for their scrap value shocks, $\{\varepsilon_i\}_i$, according to the standard logistic distribution, which determines their exit decisions by following equation (11). Then, for not exiting incumbents, generate random numbers for their innovation cost shocks, $\{v_i\}_i$, according to the standard logistic distribution, which determines their decisions on innovation activities by following equation (12).

[3] (Per-period value) Calculate and stock firm i's per-period value, $\tilde{v}_{i,t}$, with fixed parameters, θ. The value is calculated as $\tilde{v}_{i,t} \equiv \tilde{v}_t(n,I_i,I_{-i},sub_i;A;\theta) = \pi_i(s_t) + \chi_{i,t}*\sigma_\varepsilon\varepsilon_{i,t} - d_{i,t}*\{C(sub_{i,t}) + \sigma_v(sub_{i,t})v_{i,t}\}$.

[4] (State transition) Incumbents' state variables, $\{n,I_i,I_{-i},sub_i\}_i$, transit based on their decision making in [2] and the estimated transition probabilities. Set $I_{j,t+1} = 0$ for new entrant j.

[5] Repeat [2] through [4] until firm i exits or β^t becomes sufficiently small. We repeat 100 times at a maximum.

With fixed θ, this procedure yields the sequence of firm's per-period value. By using this, we can calculate the discounted sum of the value as below.

$$\tilde{V}(n, I_i, I_{-i}, sub_i\, ; A; \theta) = \Sigma_t\, \beta^{t-1}\, \tilde{v}_t\, (n, I_i, I_{-i}, sub_i\, ; A; \theta).$$

We repeat this procedure many times[39] with fixed initial state and average them, which is firm's estimated value conditional on a particular state, $\hat{V}(n, I_i, I_{-i}, sub_i\, ; A; \theta)$.

(4) Estimate primitives

The condition that a firm could not increase its value by going against its policy function in MPNE enables us to estimate primitive parameters, θ. For this purpose, we estimate firm's hypothetical value that is expected to be captured with an *alternative* policy functions, A'. We generate the alternative by multiplying firm's conditional choice probability by a uniform random number between 0.9 and 1.1. We can estimate firm's hypothetical value, $\hat{V}(n,I_i,I_{-i},sub_i;A';\theta)$, by following the same procedure as that in (3) except for assuming that firm i's action is determined by A' while others' one is by A.

Under the assumption of MPNE, every firm should behave optimally conditional on rivals' behavior. Therefore, $g(n,I_i,I_{-i},sub_i;A';\theta) \equiv \hat{V}(n,I_i,I_{-i},sub_i;A;\theta) - \hat{V}(n,I_i,I_{-i},sub_i;A';\theta)$ should be positive at the true value. We then construct a minimum distance estimator as below.

$$\hat{\theta} = \text{argmin}_{\theta\in\Theta}\ K^{-1}\, \Sigma_{k\in\{1,\ldots,K\}}\ \min\{g(X_k; \theta), 0\}^2,$$

where $X_k \equiv (n_k, I_{i,k}, I_{-i,k}, sub_{i,k}\, ; A_k')$ is randomly selected for each k.[40]

IV-2. Fitness of the model

We check the fitness of the model by comparing simulated moments with data ones by focusing on the mean value of control and state variables in our structural model. Table 2 shows the results. Simulated moments are lower than data ones for innovation activities, d_i, and innovation achievement, I_i, and slightly higher for exit, χ_i. The underestimation for the innovation-related variables might come from our assumption that a potential entrant does not conduct innovation activities upon entry, which remains to be solved. For the other variables, our model does well.

[39] We repeat this procedure for 100 times.
[40] We set $K = 1000$.

Table 2
Comparison between Data Moments and Simulated Moments (mean value)

	Data moments	Simulated moments
Innovation activities, d_i	40.30%	35.60%
Exit from the market, χ_i	15.60%	19.10%
Achievement of product innovation, I_i	33.90%	24.70%
Number of incumbents, n	14.3	13.3
Changes in the number of incumbents, Δn	-0.33	-0.09
Subsidy assignment, sub_i	8.20%	8.40%

IV-3. Estimation results

This subsection reports the estimate of primitive parameters determining incumbent's per-period profit and scrap value.[41] Table 3 shows the estimated parameters. $\tilde{A}_0$ is estimated to be very small and insignificant, which implies that a firm without product innovation faces severe competition and has trouble in making a profit. On the other hand, $\tilde{A}_1$ is estimated to be significantly positive. This is consistent with the view that product innovation increases firm's profit margin because new products are less in competition with existing ones. Furthermore, $\tilde{A}_2$ is also estimated to be positive, which supports the existence of technological spillovers. Finally, σ_ε is estimated to be insignificant.

