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Open Innovation, Productivity, and Export: Evidence from Japanese firms

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Open Innovation, Productivity, and Export: Evidence from Japanese firms*

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Abstract

This paper empirically examines the relation between a firm's productivity and its joint decision of research and development (R&D) strategy and exporting, based on Japanese firm-level data and the simple theoretical framework that extends the firm heterogeneity model so that both internal and external (outsourcing or technology purchase) R&D strategies are taken into account. The empirical results from nonparametric and semiparametric methods show that exporting firms engaged in R&D activities are more productive than non-exporters and exporters with no R&D, regardless of whether internal or external R&D strategy is adopted, and that exporters which employ both R&D strategies are the most productive. The results suggest that an open innovation strategy is complementary to an in-house R&D strategy and is crucial for further promoting innovation for internationalized firms.

Keywords: R&D, Open innovation, Productivity, Nonparametric tests

JEL classification: C14, D24, F10, O33

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1. Introduction

The recent seminal theoretical studies in international economics have focused on the role of firm heterogeneity in a firm's internationalization (Melitz, 2003; Helpman, Melitz and Yeaple, 2004; Antràs and Helpman, 2004). They suggest that more productive firms succeed in entering the international market. In other words, while less-productive firms only supply the domestic market, only the relatively more-productive firms export their products.[1] However, these previous studies rely on the assumption that firm heterogeneity, the productivity differential, is given from outside the model because they assume that firms stochastically determine their productivity level. Therefore, the role of investment in increasing productivity and the propensity to enter the export market has not been analyzed thus far.

Recently, several studies have attempted to link productivity-enhancing investments such as R&D investments to the relationship between productivity and exporting (Yeaple, 2005; Lileeva and Trefler, 2010; Aw et al., 2009, 2011; Bustos, 2011). These studies show empirical evidence on the complementarity between productivity-enhancing investment activities and exporting. Although these studies examine the link between R&D investments and exporting, they exclusively focus on a firm's in-house R&D effort or do not distinguish between in-house R&D and external R&D resources such as technology purchase or R&D outsourcing. Knowledge

[1] This self-selection into the international market is supported by a number of empirical researches that use microdata (Bernard and Jensen, 1995, 1999; Bernard et al., 2007; Head and Ries, 2001, 2003; Kimura and Kiyota, 2006; Tomiura, 2007; Wakasugi et al., 2008).

resources such as expertise, know-how, and intellectual property that improve productivity are widely distributed outside the firm. Incorporating such external knowledge resources into firms' innovation process has become important for the growth of firms. Management literature has emphasized that, in recent decades, factors such as the development of information and communication technology (ICT), increased global competition, and complexity of technology have forced firms to shift from closed innovation to open innovation, which entails an effective utilization of external knowledge resources (Chesbrough, 2003; Christensen et al., 2005). When firms enter the international market, they face more competitive pressure than in the domestic market and there is a necessity of customization to the foreign market through their R&D activities in the foreign country. Foreign direct investment (FDI) in R&D activity and offshore outsourcing is one of the major strategies of the customization. Thus, the use of external knowledge resources may be more important to serve foreign markets for the internationalized firms.

Previous studies have found a complementary relationship between internal and external R&D. As shown by Cohen and Levinthal (1989, 1990), a firm that engages in internal R&D activities increase absorptive capacity and thus the effectiveness of adopting external knowledge resources for innovation. Cassiman and Veugelers (2006) and Lokshin et al. (2008) empirically examine the impact of internal and external R&D on firm performance and show complementarity between the two R&D strategies. Hence, it is possible that productive exporters succeeded in innovation by using external knowledge resources through buyer-supplier networks, strategic alliances, or research collaborations with unrelated firms. Nevertheless, the role of open innovation as a R&D strategy has not been analyzed in the context of the internationalization of firms.

This paper empirically examines the relationship between a firm's productivity and joint decision of R&D strategies and exporting based on Japanese firm-level data and a simple theoretical framework that extends the firm heterogeneity model so that both internal (own R&D investment) and external (R&D outsourcing or technology purchase) R&D strategies are taken into account. Instead of a parametric approach, we employ both the nonparametric Kolmogorov–Smirnov (KS) tests and the semiparametric quantile regressions (QRs) that reveal the nature of data distribution. Both results are qualitatively similar in the sense that they are consistent with theoretical predictions. The results reveal that there is a remarkable heterogeneity among exporters in terms of their R&D strategy. Although a large fraction of exporters constitutes non-R&D firms, their productivity is the lowest among exporters. Both exporters with purely internal R&D and exporters with purely external R&D are more productive than non-R&D exporters. The most productive exporters are firms that engage in the both internal and external R&D. In addition, the QRs reveal an interesting result that internal

R&D is more important for less-productive firms, while external R&D is more important for more-productive firms. The results suggest that the internal R&D strategy is initially crucial for gaining access to the international market, while open innovation is essential to further promote innovations for internationalized firms.

