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Internal R&D and External Knowledge Acquisition of Start-up Firms: Exploring the Role of Entrepreneurial Human Capital

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Internal R&D and External Knowledge Acquisition of Start-up Firms: Exploring the Role of Entrepreneurial Human Capital[*]

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Abstract

This study explores internal research and development (R&D) and external knowledge acquisition of firms during the start-up period, using panel data from original questionnaire surveys conducted in Japan. In particular, the study highlights the role of entrepreneurial human capital in the adoption of internal R&D and external knowledge acquisition strategies (licensing-in and joint R&D). Based on estimates of a bivariate probit model, the analysis provides evidence that firms managed by entrepreneurs with a high level of human capital are more likely to engage both in internal R&D and external knowledge acquisition. More specifically, while generic human capital, such as educational attainment, plays a significant role in explaining internal R&D, specific human capital, such as prior work experience in a related field or innovation experience, tends to have a prominent influence on external knowledge acquisition. As a supplementary analysis, the effectiveness of internal R&D and external knowledge acquisition strategies is assessed by examining the link with innovation outcomes (product innovations and patent applications). The results suggest that the two innovation strategies have positive effects on innovation outcomes.

Keywords: Start-up, entrepreneur, internal R&D, external knowledge acquisition, generic human capital, specific human capital.

JEL Classifications: M13, L26, O32.

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1. Introduction

It is widely held that start-up firms promote competition and enhance efficiency by driving inefficient firms out of the market (e.g., Siegfried and Evans, 1994; Geroski, 1995; Ito and Kato, 2016). In particular, innovative start-ups can help boost regional development and growth through knowledge spillovers (e.g., Fritsch and Mueller, 2004; Audretsch et al., 2008; Bos and Stam, 2014). However, because start-up firms typically have limited resources and experience, it is often not easy for them to innovate successfully. In practice, start-up firms tend to face difficulties in terms of both financing research and development (R&D) and acquiring external knowledge via partnerships, mainly because of information asymmetries between themselves and external stakeholders. For policy makers considering to provide support for start-up firms, it is therefore essential to understand what factors promote or prevent innovation by firms during the start-up period. This study addresses the R&D boundaries of the firm by examining factors affecting the adoption of internal R&D and external knowledge acquisition strategies of firms during the start-up period, an issue which has not been well understood.

Studies indicate that entrepreneurial human capital plays a critical role in the post-entry performance of firms, including innovation outcomes, partly because it can compensate for a lack of resources and experience. Colombo and Grilli (2005), for example, argue that individuals with greater human capital are likely to have better entrepreneurial judgment, and found that the level of human capital has a positive effect on the growth of high-tech start-ups.[1] However, few studies have examined the effects of entrepreneurial human capital on the post-entry strategies of firms, which should determine their post-entry performance.[2] In practice, entrepreneurs with high levels of human capital may

[1] Other studies that have found that entrepreneurial human capital plays an important role in firm performance include Bates (1990), Cressy (1996), Colombo and Grilli (2010) and Rauch and Rijsdijk (2013). See Unger et al. (2011) and Marvel et al. (2016) for reviews of the evidence.

[2] Exceptions are the studies by Colombo et al. (2006) and Okamuro et al. (2011) examining the determinants of alliance formation with a focus on the role of entrepreneurial human capital.

have more strategic options, since they may be able to raise more funding for further investments through the signaling of their capabilities to external providers of finance. In addition, experienced entrepreneurs can reduce the costs incurred in transactions with external partners, because they have substantial information about the business environment. It therefore seems likely that entrepreneurial human capital plays a key role in determining the innovation strategies of firms during the start-up period.

The purpose of this study is to examine the role of entrepreneurial human capital in the R&D boundaries of the firm during the start-up period, using panel data from questionnaire surveys conducted in Japan during 2008–2011. More specifically, the analysis in this study distinguishes between types of human capital and examines whether and how generic human capital, such as educational attainment, and specific human capital, such as prior work experience in a related field or innovation experience, play a role in the adoption of internal R&D and external knowledge acquisition strategies. Further, the effectiveness of the two different innovation strategies—internal R&D and external knowledge acquisition—is assessed by examining the link with innovation outcomes, which are measured in terms of product innovations and patent applications, and the policy implications of the findings are considered.

The remainder of the study is organized as follows. Section 2 discusses the background to the issues examined here, provides an overview of the related literature, and presents the hypotheses. Next, Section 3 describes the data employed in the analysis and explains the variables and methods used. Section 4 then presents the estimation results. Section 5 presents supplementary analyses, including an examination of the performance effects of the two different innovation strategies. Finally, Section 6 discusses the findings and concludes.

2. Background and hypotheses

2.1. Internal R&D and external knowledge acquisition

There is a considerable literature addressing the important question as to what factors determine the R&D boundaries of the firm. A key approach in this context is the transaction cost theory developed by Williamson (1975).[3] This theory suggests that internal transactions should be preferable in a situation with bounded rationality, uncertainty and complexity, opportunism, and information impactedness, which lead to transaction costs. The boundaries of the firm are determined by the trade-off between the transaction costs of using the market and the organizational costs of using hierarchies (Pisano, 1990, p.160). In the case of R&D activities, internal R&D is preferable when there are substantial transaction costs in external knowledge acquisition such as the costs of searching for partners.

The issue of the R&D boundaries of the firm is also related to the resource-based view of the firm (e.g., Wernerfelt, 1984; Barney, 1991). The resource-based view is also known as the capability theory, which dates back to Penrose (1959) and stresses the importance of resource accumulation in the growth of the firm.[4] Both the resource-based view and the capabilities-based theory highlight that resources are heterogeneous across firms and are essential as sources of sustained competitive advantage. However, because accumulating resources and enhancing capabilities through investment and learning takes time and is costly, firms may decide to use outside resources if this is cheaper than developing resources and capabilities themselves. Decisions on the boundaries of the firm—that is, what to do "in-house" and what to obtain from outside the firm—thus depend on the relative level of capabilities available internally versus capabilities available externally (Nakamura and Odagiri, 2005). That is, firms will acquire necessary resources or capabilities from outside

[3]For further discussion of transaction cost theory, see, for example, Shelanski and Klein (1995).

[4]The resource-based view was further developed into dynamic capabilities theory, which emphasizes the path-dependence of firms' resources and capabilities (e.g., Teece and Pisano, 1994; Teece et al., 1997; Eisenhardt and Martin, 2000).

when outside capabilities are superior to their own internal resources. Applying this theory to the case of R&D, firms with superior capabilities may invest more in internal R&D, because of their relatively high levels of internal capabilities compared to external capabilities. In contrast, other firms may try to acquire knowledge and skills from outside.