Figure 5 graphically shows firm's estimated per-period profit function. The upper half of the figure plots the relationship between firm's profit and the number of incumbents in the market.[42] The upper left is for a firm without product innovation, I_i=0, and the upper right is for one with, I_i=1. Both of them show that increasing the number of competitors put pressure on firm's profit due to fiercer competition. Furthermore, a side-by-side comparison indicates a positive effect of firm's own product innovation on its profit. The profit of one without product innovation is near zero, which implies the difficulty of surviving a competitive market only with existing products. In contrast, a firm with its own product innovation makes a much larger profit than one without. Hence, it is considered that product innovation is associated with firm's economic value in the form of its profit, which is consistent with Petrin (2002).

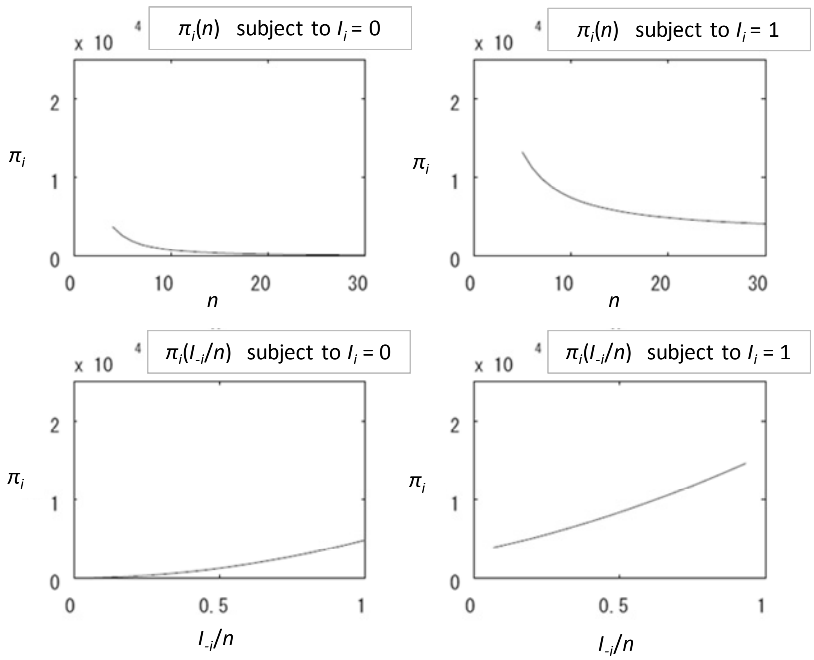
[41] Parameters determining the distribution of entry cost, θ_e, are significantly estimated at 1%. μ_e is estimated at -558625.6 (s.e. 300646.4) and σ_e is estimated at 737876.3 (s.e. 380394.8).
[42] The number of rivals with product innovation in the market is fixed at the mean.

Table 3
Estimation Results of Incumbent's Parameters (in million JPY)

	Coefficient	S.E.
$\tilde{A}_0$	17.21	32.75
$\tilde{A}_1$	176.05 ***	16.19
$\tilde{A}_2$	123.97 ***	18.33
σ_ε	-710.52	1129.9

Notes: *** indicates that the estimate is significant at 1%.

Figure 5
Estimated Per-period Profit (in million JPY)



The lower half plots the relationship between firm's profit and the share of competitors with product innovation.[43] Similarly, the lower left is for I_i=0 and the lower right is for I_i=1. They show that increasing the number of rivals with product innovation has a positive effect on firm's profit on average. In other words, it implies that a positive spillover effect in product innovation is stronger than a negative one and there are *net* positive spillover effects. Policy intervention such as public financial support can work well with net spillover effects (Spence, 1984), which will be examined further in simulation exercises. Finally, by comparing the lower left with the lower right, we can see that slope of the curve is steeper for a firm with product innovation. This is interpreted to mean that a firm with

[43] The number of incumbents in the market is fixed at the mean.

product innovation is more likely to benefit from technological spillovers and to be positively influenced by rivals' innovation.

IV-3-1. Estimation results and firm's strategic interdependence

The properties of the estimated profit function shown in Figure 5 can be associated with firms' strategic interdependence. The result of JNIS2009 indicates that rivals' achievement of product innovation[44] discourages firm's exit from the market.[45] Since the low exit rate implies that a firm can obtain big benefit by remaining in the market, this is an evidence that rivals' product innovation increases firm's profits, or in other words, there are net positive spillover effects.