The remainder of this paper is organized in the following manner. Section 2, the next section, presents the theoretical framework. Section 3 describes data and descriptive statistics of key variables. Section 4 presents the empirical strategy and results of nonparametric and semiparametric tests. Section 5 concludes the paper with a summary.

2. Theoretical framework

Our theoretical framework is based on the simple model by Bustos (2011) that demonstrates the decision of exporting and upgrading technology by heterogeneous firms. We consider a monopolistic competitive industry in which firms produce differentiated goods (Melitz, 2003). The firms face the following market demand function of a particular good *j* drawn from a Dixit–Stiglitz type utility function: $x = Ap^{-\varepsilon}$, where *Y* is the market size according to demand level in home country, *p* is the price, and $\varepsilon = 1/(1-\alpha)$ is a constant elasticity of demand where α represents a parameter for determining the elasticity of substitution between goods with $0 < \alpha < 1$.

Firms produce differentiated goods using labor and their productivity is heterogeneous as far as marginal costs differ across firms, even if they use the same technology. We index the productivity as θ. Before entering the market, firms randomly draw the productivity level θ from a cumulative distribution function $G(\theta)$ and then decide to enter or exit the market. To enter the domestic market, the firm is required to pay a fixed cost, f_D. The marginal cost for production, c, is expressed by $c = w\theta$, where θ is the productivity parameter for expressing the labor input coefficient and w is the wage rate. Since there is a symmetry assumption between the domestic and foreign countries, the wages are considered as the numeraire. For simplicity, the marginal cost of production, w, is normalized to unity. Under the above assumptions, the prices of the goods are expressed as $p = c/(\alpha\theta)$. The profit of firms operating in the domestic market is expressed in the following manner:

$$\pi_D = \phi Y - f_D , \tag{1}$$

where $\phi = \theta^{\varepsilon-1}$ is an easily recognized transformation of productivity measurement and $Y = (\varepsilon - 1)^{\varepsilon-1} \varepsilon^{-\varepsilon} A$ is the mark-up adjusted demand level in home market. To enter export market, firms must pay additional fixed cost and transportation costs. The fixed cost of export is f_E, and transportation costs are expressed by τ as iceberg trade costs ($\tau > 1$). From the symmetry assumption, the demand function of the foreign country for a particular good is given by $x^* = A^* p^{-\varepsilon}$, and then the profit function including decision of export is rewritten as:

$$\pi_E = \phi\left(Y + E\tau^{-\varepsilon}Y^*\right) - Ef_E \,, \tag{2}$$

where $E \in (0,1)$ indicates the firm's exporting decision and Y^* is the mark-up adjusted demand level in the home market. As described in Melitz (2003), the firm enters the export market when ϕ surpasses the cut-off point of $f_E / \left(\tau^{-\varepsilon}Y^*\right)$.

Firms have the option to upgrade their technology by paying an additional fixed cost such as R&D. There are two choices of R&D strategies. One is internal R&D strategy, which implies that firms implement own R&D, and the other one is external R&D strategy, which implies that firms rely on R&D outsourcing or technology purchase. Firms that employ the internal R&D strategy pay an additional fixed cost f_{IR} and can increase their productivity from ϕ to $\delta\phi$ $(\delta > 1)$, while those that employ the external R&D strategy pay an additional fixed cost f_{ER} and can increase the productivity from ϕ to $\lambda\phi$ $(\lambda > 1)$. The profit of a firm with internal R&D strategy and that of a firm with external R&D strategy are expressed in the following manner, respectively:

$$\pi_{E,IR} = \delta\phi\left(Y + E\tau^{-\varepsilon}Y^*\right) - Ef_E - f_{IR} \,, \tag{3}$$

$$\pi_{E,ER} = \lambda\phi\left(Y + E\tau^{-\varepsilon}Y^*\right) - Ef_E - f_{ER} \,. \tag{4}$$