There is a rich body of literature empirically examining the R&D boundaries of the firm. For example, examining the determinants of internal R&D and external knowledge acquisition, Veugelers (1997) found that large firms tend to engage in internal R&D, and the propensity to cooperate on R&D decreases with firm size. Meanwhile, Veugelers and Cassiman (1999) found that smaller firms are more likely to choose an exclusive make-or-buy strategy, while larger firms tend to combine both make and buy strategies. On the other hand, some studies, such as Pisano (1990), highlight the importance of absorptive capacity that is needed to assimilate and exploit external knowledge. Audretsch et al. (1996) examined factors determining the decision of whether to rely on external knowledge and provided evidence that industry-specific characteristics, such as capital intensity, are important determinants. Furthermore, other studies, including Nakamura and Odagiri (2005), examined the role of appropriability conditions in industries as a determinant of the R&D boundaries of the firm. However, these studies have focused on established firms and there is little evidence on start-up firms.

Meanwhile, internal R&D and external knowledge acquisition are not necessarily mutually exclusive strategies, since many firms cannot complete the entire R&D process internally (see, e.g., Odagiri, 2003). To complement internal R&D, firms often rely on external knowledge from universities, public institutes, or other firms. Organisation for Economic Co-operation and Development (2015, p.143) shows that about 60% of R&D-active firms in Japan engage in collaboration for innovation. However, the study by Veugelers and Cassiman (1999), suggests that, as mentioned, small firms may be more likely to exclusively pursue either internal R&D or external knowledge acquisition than large firms, partly because of resource constraints.

2.2. The role of entrepreneurial human capital

It is widely recognized that start-up firms make a substantial contribution to the creation of new knowledge in the economy (see, e.g., Acs and Audretsch, 1990). As already discussed, however, it is not easy for start-up firms to be successful in innovation, because of scarce resources and experience. On the one hand, while innovative start-ups try to invest in R&D for new products, many of them encounter financial constraints (Denis 2004; Honjo et al. 2014). On the other hand, while many firms rely increasingly on external knowledge sources to compensate for a lack of resources or to obtain complementary assets, start-up firms tend to face difficulties in acquiring external technologies. While previous studies have addressed the R&D boundaries of the firm by asking whether firms conduct internal R&D and/or rely on external knowledge sources, few studies have been conducted on these issues focusing on start-up firms, which are quite different from established firms in terms of resource constraints and thus strategic options.

Given imperfections in capital markets, firms face difficulties in financing during the start-up period reflecting information asymmetries between them and external providers of finance due to the lack of a financial track record. As a result, external financing typically is more expensive than internal financing, so that entrepreneurs tend to rely on internal financing before resorting to external financing (Carpenter and Petersen, 2002). While firms normally rely on external financing once they have exhausted internal financing, firms during the start-up period often cannot obtain sufficient funds from capital markets due to credit rationing. It may therefore be harder for start-up firms to finance R&D than other firms. As highlighted by Carpenter and Petersen (2002), the returns to R&D investment tend to be skewed and highly uncertain, since R&D projects have a low probability of financial success. Meanwhile, Himmelberg and Petersen (1994) suggest that high-tech firms tend to be more credit-rationed than low-tech ones, partly because information asymmetries between firms and external providers of finance are more severe, so that adverse selection problems may be more pronounced in high-tech sectors. Moreover, unlike established firms, start-up firms cannot use accumulated retained profits to finance their R&D projects (Czarnitzki and Hottenrott, 2011). Finally, firms may be reluctant to reveal details of their R&D projects to outside lenders due to fears over disclosure to their rivals (Kamien and Schwartz, 1978; Guiso, 1998; Hall and Lerner, 2010).

Start-up firms are also confronted with information asymmetries between them and their prospective partners when acquiring external knowledge, because of a lack of experience in the field. As highlighted by Fontana et al. (2006), searching for useful sources of information, screening to identify the most suitable partners, and signaling technical and scientific capabilities to attract prospective partners plays an important role in external knowledge acquisition. In practice, firms without R&D experience may fail to find suitable partners, because they cannot convince prospective partners of their capabilities. Conversely, prospective partners may want to know details about the start-up firm and then identify whether the firm's knowledge and capabilities are valuable. Yet, although start-up firms tend to face the difficulties in acquiring external knowledge just described, they can increase opportunities for collaboration by mitigating information asymmetries through the signaling of their capabilities.

In this context, entrepreneurial human capital, consisting of generic and specific human capital, likely plays an important role and may therefore have a crucial impact on firms' innovation strategy during the start-up period.[5] On the one hand, generic human

[5] Several studies have examined the effects of entrepreneurial human capital on innovation performance, distinguishing between generic and specific human capital. For example, Marvel and Lumpkin (2007), using a sample of 145 technology entrepreneurs operating within university-affiliated incubators, found that both general and specific human capital affect innovation radicalness. Kato et al. (2015) also found that innovation-specific human capital, such as prior innovation experience, is directly associated with innovation outcomes, whereas generic human capital, such as educational attainment, affects innovation outcomes indirectly through R&D investment.

capital, which is often defined as general knowledge acquired through formal education, may be associated particularly with the adoption of internal R&D. The resource-based view of the firm suggests that firms managed by entrepreneurs with higher educational attainment may be able to raise more R&D funding, since educational attainment acts as a signal of capabilities to external providers of finance. The study by Parker and van Praag (2006) indicates that this is indeed the case. They found that an extra year of schooling relaxes the capital constraints of start-up firms, indicating that lenders are more willing to provide funds to better-educated entrepreneurs.[6] Moreover, as pointed out by Backes-Gellner and Werner (2007), entrepreneurs require analytical and problem-solving skills, especially in rapidly-changing circumstances under uncertainty. They argue that, consequently, narrow occupational skills very quickly become obsolete, while the ability to reason, analyze, communicate, and cross-check information is of more enduring value. Against this background, they found that entrepreneurs' educational attainment was more important than patent holdings to signal their capabilities to external providers of finance.[7]

On the other hand, specific human capital, which is generally formed through specific occupational experience such as work experience in a related field or innovation experience, may have some influence on the innovation strategies of firms, especially external knowledge acquisition.[8] Previous work experience in a related field is closely associated with specific occupational knowledge and skills as well as networks formed in previous jobs. Cassar (2014) argues that entrepreneurs with industry experience are able to more accurately forecast the performance of their firm, since experience in similar settings re-

[6]In addition, generic human capital tends to be positively associated with entrepreneurs' incomes (Åstebro and Bernhardt, 2005; Colombo and Grilli, 2005). Because of such a "wealth effect," entrepreneurs with high levels of human capital are less likely to be financially constrained than others, since they have access to their own personal capital.

[7]Furthermore, Honjo et al. (2014) argue that highly educated entrepreneurs have higher demand for R&D investment than less educated ones, because such entrepreneurs are more likely to have superior abilities to find better opportunities and conduct large-scale projects. Their analysis supports this argument, indicating that start-ups firms managed by highly educated entrepreneurs tended to invest more in R&D.