As for innovation activities, the result of JNIS2009 indicates that rivals' achievement of product innovation encourages firm's innovation activities,[46] which is a kind of "intertemporal strategic complementarity" in Vives (2009). This is consistent with the idea that firm's own product innovation and rivals' product innovation increase their profit in a mutually complementary manner or with the fact that slope of the curve in Figure 5 is steeper for the lower right than for the lower left.

V. Simulation

This section presents a simulation procedure for evaluating the current innovation policy. We focus on public financial support for firm's innovation activities in the form of subsidies herein.

Table 4
Share of Firms with Public Financial Support

	All sizes All ages	Small Young	Small Old	Large Young	Large Old
All industries	8.20%	11.50%	4.60%	5.30%	9.30%
Manufacturing	13.40%	24.20%	5.60%	6.30%	15.50%
Service	5.10%	6.20%	2.70%	5.20%	5.50%

44 The result of JNIS2009 shows that a firm with product innovation tends to conduct additional innovation activities, which corresponds to "increasing dominance" discussed in Athey and Schmutzler (2001). Hence, it is expected that a rival with product innovation today is more likely to achieve product innovation tomorrow.

45 As for firms without public financial support, the share of firms that would exit from the market conditional on rivals' product innovation is 17.7% and that conditional on rivals' no product innovation is 15.1%.

46 As for firms without public financial support, the share of firms that would conduct innovation activities conditional on rivals' product innovation is 34.4% and that conditional on rivals' no product innovation is 36.1%.

Table 4 summarizes the share of firms receiving public financial support by firm characteristics. The share is about 10% for small-young or large-old firms, which is two times higher than that for the other groups. While this tendency is maintained even if we look at the share by industry, there is less difference in the share by firm size and age for service industries.

V-1. Simulation procedure

Evaluating the effect of subsidies for firm's innovation activities is not possible without comparing the current situation with the hypothetical one where no one receives subsidies. The problem here is that there have been no controlled experiments for comparing different schemes of innovation policy in Japan as far as we know, and that we cannot conducts a reduced form analysis (e.g. difference-in-differences analysis) for evaluating the effect of public financial support. However, our structural estimation approach enables us to perform quantitative analysis on the existing allocation of subsidies by simulating economic outcomes in the hypothetical situation.

For the purpose of comparison, we also run a simulation based on an existing subsidy scheme. Our simulation procedure is precisely the same as one introduced in Section IV-1-2(3) and we can estimate the mean of firm's value in the current situation. This procedure is also effective for checking the fitness of the model as already conducted in Section IV-2. As for the counterfactual situation where no firm receives any subsidies, we set the probability of subsidized to zero, and run the same simulation as one for the current situation in other respects.

In our model, public financial support with subsidies encourages firm's innovation activities by decreasing innovation cost. Hence, we can naturally define firm's received amount of subsidies as the difference between innovation cost with subsidies and one without subsidies. By estimating the total amount allocated subsidies and firm's value increased with the subsidies, we can assess the efficiency of the current subsidy allocation.

VI. Conclusion

This paper quantifies spillover effects of product innovation in the private sector in Japan, and proposes an approach for evaluating the effect of innovation policy. Specifically, we focus on public financial support for firm's innovation activities in the form of subsidies. By using Japanese firm-level data on product innovation, our approach based on a structural estimation enables us to capture net spillover effects including complex factors and to draw policy implications.

The estimation results suggest that there exist technological spillovers in firm's product innovation, whose effects are estimated to be greater than those of negative spillovers due to increased competition in the product market. The existence of the net positive spillover effects is a necessary condition for the validity of public financial support.

We need to keep two points in mind in interpreting the results obtained in this paper. First, we restrict our sample to firms bringing its products only to domestic markets for the purpose of addressing geographical scope in competition. As for exporting firms, it is also worthy of our interest whether their innovation activities and economic outcomes are different from those of domestic firms and whether their technology is spilled out to foreign countries. Second, we capture firm's innovation activities and innovation achievement based on binary information and do not consider the intensity of them. It is one of future tasks to construct quantitative measures of them.

The next step is to perform simulation exercises proposed in this paper and to quantitatively evaluate the efficiency of the current subsidy allocation. Furthermore, associating allocated subsidies with recipient's observable characteristics is a significant step for discussing reform of public financial support.

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