Further, we also consider a firm that adopts both internal and external R&D strategies. Such a firm can improve its productivity from ϕ to $\gamma\phi$ $(\gamma > 1)$, and the profit when the firm uses the two R&D strategies is expressed in the following manner:

$$\pi_{E,IR,ER} = \gamma\phi\left(Y + E\tau^{-\varepsilon}Y^{*}\right) - Ef_{E} - f_{IR} - f_{ER}\,. \tag{5}$$

From these profits, and according to possible choices, only firms with a productivity level above the following cut-off find it profitable to engage in R&D for each strategy.

$$\phi_{IR} > \frac{f_{IR}}{(\delta - 1)\left(Y + E\tau^{-\varepsilon}Y^{*}\right)}, \tag{6}$$

$$\phi_{ER} > \frac{f_{ER}}{(\lambda - 1)\left(Y + E\tau^{-\varepsilon}Y^{*}\right)}, \tag{7}$$

$$\phi_{IR,ER} > \frac{\left(f_{IR} + f_{ER}\right)}{(\gamma - 1)\left(Y + E\tau^{-\varepsilon}Y^{*}\right)}. \tag{8}$$

Following Bustos (2011), we focus on the case where the productivity level is higher when the firm engages in R&D than when it engages only in export. Due to this restriction, the case of firms operating only in the domestic market with R&D strategy is not considered although such firms do exist in our data.

It is interesting to derive the cut-off among the three modes of R&D strategies employed by exporters: (i) internal R&D, (ii) external R&D, and (iii) both internal and external R&D strategies. The decision whether the firm chooses internal R&D or external R&D depends on the parameter of shifting the productivity and fixed costs. However, it is difficult to determine the magnitude relationship of these factors between internal R&D and external R&D. The theory of “make-or-buy” decisions has been led by two main approaches: the transaction cost economics approach represented by Williamson (1975; 1985) and the property rights theory approach represented by Grossman and Hart (1986) and Hart and Moore (1990). Based on the assumption of incomplete contracts and relationship-specific investment, the two approaches propose a method for overcoming the possible hold-up problem due to ex-post opportunistic behavior. The transaction cost economics approach insists that the hold-up problem can be avoided by vertical integration, and firms are likely to be more vertically integrated when the relation specificity is greater. On the other hand, the property right theory approach emphasizes allocating residual rights of control to the firm whose relation-specific investment is more important in making production efficient. This argument is associated with the fact that the outside option, which is the payoff one party receives if bargaining fails, is different between vertical integration and non-integration (i.e., outsourcing). If a firm chooses vertical integration, its outside options increase by obtaining the residual rights of control and foregoing the supplier's incentive to invest in the relationship. Hence, vertical integration is not always efficient. On the other hand, outsourcing strategy is incentive for the supplier to invest in the relationship when the supplier's investment plays an important role in the relation. From the transaction cost economics approach, it is predicted that greater asset specificity such as specialized equipment that is required to produce a specific product is positively correlated with vertical integration regardless of which firm conducts the relationship-specific investment. The prediction propounded by the property rights theory is that an increase in the relationship-specific investment by the buyer has a positive effect on the probability of vertical integration, while that of the supplier has a negative effect on it. Assuming that asset specificity can be attributed to firm-specific factors such as know-how and skills, the decision of adopting either R&D strategy is influenced by not only the parameter that shifts the productivity and fixed cost but also firm-specific factors. Hence, some firms prefer internal R&D while other firms likely prefer external R&D even if their productivity level is the same.

On the other hand, comparing the profit obtained from a mixed strategy of internal and external R&D with that from a single strategy, the cut-off for switching from the single strategy to the mixed strategy is derived in the following manner:

$$\phi'_{IR,ER} > \frac{f_{ER}}{(\gamma-\delta)\left(Y+E\tau^{-\varepsilon}Y^{*}\right)}, \tag{9}$$

$$\phi''_{IR,ER} > \frac{f_{IR}}{(\gamma-\lambda)\left(Y+E\tau^{-\varepsilon}Y^{*}\right)}, \tag{10}$$

where $\phi'_{IR,ER}$ is the cut-off for switching from the internal R&D strategy to the mixed strategy, while $\phi''_{IR,ER}$ denotes switching from the external R&D strategy to the mixed strategy. Suppose that these cut-off values are larger than ϕ_{IR} or ϕ_{ER}, both inequalities $\phi'_{IR,ER} > \phi_{IR}$ and $\phi''_{IR,ER} > \phi_{ER}$ must be satisfied. Combining the two inequalities yields the following inequality.