[8]According to Colombo and Grilli (2005), specific human capital consists of capabilities that entrepreneurs can directly apply to the entrepreneurial job in the newly created firm.

duces the number of unknowns and assumptions and provides entrepreneurs with more relevant and more accurate information about the environment in which they operate. Therefore, such entrepreneurs may have lower transaction costs, since they know more about their business environment, including prospective partners.

Meanwhile, previous innovation experience may reduce the costs incurred in searching for a partner, since entrepreneurs with innovation experience may have established a wide network with prospective partners, including academic institutions or other firms. Innovation experience may also serve as a signal of a firm's technological strength to external stakeholders (Narin et al., 1987). Such signaling may be effective for raising R&D funding from external providers of finance as well as convincing prospective partners of the firm's capabilities, so that it mitigates information asymmetries between firms and external stakeholders. Furthermore, as suggested by Cohen and Levinthal (1989, 1990), external knowledge acquisition may require a certain level of absorptive capacity, that is, the ability to identify, assimilate, and exploit external knowledge. While the literature focusing on established firms tends to regard the R&D stock as a measure of their absorptive capacity, in the case of start-up firms without R&D history, absorptive capacity can be regarded as essentially consisting of the entrepreneur's prior innovation experience. This suggests that firms managed by entrepreneurs with a high level of specific human capital, such as innovation experience, may have an advantage in pursuing collaborations and may also be able to raise more R&D funding.

For these reasons, it can be said that the role of entrepreneurial human capital, which is not well explored in the literature, is essential in firms' adoption of internal R&D and external knowledge acquisition strategies during the start-up period.

2.3. Hypotheses

Based on the above considerations, this section presents a number of hypotheses on the role of entrepreneurial human capital in explaining the adoption of internal R&D and external knowledge acquisition strategies.

Regarding internal R&D, entrepreneurs with a high level of human capital, especially generic human capital consisting of general knowledge acquired through formal education, are more likely to have access to external finance, since the level of human capital acts as a signal of the firm's capabilities to external providers of finance. In contrast, specific human capital, such as work experience in a related field or innovation experience, may signal specific occupational skills or technological strengths to external stakeholders, including external providers of finance. Therefore, entrepreneurs with a high level of specific human capital may be able to raise more R&D funding through external finance. As already explained, however, generic human capital may play a more important role than specific occupational skills in signaling capabilities to external providers of finance. This suggests that generic human capital may be particularly critical in financing R&D projects with higher risks. Taking these considerations into account, the following hypotheses are postulated.

Hypothesis 1a: Firms managed by entrepreneurs with a high level of human capital are more likely to engage in internal R&D.

Hypothesis 1b: Generic human capital is likely to play a more important role in internal R&D than specific human capital.

Meanwhile, as already discussed, specific human capital reduces the costs incurred in transactions with external partners, since entrepreneurs with a high level of specific human capital have substantial information about their business environment. Specific human capital also acts as a signal of a firm's technological strength to prospective partners, mitigating information asymmetries. Furthermore, prior innovation experience likely means that the firm has greater absorptive capacity, which in turn may facilitate collaboration with external partners. Consequently, specific human capital likely plays a critical role in the acquisition of external knowledge. In contrast, generic human capital may not necessarily be directly associated with capabilities for the acquisition of new knowledge from external partners. While this type of human capital is closely related to analytical and problem-solving skills, it cannot necessarily be directly applied to business situations. Generic human capital therefore likely is a weaker signal to prospective partners and specific human capital may be more effective in convincing prospective partners that innovation outcomes have a greater certainty. Based on these considerations, the following hypotheses are posited.

Hypothesis 2a: Firms managed by entrepreneurs with a high level of human capital are more likely to engage in external knowledge acquisition.

Hypothesis 2b: Specific human capital is likely to play a more important role in external knowledge acquisition than generic human capital.

The following section explains the data and empirical approach employed to test these hypotheses.

3. Data and approach

3.1. Data source

To the best of the author's knowledge, there is no publicly available dataset providing firm-level data on start-up firms in Japan. While the *Establishment and Enterprise Census* compiled by the government covers all establishments and firms in Japan, it does not include information on entrepreneur-specific characteristics. In addition, it is quite difficult to obtain information on firms' innovation activities during the start-up period. Therefore, this study is based on original questionnaire surveys of start-up firms in Japan conducted in the four years from 2008 to 2011 (four surveys in total). The first survey in November 2008 was sent to 13,582 firms in the manufacturing and software sectors that were incorporated between January 2007 and August 2008. Target firms were selected based on information obtained from Tokyo Shoko Research (TSR), a major Japanese credit reporting company. In the questionnaires, the founder of the firm was asked about firm-specific characteristics, such as the firm's finances, employment, and innovation activities, as well as the founder's personal characteristics, such as his/her education and experience.[9]

In the first survey conducted in 2008, the number of effective responses was 1,514 firms (for a response rate of approximately 11%). In the second and third surveys, the questionnaires were sent to the respondents of the first survey, that is, 1,514 firms. The numbers of effective responses in the second and third surveys were 899 (response rate: 59%) and 727 (48%). The questionnaires were then sent to those firms that had participated in the third survey, and effective responses were obtained from 508 firms (response rate: 70%). Therefore, overall, one-third of respondents to the first survey answered all survey rounds until 2011.

From among the responses in the first survey, 1,060 start-up firms that were established in 2007 or 2008 were identified. The database compiled by TSR contains newly incorporated firms, but also includes firms that had already been established as sole proprietorships before incorporation. In fact, the questionnaires indicated that one-third of responding firms had been established before December 2006. These were excluded from the sample since they were not "real" start-up firms. Meanwhile, because this study focuses on firms undertaking R&D activities, R&D-oriented start-up firms were identified based on whether founders conducted R&D or whether the firm employed R&D person-

[9] In the sample, there are some firms that have multiple founders. In these cases, the survey asked about the personal characteristics of the president of the firm.

nel at the time of start-up or afterward. 672 such firms were identified in the first survey. Dropping firms with missing values left an unbalanced panel of 357 R&D-oriented start-up firms (715 observations) for the period from 2008 to 2011.[10]

3.2. Variables

The dependent variables in this study are binary variables representing whether a firm had adopted internal R&D (INT) and/or engaged in external knowledge acquisition (EXT). INT is a dummy variable taking a value of 1 if the firm has positive R&D expenditures. EXT is a dummy variable taking a value of 1 if the firm has a contract for licensing-in or joint R&D projects. These variables are observed annually during 2008–2011, and therefore the values for each firm can change over time.