$$\frac{(\gamma-\lambda)}{(\lambda-1)} < \frac{f_{IR}}{f_{ER}} < \frac{(\delta-1)}{(\gamma-\delta)}. \tag{11}$$

Under this condition, only firms with a productivity level above the cut-offs given in Eqs (9) and (10) find it profitable to engage in both internal and external R&D as compared to a single R&D strategy. In our empirical analysis, the following order of productivity level can be tested,

$\phi_D < \phi_E < \phi_{E,IR}$ or $\phi_{E,ER} < \phi_{E,IR,ER}$. In other words, exporters engaged in both internal and external R&D are the most productive and they are followed—in descending order of productivity—by exporters engaged in internal or external R&D, exporters that do not engage in R&D, and nonexporters.

3. Data and descriptive statistics

3.1 Data

Our empirical analysis is based on firm-level data retrieved from the *Basic Survey of Japanese Business Structure and Activities* (*Kigyo Katsudo Kihon Chosa* in Japanese) for the period 1997–2007 conducted by the Japan Ministry of Economy, Trade, and Industry (METI). Completing this annual national survey is mandatory for all firms with 50 or more employees and paid-up capital or investment funds exceeding ¥30 million in the mining, manufacturing, wholesale, retail, and food and beverage industries.[2]

We used the total factor productivity (TFP) of Japanese parent firms' as the measure of productivity. The TFP is obtained from an estimated two-digit industry-specific production function, using the estimation techniques employed by Levinsohn and Petrin (2003). We used the real value-added of Japanese parent firms as the output and hours worked (*L*) and fixed

[2] The response rate of the METI survey is more than 80% of population.

tangible assets (*K*) as inputs. Following Arnold and Hussinger (2010), who examine the relationship between productivity and patterns of export and FDI, we used the relative TFP to compare the TFP of firms in various industries. The relative TFP is obtained by dividing the TFP estimates by the average TFP in the respective industry and year. All nominal values are deflated by an industry-level deflator, which is taken from the System of National Account Statistics.

3.2 Descriptive statistics

The data provides information on whether a firm (i) conducts own R&D, (ii) outsources R&D, or (iii) purchases technological knowledge. We define own R&D as internal R&D and outsourcing R&D and technology purchase as external R&D. Based on this definition and exporting status, we classify all firms into eight types: nonexporters without any R&D, nonexporters with internal R&D, nonexporters with external R&D, nonexporters with both internal and external R&D, exporters without any R&D, exporters with internal R&D, exporters with external R&D, and exporters with both internal and external R&D.

Table 1 displays the number of firms in each of the eight types of firms. Nonexporters without any R&D are in the majority. Although there are nonexporters with internal and/or external R&D in our data, we excluded them since our theoretical model does not necessitate their inclusion. However, including them in the analysis yielded qualitatively similar results, as reported in Tables A1 and A2 of the Appendix. Among exporters, there are a large number of exporters without any R&D expenditure. Many exporters conduct only internal R&D, while a relatively small number of exporters conduct only external R&D; there are numerous exporters that conduct both types of R&D.

Table 1 The number of firms belonging to various types

	Non-exporters	Exporters	Total
No R&D	6177	1210	7387
Internal R&D	2297	1865	4162
External R&D	253	170	423
Both R&D	539	1113	1652
Total	9266	4358	13624

Table 2 presents the mean of TFP according to the eight firm types. It shows that exporters are, on average, more productive than nonexporters, which is in line with the previous studies. However, it reveals that there is substantial heterogeneity among exporters. Exporters without any R&D are less productive than exporters with R&D and they are even less productive than nonexporters with R&D. Among firms with R&D, firms with both internal and external R&D are more productive than firms with a single type of R&D. These results suggest that there is a relationship between firm productivity and R&D status.

Table 2 Average TFP by firm types

	Non-exporters	Exporters	Total
No R&D	0.394	0.586	0.425
Internal R&D	0.688	1.133	0.887
External R&D	0.887	1.409	1.096
Both R&D	2.989	4.268	3.850
Total	0.630	1.790	1.000

4. Empirical strategy

4.1. KS tests

Here, we employ two empirical methods to examine the relationship between firm productivity and various R&D and export statuses. First, we employ the nonparametric Kolmogorov–Smirnov (KS) test. We use the KS test because it is a stricter test of productivity differences than merely comparing mean levels of productivity in the sense that it considers all moments of the distribution. The KS tests allow us to compare overall productivity distribution of firms by R&D and export status, based on the concept of first-order stochastic dominance. First-order stochastic dominance of $G_1(\theta)$ with respect to $G_2(\theta)$ is defined as $G_1(\theta) - G_2(\theta) \leq 0$, uniformly in $\theta \in \Re$, with strict equality for some θ. In order to examine the stochastic dominance, we conducted one-sided and two-sided KS tests.

The two-sided KS test examines the hypothesis that both distributions, $G_1(\theta)$ and $G_2(\theta)$, are identical. The null and alternative hypotheses can be expressed as

$$H_0 : G_1(\theta) - G_2(\theta) = 0 \text{ for all } \theta \in \Re \quad \text{vs.} \quad H_1 : G_1(\theta) - G_2(\theta) \neq 0 \text{ for some } \theta \in \Re .$$

The one-sided test of stochastic dominance can be formulated as

$$H_0 : G_1(\theta) - G_2(\theta) \leq 0 \text{ for all } \theta \in \Re \quad \text{vs.} \quad H_1 : G_1(\theta) - G_2(\theta) > 0 \text{ for some } \theta \in \Re .$$

If the null hypothesis for the two-sided test is rejected and the null hypothesis for the one-sided test is not rejected, we can conclude that $G_1(\theta)$ is stochastically dominant $G_2(\theta)$. Following previous studies such as Delgado et al. (2002), we conducted the KS test separately for each year from 2001 to 2008, since the independence assumption is likely to be violated if we use pooled observations from several years for the KS test.

4.2. Quantile regression

Second, we also used the semiparametric quantile regression (QR)[3] to examine the relationship between firm productivity and exporting/R&D status. QRs have several attractive features and were used by Wagner (2006) and Arnold and Hussinger (2010) in trade literature. One of these attractive features is that QR estimates are more robust to outliers than ordinary least squares (OLS) estimates since the normality assumption is relaxed in the former.[4] Another attractive feature is that the QRs allow us to estimate the impacts of covariates on any particular percentile

[3] This paper does not provide detailed technical explanation on QRs. Koenker and Hallock (2001) provide a brief introduction to QRs.

[4] In fact, the distribution of TFP is highly skewed. The Shapiro–Wilk test rejects the normality at the significance level of 1%.

of the distribution, while OLS allows us only to estimate the average relationship. The estimation of impacts of covariates on percentiles enables us to examine whether the impact of R&D strategy is different according to the TFP level or not.

Using the QRs, we obtain the q th QR estimator β_q which minimizes over β_q the following objective function:

$$Q(\beta_q) = \sum_{i:y_i \geq x_i'\beta_q}^{N} q\left|\ln TFP_i - x_i'\beta_q\right| + \sum_{i:y_i < x_i'\beta_q}^{N} (1-q)\left|\ln TFP_i - x_i'\beta_q\right|, \qquad (12)$$

where $0 < q < 1$, i indexes firm, and x_i is a vector of covariates. We obtained the coefficients using the linear programming method since the objective function is not differentiable. All the data was used for each QR. The weights q vary across each QR. Since QRs can provide parameter estimates at different quantiles, the estimated coefficients can be interpreted as partial derivatives of the conditional quantile of the dependent variable with respect to a particular covariate. In our case, for example, the estimated coefficient indicates that the marginal change in the log of TFP at the q th conditional quantile is due to a marginal change in the capital-labor ratio. QR is semiparametric in the sense that it avoids assumptions regarding a parametric distribution of regression errors.

5. Results

5.1 The KS tests

Before presenting the results of the KS tests, we graphically examine the cumulative distribution functions (CDF) of TFP by exporting and R&D status. Figure 1 displays the CDF of TFP. The TFP distributions of exporters are located on the right-hand side of that of nonexporters. Among exporters, exporters without R&D are distributed over the lowest productivity range, while exporters with both internal and external R&D are distributed over the highest productivity range. Exporters with internal R&D only and exporters with external R&D only are distributed over the middle productivity range. These graphical assessments suggest that i) exporters are more productive than nonexporters, ii) that among exporters, exporters with R&D are more productive than exporters without R&D, and iii) that exporters with both types of R&D are more productive than exporters with a single type of R&D.