Turning to independent variables representing factors that potentially affect internal R&D and external knowledge acquisition, a range of variables capturing entrepreneur-, firm-, sector-, and year-specific characteristics are employed. Regarding entrepreneur-specific characteristics, educational attainment (EDU) is used as a measure of generic human capital. This is a dummy variable taking a value of 1 if the entrepreneur has university education at the undergraduate or graduate level. Work experience in a related field (REL_W) is used as a measure of specific human capital. REL_W is a dummy variable that takes a value of 1 if the entrepreneur has work experience in a related field gained before starting the firm. Another measure of specific human capital included in the model is prior innovation experience ($PINN$), which is a dummy variable that takes a value of 1 if the entrepreneur has produced innovation output (product/process innovations or patent applications) prior to the start-up of the firm.

Further, a dummy variable for entrepreneurs' work experience as a regular employee

[10]To focus on independent start-up firms, firms that were subsidiaries or affiliated firms were dropped from the sample.

(REG_W) in any field—not only a related field—is used. That is, while REL_W indicates work experience as a regular or non-regular employee in a related field, REG_W measures work experience more generally. Yet another variable included in the model is managerial experience ($MEXP$) to control for differences in knowledge and skills regarding how to manage a firm. $MEXP$ is a dummy variable taking a value of 1 if the entrepreneur has gained managerial experience in another firm before setting up the start-up firm. REG_W and $MEXP$ cannot be readily categorized as representing generic or specific human capital and are regarded as control variables, since they may involve both types of human capital.

Moreover, a dummy variable for affiliation to an academic association in the natural sciences ($ACAD$) is used to capture entrepreneurs' academic network. Entrepreneurs' age ($EAGE$) at start-up is also included as a control variable.

Regarding firm-specific characteristics, a number of variables are included in the model. The first is the amount of internal funding (IF). As discussed earlier, the cost of internal funding tends to be lower than that of external financing, so that firms typically use external financing only after their internal funding has been exhausted (e.g., Fazzari et al., 1988; Berger and Udell, 1998). Therefore, entrepreneurs that have more personal capital as a source of internal funding are less likely to be financially constrained than other entrepreneurs (e.g., Åstebro and Bernhardt, 2005; Colombo and Grilli, 2005). Including this variable in the model makes it possible to assess the effects of human capital while controlling for the wealth effect as measured by the amount of internal funding by entrepreneurs. In the questionnaire, entrepreneurs were asked about the amount of funding obtained at start-up from different sources such as the entrepreneurs themselves, their family, and friends. Here, the amount of internal funding is defined as the initial funding provided by the entrepreneurs themselves and their family and friends.

The second variable for firm-specific characteristics is firm age ($FAGE$), which is measured in terms of the number of months since the establishment of the firm. The variable is included to take into account the length of operation since start-up. Third, the number of workers ($SIZE$) is used to control for size differences between firms. The fourth variable for firm-specific characteristics is a dummy for firms established by more than one founder ($MFOUN$) to take into account the possibility that such firms are different from those founded by one entrepreneur in terms of their network and/or resources. Fifth, a variable representing perceived competitive pressure ($COMP$) is used to examine the effects of competition surrounding start-up firms, which is measured in terms of a 5-point Likert scale.

In addition to these variables for firm-specific characteristics, two sector dummies for the high-tech manufacturing and software sectors (the reference is the low-tech manufacturing sector) are included to control for sector-specific effects such as appropriability conditions. Finally, three year dummies (the reference year is the year 2008) are included in the model to take into account differences in macroeconomic conditions during the observation period.

Definitions of these variables are shown in Table 1.[11]

3.3. Estimation approach

Next, the empirical model to examine the factors affecting the adoption of internal R&D and external knowledge acquisition strategies are presented. As already discussed, while internal R&D and external knowledge acquisition are not necessarily mutually exclusive strategies, small firms are more likely to be involved in either internal R&D or external knowledge acquisition rather than both at the same time (Veugelers and Cassiman, 1999). Especially during the start-up period, small firms may not be able to raise funding for R&D due to information asymmetries and may therefore choose to rely on external knowledge

[11]Appendix Table A provides a correlation matrix of the variables.

sources. In practice, some firms do not have any internal R&D expenditures even when they are engaged in licensing-in or joint R&D projects. For example, there are some firms in the dataset in which firms collaborate with universities or public research institutes (PRIs) for which they do not have to use their own funds (e.g., in collaborations such as national projects funded by the government). Thus, while established firms tend to adopt external knowledge acquisition to complement internal R&D, it is not clear whether this is also the case for start-up firms.

The following two equations are employed to examine respectively the factors affecting the adoption of internal R&D and external knowledge acquisition strategies:

$$\text{Prob}(INT = 1) = f(Entrepreneur, Firm, Sector, Year, \epsilon), \tag{1}$$

$$\text{Prob}(EXT = 1) = f(Entrepreneur, Firm, Sector, Year, u), \tag{2}$$

where INT and EXT are the dependent variables, while $Entrepreneur$, $Firm$, $Sector$, and $Year$ stand for the variables representing entrepreneur-, firm-, sector-, and year-specific characteristics, and ϵ and u are the error terms. Since the dependent variables are binary, a probit model is adopted for each equation. While the causal relationship between internal R&D and external knowledge acquisition strategies is not clear, there is a possibility that the factors affecting decisions regarding the two strategies are interrelated. Therefore, if the correlation (ρ) between the error terms (ϵ and u) of the equations is not zero, a bivariate probit model is appropriate. In contrast, if the correlation (ρ) is zero, separate estimation of univariate probit models is appropriate. Based on a Wald test to verify if $\rho = 0$, the estimation results using the appropriate method are shown in the next section.

4. Results

4.1. Descriptive statistics

Before showing the estimation results, summary statistics for the dependent and independent variables are presented in Table 2. Starting with INT, Table 2 indicates that about 58% of R&D-oriented start-up firms in the sample have positive R&D expenditures. Further, with regard to EXT, the table shows that 43% of firms are engaged in external knowledge acquisition strategies (licensing-in or/and joint R&D).

Turning to the independent variables, 62% of entrepreneurs in the sample had university education at the undergraduate or graduate level (EDU), and 88% had work experience in a related field (REL_W). Further, 40% of entrepreneurs in the sample had a record of innovation output (product/process innovations or patent applications) prior to starting their firm. In addition, 93% of entrepreneurs had work experience as a regular employee (REG_W), and 30% had managerial experience in another firm ($MEXP$). The mean value of the logarithm of entrepreneurs' age at start-up ($EAGE$) is 3.8 (equivalent to about 46 years of age). The variable regarding academic affiliations ($ACAD$) indicates that 15% of entrepreneurs were affiliated with an academic association in the natural sciences.