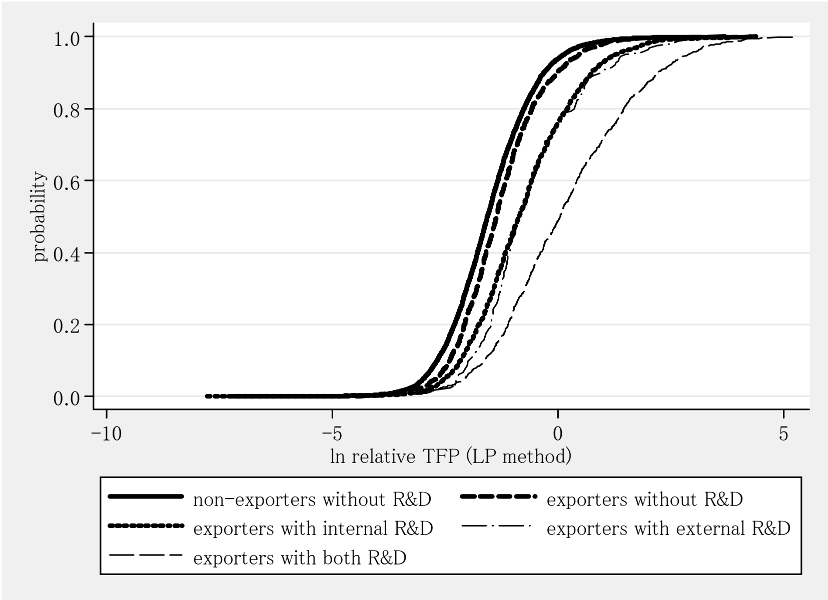

Figure 1: CDF of TFP in the manufacturing sector (2008).

Next, we formally examine the relationship between firm productivity and export/R&D status using the KS tests. Table 3 presents the KS test statistics for type A firms versus type B firms. From the test statistics, we can derive several conclusions regarding the TFP distribution: (i) the first row indicates that the productivity distribution of exporters with no R&D stochastically dominates the productivity distribution of nonexporters with no R&D, (ii) the second and third rows indicate that the productivity distribution of exporters with internal or external R&D only stochastically dominates the productivity distribution of exporters with no R&D, and (iii) the fifth and sixth rows indicate that the productivity distribution of exporters with both internal and external R&D stochastically dominates the productivity distribution of exporters with internal or external R&D only. Thus, we cannot reject the hypothesis of identical distributions of TFP for exporters with internal R&D relative to exporters with external R&D only.

Table 3

Kolmogorov-Smirnov tests statistic: Exports and R&D status (2008): Restricted sample			
N. of firms		Statistic	
Type A	Type B	Two-sided	One-sided
Non-exporter, No R&D	Exporter, No R&D	H0: equality	H0: A < B
6177	1210	0.096	-0.003
(45.3)	(08.9)	[0.000]	[0.979]
Exporter, No R&D	Exporter, Internal R&D	H0: equality	H0: A < B
1210	1865	0.220	-0.003
(08.9)	(13.7)	[0.000]	[0.989]
Exporter, No R&D	Exporter, External R&D	H0: equality	H0: A < B
1210	170	0.259	-0.002
(8.9)	(1.3)	[0.000]	[0.999]
Exporter, Internal R&D	Exporter, External R&D	H0: equality	H0: A < B
1865	170	0.086	-0.019
(13.7)	(1.3)	[0.217]	[0.893]
Exporter, Internal R&D	Exporter, Both R&D	H0: equality	H0: A < B
1865	1113	0.276	0.000
(13.7)	(8.2)	[0.000]	[1.000]
Exporter, External R&D	Exporter, Both R&D	H0: equality	H0: A < B
170	1113	0.282	-0.012
(1.3)	(8.2)	[0.000]	[0.961]

Notes: The data are for Japanese firms in 2008. The Table shows the Kolmogorov-Smirnov tests statistics for type A firms versus type B firms. Asymptotic P-values are shown in brackets. The share of each firm type in all types is shown in parenthesis.

Although the results of the KS test have the advantage of allowing the distributional nature of data, other factors affecting the performance are not considered here. The following section summarizes the results of the regression approach, which enables us to control for other influences on the performance of firms.

5.2 The QRs

Table 4 Estimation results of the QRs

Premia (dependent variable: ln TFP): Restricted sample						
	Pooled OLS	Quantile regressions				
		0.10	0.25	0.50	0.75	0.90
Export, No R&D	0.067***	0.070***	0.056***	0.065***	0.068***	0.049***
	[0.017]	[0.014]	[0.006]	[0.006]	[0.006]	[0.014]
Export, Internal R&D	0.147***	0.182***	0.154***	0.147***	0.133***	0.108***
	[0.021]	[0.009]	[0.004]	[0.005]	[0.004]	[0.010]
Export, External R&D	0.194***	0.151***	0.176***	0.162***	0.185***	0.240***
	[0.034]	[0.023]	[0.015]	[0.013]	[0.021]	[0.026]
Export, Both R&D	0.228***	0.259***	0.235***	0.219***	0.210***	0.194***
	[0.026]	[0.013]	[0.007]	[0.008]	[0.010]	[0.012]
ln K/L	0.139***	0.179***	0.173***	0.153***	0.133***	0.121***
	[0.021]	[0.005]	[0.004]	[0.003]	[0.004]	[0.003]
Foreign ownership ratio	0.239***	0.125***	0.168***	0.221***	0.272***	0.337***
	[0.033]	[0.014]	[0.014]	[0.013]	[0.018]	[0.011]
ln Labor	1.067***	1.075***	1.070***	1.067***	1.064***	1.060***
	[0.012]	[0.002]	[0.003]	[0.002]	[0.003]	[0.004]
R square	0.865	0.552	0.610	0.651	0.680	0.697
N	79248	79248				

Notes: Constants and industry and year fixed effects are suppressed. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in brackets. Nonexporters with positive R&D expenditure are excluded.

Next, we employ the QRs. While the KS tests only focus on firm productivity, the QRs allow us to examine the relationship between firm productivity and exporting/R&D status, controlling for other firm-specific variables such as capital-labor ratio, firm size, and foreign-ownership ratio.

We also employ OLS regression as a benchmark.

Table 4 presents the results. The results from the OLS indicate that the productivity premia are the largest for exporters with both types of R&D, followed by exporters with internal or external R&D only. Productivity premia of exporters with no-R&D against nonexporters is also positively significant.[5] The OLS estimates also show that capital-labor ratio, foreign-ownership ratio, and firm size are all statistically significantly and positively associated with higher productivity.

The results from QRs are qualitatively similar with the results from the KS tests in the sense that the results are consistent with the theoretically predicted ranking of productivity. The results show statistically significant and positive productivity premia for all types of exporters relative to nonexporters with no R&D in all cases.

Following Arnold and Hussinger (2010), we conducted *t*-tests to examine the statistical significance of the difference between random pairs of coefficients. The comparison of the estimated coefficients reveals that the premia for exporters with both types of R&D are consistently and significantly higher than for exporters with internal or external R&D only, with the exception of the highest two TFP quantiles in the comparison between exporters with both type of R&D and exporters with external R&D only. Further, the comparison also reveals that

[5] However, productivity premia of exporters with no-R&D as compared to non-exporters is positive but insignificant when we include non-exporters with R&D into non-exporters, as shown in Table A2.

the premia for exporters with single type of R&D are consistently and significantly higher than for exporters with no R&D.

While the OLS estimates only reveal the average relationship, the QR estimates reveal a richer description of the relationship between firm productivity and firm types. Specifically, the QRs reveal that the magnitude of the internal R&D dummy is large for less-productive firms, while that of external R&D is found to be large for more-productive firms. This result suggests that it is relatively easy for the least productive exporters to engage in external R&D but not internal R&D, while the most productive firms are likely to prefer external R&D to internal R&D.

With regard to the covariates, the QRs show that capital-labor ratio, foreign-ownership ratio, and firm size are all statistically significantly and positively associated with higher productivity. These results are the same as the results of the OLS.

Table A2 shows the result of QRs using the entire sample, including nonexporters engaged in R&D as the control group dummy. Again, the results indicate statistically significant and positive productivity premia for all types of exporters relative to nonexporters in almost all cases, with the exception of the highest TFP quantile for the exporters with no R&D dummy. One possible reason for this exception may be a lack of variation in the top quantile, since the number of exporters with no R&D decreases as the top of the productivity distribution approaches, as suggested in Arnold and Hussinger (2010).