The mean value of the variable for internal funding at start-up (IF) is 5.726 (equivalent to 3.1 million yen), with a range between 0 and 9.210 (100 million yen). The mean value of the logarithm of firm age measured in number of months ($FAGE$) is 2.969 (about 19.5 months). The average of the logarithm of the number of workers ($SIZE$) is 1.05 (fewer than 3 persons). Meanwhile, 46% of firms in the sample were established by multiple founders ($MFOUN$). The mean score of perceived competitive pressure is about 3.2, indicating that sample firms tended to face a moderately competitive environment.[12]

The number of observations and the frequency of internal R&D and external knowledge acquisition strategies by industry are shown in Table 3. For instance, looking at industries with at least 10 observations, while the share of firms conducting internal R&D is fairly high in some industries, such as electronic parts and devices (75.0%), it is much lower in other industries. In contrast, the share in the beverage and feed industry is only 36.4%, well below the average of 58.0% for all industries. Turning to external knowledge acquisition through either licensing-in or joint R&D, the share tends to be high in high-tech manufacturing sectors, such as precision machinery (77.4%), but below average (42.8%) in low-tech manufacturing and software sectors, such as beverage and feed (27.3%) and information services (35.8%). Furthermore, an important finding here is that EXT is more frequent than INT in some sectors such as information and communications equipment or precision machinery, suggesting that some firms engaged in external knowledge acquisition do not conduct internal R&D.

Next, Table 4 compares the means of the independent variables for firms that conduct internal R&D ($INT = 1$) and those that do not ($INT = 0$) and similarly for firms that are engaged in external knowledge acquisition ($EXT = 1$) and those that are not ($EXT = 0$). Starting with internal R&D, the table shows that the means of the educational attainment (EDU) and prior innovation experience ($PINN$) dummies and the dummy for membership in an academic association ($ACAD$) are significantly higher for firms that conduct internal R&D than firms that do not. The amount of internal funding (IF) is significantly higher for firms that engage in internal R&D. The means of the variables

[12] Although not shown in the table, the sector distribution of firms in the sample is as follows: 29% of firms fell into the high-tech manufacturing sector, 31% fell into the low-tech manufacturing sector, and the remaining 40% fell into the software sector. Further, the year dummies indicate that 47% of observations are for the first round of the survey. The number of observations declines over time, since some of the firms that responded to the first round did not reply to subsequent surveys or exited during the observation period.

for firm age and size ($FAGE$ and $SIZE$) are also significantly higher, suggesting that older and larger firms are more likely to engage in internal R&D than younger and smaller ones. Moreover, firms that face a less competitive environment ($COMP$) are more likely to engage in internal R&D.

Turning to EXT, firms that engage in external knowledge acquisition have significantly higher means of EDU, REL_W, $PINN$, $EAGE$, and $ACAD$ than firms that do not engage in external knowledge acquisition. In addition, as in the case of internal R&D, the amount of internal funding (IF) is significantly higher for firms that have adopted an external knowledge acquisition strategy; the means of the variables for firm age and size ($FAGE$ and $SIZE$) are significantly higher for such firms, suggesting that older and larger firms are more likely to engage in external knowledge acquisition than younger and smaller ones; and firms that face a less competitive environment ($COMP$) are more likely to engage in external knowledge acquisition.

4.2. Estimation results

The estimation results using the bivariate probit model are shown in Table 5, since—as shown at the bottom of the table—the error terms (ϵ and u) of Equations (1) and (2) presented in Section 3.3 are significantly correlated.

Starting with the role of generic human capital, the coefficient on the variable for educational attainment (EDU) is positive and statistically significant in the estimation for INT in columns (i), (iii), and (v), and positive but not significant in the estimation for EXT in columns (ii), (iv), and (vi). These results indicate that firms managed by entrepreneurs with a high level of generic human capital, as measured by educational attainment, are more likely to engage in internal R&D than other entrepreneurs. A possible interpretation based on the discussion above is that generic human capital acts as a signal of entrepreneurs' capabilities and that entrepreneurs with greater generic human capital hence find it easier to get access to external finance to fund internal R&D.

The effect of work experience in a related field (REL_W) is positive and statistically significant in the estimation for EXT in columns (ii), (iv), and (vi), while it is positive but insignificant in the estimation for INT in columns (i), (iii), and (v). This indicates that firms managed by entrepreneurs with high levels of specific human capital, as measured by their work experience prior to starting the firm, are more likely to engage in external knowledge acquisition. A possible interpretation of this result is that entrepreneurs' capabilities gained in a related field reduce the transaction costs involved in activities for external knowledge acquisition.

In addition, as shown in columns (i)–(vi) of Table 5, prior innovation experience ($PINN$) has a positive and significant effect both on INT and EXT. This indicates that firms managed by entrepreneurs with specific human capital, as measured by prior innovation experience, are more likely to engage both in internal R&D and external knowledge acquisition. Comparing the size of the coefficients and the significance levels, prior innovation experience has a greater effect on external knowledge acquisition than on internal R&D. As highlighted above, these results likely reflect that prior innovation experience potentially acts as a signal of superior technological capabilities to prospective partners as well as external providers of finance, reduces the costs of searching for partners, and may be related to the ability to identify, assimilate, and exploit external knowledge.

In contrast, work experience as a regular employee (REG_W) and managerial experience ($MEXP$) do not appear to have a significant impact on INT and EXT. Next, turning to entrepreneurs' age ($EAGE$), this has a significant negative effect on INT but no significant effect on EXT. While this variable was only included as a control variable, the negative effect on INT suggests that younger entrepreneurs are more likely to engage in internal R&D. The variable for affiliation with an academic association in the natural sciences ($ACAD$) has a positive and significant effect on both INT and EXT. While this variable was included to control for the extent of entrepreneurs' academic network, the significant coefficients indicate that such networks do play a role.

Looking at the other variables, internal funding (IF), which, as mentioned, was included to control for wealth effects, has a positive and significant impact only on INT. The effect of firm age ($FAGE$) is insignificant. Firm size ($SIZE$) has a positive and significant effect in all columns except (i), indicating that larger firms are more likely to engage both in internal R&D and external knowledge acquisition than smaller ones. On the other hand, the coefficient on the dummy for firms established by multiple founders ($MFOUN$) is insignificant in all specifications. Finally, the coefficients on the variable for perceived competitive pressure ($COMP$) are negative and significant in all columns, suggesting that less competitive conditions favor innovation.

In sum, the findings indicate that entrepreneurial human capital plays a crucial role in internal R&D and external knowledge acquisition strategies. The hypotheses presented in Section 2 are generally supported by the above findings.

5. Supplementary analysis

5.1. Alternative specification

So far, this study has examined factors affecting the adoption of internal R&D and external knowledge acquisition strategies, applying a bivariate probit model taking into account the correlation between the error terms of the two equations. To ensure the robustness of the findings, a multinomial logit model is estimated as an alternative, in which innovation strategies are classified into four mutually exclusive categories, namely, internal R&D only (INT_only), external knowledge acquisition only (EXT_only), both internal R&D and external knowledge acquisition (INT_EXT), and neither internal R&D nor external knowledge acquisition (NO_RD, base outcome). In the model, the choice among these alternatives is used as the dependent variable, based on the assumption that they are independent of each other. The means are as follows: INT_only, 0.298 (29.8%); EXT_only, 0.145 (14.5%); INT_EXT, 0.283 (28.3%); and NO_RD, 0.274 (27.4%). The independent variables are same as those used in the probit models.

The estimation results using the multinomial logit model are shown in Table 6. The variable for entrepreneurs' educational attainment (EDU), representing generic human capital, has a positive and significant effect on INT_EXT. In addition, the variable for work experience in a related field (REL_W) has a positive and significant effect on EXT_only and INT_EXT, with the coefficient being larger for the latter, INT_EXT. Furthermore, the variable for prior innovation experience ($PINN$) has a significant positive effect on INT_only, EXT_only, and INT_EXT, suggesting that entrepreneurs' prior innovation experience promotes R&D after start-up, regardless of the type of innovation strategies. Meanwhile, the results for the other variables are not very different from those using the bivariate probit model.

In sum, the results using the multinomial logit model indicate that firms managed by entrepreneurs with high levels of human capital are more likely to adopt internal R&D and external knowledge acquisition strategies, and therefore are generally consistent with the results of the probit model.

5.2. Performance effects

The analysis so far has examined factors affecting internal R&D and external knowledge acquisition strategies. However, it has not yet addressed whether and how innovation strategies are linked to innovation outcomes, a better understanding of which may help when considering public policies for R&D-oriented start-ups. As a supplementary analysis, therefore, the effectiveness of the two innovation strategies—internal R&D and external knowledge acquisition—is assessed by examining the link with innovation outcomes.

The relationship between R&D investment and innovation outcomes has been examined in a rich stream of literature (e.g., Pakes and Grilliches, 1984; Hall et al., 1986). In addition, previous studies on the effects of external knowledge acquisition have argued that relying on external knowledge sources is an essential strategy to obtain complimentary assets and achieve innovation outcomes efficiently. However, it is not always clear if external knowledge acquisition improves performance, since it involves a variety of transaction costs, including opportunistic behavior from partners (e.g., Williamson, 1975; Pisano, 1990). To clarify if innovation strategies are positively linked with outcomes, some scholars have addressed the effects of different innovation strategies. For example, Beneito (2006) examined the effects of in-house and contracted R&D on innovation performance, using patents and utility models. She found that internal R&D tends to lead to significant innovations, while contracted R&D tends to result in incremental innovations. Meanwhile, investigating the impact of internal and external R&D strategies on the profits of firms, Mata and Woerter (2013) found that external R&D strategies increase median profits as well as the dispersion of profits while the effect of internal R&D was not significant.[13]

This section conducts an analysis of the effects of internal R&D and external knowledge acquisition strategies on subsequent innovation outcomes using a probit model, in order to clarify not only whether those innovation strategies are linked with innovation outcomes but also whether there are complementarities between internal R&D and external knowledge acquisition strategies.

Here, to examine the link between innovation strategies and innovation outcomes, two

[13]On the other hand, there are also a number of studies examining whether there are complementarities between internal R&D and external knowledge acquisition. Tsai and Wang (2008), for example, found that while external knowledge acquisition has no significant effect on innovation performance per se, it does have a positive impact on the performance of firms that also conduct internal R&D. Other empirical studies, including Cassiman and Veugelers (2006), Lokshin et al. (2008), and Hagedoorn and Wang (2012), also found evidence of the existence of complementarities between the two types of R&D.

measures are used, product innovations (INN) and patent applications (PAT). To ensure that the analysis picks up the causal relationship from innovation strategies to innovation outcomes, innovation outcomes are measured in the following period, $t+1$. That is, the dummy variables INN and PAT take a value of one if firms achieve a product innovation or apply for a patent in $t+1$. The mean values of INN and PAT are 0.450 and 0.159, indicating that, on average, each year 45.0% of sample firms achieved a product innovation and 15.9% applied for a patent. As control variables, sector and year dummies are included in the model.

The estimation results are shown in Table 7. It should be noted that instead of coefficients the table presents marginal effects ($\mathrm{d}F/\mathrm{d}x$). INT and EXT are used as independent variables representing firms' innovation strategies, and columns (i) and (ii) show that they have a positive and significant effect on both INN and PAT. This result suggests that both internal R&D and external knowledge acquisition are important for achieving innovation outcomes. Next, in columns (iii) and (iv), INT_only, EXT_only, and INT_EXT (defined in the previous subsection) instead of INT and EXT are used as independent variables to represent the different combinations of innovation strategies. The columns indicate that firms that have adopted both internal R&D and external knowledge acquisition strategies are the most likely to achieve product innovations and patent applications. This result suggests that firms can achieve innovation outcomes when pursuing both internal R&D and external knowledge acquisition simultaneously, implying that there are complementarities between internal R&D and external knowledge acquisition.

6. Discussion and conclusions

Using a novel data set based on original questionnaire surveys conducted in Japan, this paper explored the role of entrepreneurial human capital, consisting of generic and specific human capital, in the adoption of internal R&D and external knowledge acquisition strategies. Unlike established firms, start-up firms tend to face difficulties in raising R&D funding and acquiring external knowledge, mainly because of severe information asymmetries between them and external stakeholders. Given this, it was argued that entrepreneurial human capital plays a crucial role in the innovation strategies of firms during the start-up period. The estimation results using the bivariate probit model indicate that entrepreneurs' educational attainment, which was employed as a measure of generic human capital, plays a significant role in the adoption of internal R&D strategies, but does not have a significant effect on the adoption of external knowledge acquisition strategies. In contrast, the entrepreneur's prior work experience in a related field, which was employed as a measure of specific human capital, has a significant influence on external knowledge acquisition, but does not affect internal R&D. In addition, it was found that prior innovation experience—another measure of specific human capital—has a significant impact on both internal R&D and external knowledge acquisition strategies, but it plays a larger and more significance role in the case of the latter. In these respects, the estimation results generally support the hypotheses suggesting that generic and specific human capital play different roles in internal R&D and external knowledge acquisition of firms during the start-up period.

Moreover, the supplementary analysis showed that firms that had adopted internal R&D and external knowledge acquisition strategies were more likely to achieve innovation outcomes. In particular, firms adopting the two strategies simultaneously are the most likely to achieve innovation outcomes. Taking the results in Tables 5–7 into account, it is likely that firms managed by entrepreneurs with a high level of human capital, by engaging in innovation strategies, contribute disproportionately to innovation. While previous studies have focused on firm- or industry-level factors, such as size and appropriability conditions, this study suggests that entrepreneur-specific factors are crucial in the innovation strategies of firms during the start-up period, regardless of whether they focus on internal R&D or external knowledge acquisition.