6. Conclusion

The recent empirical literature on firm heterogeneity and international trade has attempted to relate a firm's R&D investment with exporting and suggested complementarity between the two activities. Nevertheless, the rise of open innovation in the past decade as a new R&D strategy has received little empirical attention in this context. To illuminate this issue, using firm-level data for Japanese manufacturing industries, this study examined the relationship between a firm's productivity and joint decision of R&D strategies and exporting.

First, exporting firms engaged in R&D activities were found to be more productive than nonexporters and exporters with no R&D, regardless of the internal and external R&D strategy. Further, exporters engaged in both R&D strategies were found to be most productive. The results suggest that the open innovation strategy is complementary to the in-house R&D strategy and crucial for further promoting innovations among internationalized firms. Second, in terms of whether there is a significant difference in the productivity of a firm that exports and employs the internal R&D strategy and one that exports and employs the external R&D strategy, the result of the nonparametric tests do not reject the equality of distributions. However, the results from QRs suggest that the choice between internal and external R&D by exporters differs according to productivity level. An external R&D strategy may be more applicable than an internal R&D strategy for less-productive exporters, and vice versa for more-productive exporters. This may reflect internalization by knowledge-intensive firms that face transaction costs associated with higher degrees of asset specificity.

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Appendix: Results using full sample

Table A1 KS test statistic: Exports and R&D status (2008): Full sample

N. of firms		Statistic	
Type A	Type B	Two-sided	One-sided
Non-exporter	Exporter, No R&D	H0: equality	H0: A < B
9266	1210	0.054	-0.024
(68.0)	(08.9)	[0.004]	[0.301]
Exporter, No R&D	Exporter, Internal R&D	H0: equality	H0: A < B
1210	1865	0.220	-0.003
(08.9)	(13.7)	[0.000]	[0.989]
Exporter, No R&D	Exporter, External R&D	H0: equality	H0: A < B
1210	170	0.259	-0.002
(8.9)	(1.3)	[0.000]	[0.999]
Exporter, Internal R&D	Exporter, External R&D	H0: equality	H0: A < B
1865	170	0.086	-0.019
(13.7)	(1.3)	[0.217]	[0.893]
Exporter, Internal R&D	Exporter, Both R&D	H0: equality	H0: A < B
1865	1113	0.276	0.000
(13.7)	(8.2)	[0.000]	[1.000]
Exporter, External R&D	Exporter, Both R&D	H0: equality	H0: A < B
170	1113	0.282	-0.012
(1.3)	(8.2)	[0.000]	[0.961]

Notes: The data are for Japanese firms in 2008. The Table shows the Kolmogorov-Smirnov tests statistics for type A firms versus type B firms. Asymptotic P-values are shown in brackets. The share of each firm type in all types is shown in parenthesis. Non-exporters including non-exporters with positive R&D expenditure.

Table A2 Productivity premia (dependent variable: ln TFP): Full sample

	Pooled OLS	Quantile regressions				
		0.10	0.25	0.50	0.75	0.90
Export, No R&D	0.022	0.034***	0.022***	0.026***	0.019***	-0.003
	[0.016]	[0.012]	[0.004]	[0.004]	[0.004]	[0.008]
Export, Internarl R&D	0.092***	0.130***	0.109***	0.097***	0.074***	0.047***
	[0.013]	[0.009]	[0.004]	[0.005]	[0.004]	[0.008]
Export, External R&D	0.140***	0.114***	0.131***	0.116***	0.129***	0.182***
	[0.032]	[0.025]	[0.020]	[0.011]	[0.019]	[0.037]
Export, Both R&D	0.157***	0.198***	0.172***	0.152***	0.135***	0.116***
	[0.017]	[0.009]	[0.009]	[0.007]	[0.010]	[0.007]
ln K/L	0.154***	0.194***	0.189***	0.169***	0.148***	0.135***
	[0.025]	[0.002]	[0.003]	[0.002]	[0.003]	[0.002]
Foreign ownership ratio	0.254***	0.123***	0.173***	0.228***	0.288***	0.372***
	[0.037]	[0.014]	[0.010]	[0.008]	[0.007]	[0.013]
ln Labor	1.078***	1.085***	1.081***	1.079***	1.077***	1.070***
	[0.010]	[0.003]	[0.001]	[0.002]	[0.002]	[0.003]
Pseudo R square	0.862	0.552	0.610	0.649	0.674	0.688
N	105023	105023				

Notes: Constants and industry and year fixed effects are suppressed. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in brackets.