A number of limitations of this study should be pointed out. The first is that in terms of external knowledge acquisition strategies the analysis considered only formal R&D partnerships, namely licensing-in and joint R&D. However, external knowledge acquisition can also occur through informal networks—such as informal links to external organizations through science parks or industry clusters—that facilitate innovative activities and promote knowledge spillovers (e.g., Fukugawa, 2006; Link et al., 2007; Nishimura and Okamuro, 2011). The role of such informal links was not taken into account in the analysis. Second, while this study examined the role of entrepreneurial human capital focusing on the attributes of the president of the firm, some studies argue that the characteristics of the founding team, such as diverse prior affiliations, are important determinants of the performance of start-up firms (e.g., Delmar and Shane, 2006; Beckman et al., 2007). While this study took into account the presence of co-founders by including a dummy for firms with multiple founders, it did not explicitly examine the effects of characteristics of the founding team. Third, as highlighted in studies such as those by Unger et al. (2011) and Kato and Honjo (2015), the role of entrepreneurial human capital may differ depending on the industry environment. While this study controlled for differences in the business environment by including sector dummies, it did not address this issue explicitly. Finally, it is possible that there are response or survivorship biases in the repeated questionnaire surveys, since some firms did not respond to the surveys, while others exited over time. To check for response biases in the first survey, the region and industry distributions of the survey population and responding firms were compared. While this comparison provided little evidence of response bias in the first survey, data limitations meant that it was not possible to check for any survivorship biases. These limitations should be taken into account in future analyses.

This study has some implications for public policies. Since there may be underinvestment in R&D relative to the social optimum in the presence of R&D spillovers (that is, positive externalities), the government can justify intervention in support of R&D-oriented start-ups. On the one hand, as some scholars argue, public policies could focus more on start-ups with significant growth potential in order to boost economic growth (e.g., Santarelli and Vivarelli 2002; Shane, 2009; Grilli, 2014). In this regard, the present study suggests that the government should place high priority on public support for entrepreneurs with high levels of human capital as a way to achieve further innovation and thus economic growth. On the other hand, start-ups with growth potential may attract more investment from the private sector, including venture capital, than other start-ups. Therefore, there may not be any need for the government to support start-up entrepreneurs in terms of R&D financing, and such support might in fact crowd out R&D investment from the private sector (e.g., Wallsten, 2000; Lach, 2002; García-Quevedo, 2004). Alternatively, the government could support entrepreneurs with low levels of human capital, since such entrepreneurs may not attract investment from the private sector, including venture capital. In addition, policy makers should consider more opportunities for research matching for entrepreneurs that encounter difficulties in finding external partners. In these respects, this study provides some clues for the future direction of public policies on innovative start-ups.

Appendix

This appendix provides additional evidence on factors affecting internal R&D and external knowledge acquisition strategies by distinguishing different modes of external knowledge acquisition, that is, licensing-in and joint R&D. In the case of external knowledge acquisition through licensing-in, the technology to be traded has already been invented and patented before the contract is made for the transaction (Odagiri, 2003). While invented technology is typically complete, when it is incomplete further R&D efforts by the licensee are necessary. In contrast, joint R&D is conducted by researchers across multiple organizations, including firms, universities, and public research institutes (PRIs). According to Odagiri (2003), typically, research is determined by mutual consent between partners, the expenditures are shared, and the property rights are jointly held. In some joint R&D projects with universities and PRIs (e.g., national projects funded by the government), firms do not have to spend any funds. In the case of joint R&D, the licensee has to make some effort to achieve innovation outcomes, unlike in the case of technology acquisition through licensing-in.

To estimate the factors affecting internal R&D (INT), licensing-in ($LICEN$), and joint R&D (JO_RD) respectively, a multivariate probit model taking the correlations between the three equations into account is adopted. The estimation results are presented in Appendix Table B. They show that while specific human capital, represented by work experience in a related field and innovation experience, has a positive and significant effect on joint R&D (JO_RD), it has no significant effect on licensing-in ($LICEN$). This result indicates that entrepreneurial human capital plays a more important role in conducting joint R&D than in technology acquisition through licensing-in.

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Table 1: Definition of variables

Variable	Definition
(Dependent variables)	
INT	Dummy variable: 1 if the firm has positive R&D expenditures in period t, 0 otherwise.
EXT	Dummy variable: 1 if the firm has a contract for licensing-in or joint R&D projects in period t, 0 otherwise.
(Independent variables)	
Entrepreneur-specific characteristics	
EDU	Dummy variable: 1 if the entrepreneur has university education at the undergraduate or graduate level, 0 otherwise.
REL_W	Dummy variable: 1 if the entrepreneur has work experience in a related field, 0 otherwise.
$PINN$	Dummy variable: 1 if the entrepreneur has experience in product/process innovation or patent applications, 0 otherwise.
REG_W	Dummy variable: 1 if the entrepreneur has work experience as a regular employee in another firm, 0 otherwise.
$MEXP$	Dummy variable: 1 if the entrepreneur has managerial experience in another firm, 0 otherwise.
$EAGE$	Natural logarithm of the entrepreneur's age at start-up.
$ACAD$	Dummy variable: 1 if the entrepreneur is a member of an academic association in the natural sciences, 0 otherwise
Other characteristics	
IF	Logarithm of the amount of internal funding (founder's own funding plus his or her family's and friends' funding; million yen) at start-up, plus one.
$FAGE$	Natural logarithm of the number of months since the establishment of the firm in period t.
$SIZE$	Natural logarithm of the number of workers (including the manager) in period t.
$MFOUN$	Dummy variable: 1 if the firm was established by multiple founders, 0 otherwise.
$COMP$	5-point Likert scale on the intensity of competition perceived by the firm in period t, with a range from 1 (competition is weak) to 5 (competition is strong).

Table 2: Summary statistics for variables

Variable	Mean	S.D.	Min.	Max.
(Dependent variables)				
INT	0.580	0.494	0	1
EXT	0.428	0.495	0	1
(Independent variables)				
Entrepreneur-specific characteristics				
EDU	0.621	0.485	0	1
REL_W	0.880	0.326	0	1
$PINN$	0.399	0.490	0	1
REG_W	0.927	0.260	0	1
$MEXP$	0.299	0.458	0	1
$EAGE$	3.806	0.254	2.996	4.477
$ACAD$	0.147	0.354	0	1
Other characteristics				
IF	5.726	1.342	0	9.210
$FAGE$	2.969	0.666	1.386	4.060
$SIZE$	1.046	0.857	0	3.689
$MFOUN$	0.462	0.499	0	1
$COMP$	3.176	1.379	1	5

Note: The number of observations is 715. S.D. stands for standard deviation.

Table 3: Adoption of internal R&D (INT) and external knowledge acquisition strategies (EXT) by industry

Industry	INT		EXT		N
	Yes	(%)	Yes	(%)	
Food	15	46.9	14	43.8	32
Beverage and feed	4	36.4	3	27.3	11
Textiles	4	100.0	1	25.0	4
Apparel and textiles products	21	63.6	15	45.5	33
Lumber and wood products	4	40.0	4	40.0	10
Furniture and fixtures	4	80.0	1	20.0	5
Pulp, paper, and paper products	2	33.3	3	50.0	6
Printing	3	42.9	2	28.6	7
Chemicals	25	71.4	21	60.0	35
Petroleum and coal products	1	50.0	0	0.0	2
Plastic products	8	61.5	7	53.8	13
Rubber products	0	0.0	0	0.0	3
Leather, leather products, and fur skins	0	0.0	0	0.0	2
Ceramic, stone, clay products	7	63.6	5	45.5	11
Iron and steel	0	0.0	0	0.0	1
Non-ferrous metals and products	2	50.0	2	50.0	4
Fabricated metal products	10	58.8	6	35.3	17
General machinery	41	66.1	31	50.0	62
Electrical machinery	21	63.6	14	42.4	33
Information and communications equipment	7	53.8	9	69.2	13
Electronic parts and devices	21	75.0	14	50.0	28
Transportation machinery	2	33.3	1	16.7	6
Precision machinery	21	67.7	24	77.4	31
Miscellaneous manufacturing	30	51.7	26	44.8	58
Information services	162	56.3	103	35.8	288
Total	415	58.0	306	42.8	715

Note: N indicates the number of observations.

Table 4: Means of independent variables for INT=1 vs. 0 and EXT=1 vs. 0.

	INT			EXT		
Variable	0 (N=300)	1 (N=415)	p-value	0 (N=409)	1 (N=306)	p-value
(Entrepreneur-specific characteristics)						
EDU	0.547	0.675	0.001	0.592	0.660	0.062
REL_W	0.863	0.892	0.252	0.851	0.918	0.006
$PINN$	0.327	0.451	0.001	0.301	0.529	0.000
REG_W	0.923	0.930	0.730	0.917	0.941	0.216
$MEXP$	0.307	0.294	0.715	0.293	0.307	0.691
$EAGE$	3.802	3.809	0.711	3.790	3.828	0.047
$ACAD$	0.073	0.200	0.000	0.098	0.212	0.000
(Other characteristics)						
IF	5.546	5.856	0.002	5.649	5.829	0.076
$FAGE$	2.902	3.017	0.023	2.879	3.089	0.000
$SIZE$	0.975	1.097	0.061	0.948	1.176	0.000
$MFOUN$	0.480	0.448	0.400	0.443	0.487	0.239
$COMP$	3.337	3.060	0.007	3.297	3.015	0.006

Note: The table compares the means of firms that conduct internal R&D ($INT = 1$) and those that do not ($INT = 0$) and similarly for firms that are engaged in external knowledge acquisition ($EXT = 1$) and those that are not ($EXT = 0$). N indicates the number of observations. The columns labeled p-value show the p-value of significance tests for the difference in the means (t test for continuous variables and Wilcoxon rank-sum (Mann-Whitney) test for discrete variables).

Table 5: Estimation results: Internal R&D (INT) and external knowledge acquisition (EXT)

Variable	Bivariate probit model		Bivariate probit model		Bivariate probit model	
	(i) INT	(ii) EXT	(iii) INT	(iv) EXT	(v) INT	(vi) EXT
(Entrepreneur-specific characteristics)						
EDU	0.252**	0.112	0.320***	0.159	0.272***	0.112
	(0.105)	(0.106)	(0.104)	(0.104)	(0.104)	(0.106)
REL_W	0.211	0.609***	0.174	0.585***	0.221	0.608***
	(0.164)	(0.176)	(0.161)	(0.177)	(0.163)	(0.177)
$PINN$	0.222**	0.513***	0.263**	0.549***	0.217**	0.512***
	(0.107)	(0.107)	(0.105)	(0.106)	(0.107)	(0.107)
REG_W	-0.246	-0.118	-0.235	-0.102	-0.257	-0.118
	(0.202)	(0.209)	(0.201)	(0.209)	(0.202)	(0.209)
$MEXP$	-0.011	0.061	-0.035	0.050	-0.004	0.062
	(0.112)	(0.114)	(0.112)	(0.113)	(0.111)	(0.114)
$EAGE$	-0.415*	-0.294	-0.369*	-0.266	-0.388*	-0.293
	(0.219)	(0.228)	(0.217)	(0.225)	(0.219)	(0.227)
$ACAD$	0.500***	0.349**			0.499***	0.349**
	(0.158)	(0.150)			(0.158)	(0.150)
(Other characteristics)						
IF	0.068*	0.002	0.0685*	0.003		
	(0.038)	(0.040)	(0.038)	(0.039)		
$FAGE$	-0.132	0.109	-0.119	0.118	-0.144	0.109
	(0.142)	(0.153)	(0.142)	(0.152)	(0.142)	(0.153)
$SIZE$	0.101	0.153**	0.115*	0.165**	0.123*	0.153**
	(0.065)	(0.066)	(0.064)	(0.066)	(0.064)	(0.064)
$MFOUN$	-0.089	0.133	-0.112	0.113	-0.092	0.133
	(0.107)	(0.108)	(0.106)	(0.108)	(0.108)	(0.108)
$COMP$	-0.091**	-0.110***	-0.106***	-0.123***	-0.095**	-0.110***
	(0.038)	(0.038)	(0.038)	(0.037)	(0.038)	(0.038)
Constant term	1.491	-0.071	1.330	-0.178	1.779*	-0.063
	(0.970)	(1.029)	(0.963)	(1.020)	(0.959)	(1.019)
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
ρ	0.115		0.128		0.116	
	(0.064)		(0.063)		(0.064)	
Number of observations	715		715		715	
Log pseudolikelihood	-889.474		-896.484		-891.063	
Wald test (ρ=0)	3.197*		4.047**		3.244*	

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Table 6: Estimation results: Internal R&D only (INT_only), external knowledge acquisition only (EXT_only), and both (INT_EXT).

Variable	Multinomial logit model (i)			Multinomial logit model (ii)			Multinomial logit model (iii)		
	INT_only	EXT_only	INT_EXT	INT_only	EXT_only	INT_EXT	INT_only	EXT_only	INT_EXT
(Entrepreneur-specific characteristics)									
EDU	0.261	-0.045	0.610**	0.292	-0.080	0.756***	0.314	-0.013	0.634***
	(0.219)	(0.259)	(0.241)	(0.217)	(0.262)	(0.235)	(0.218)	(0.259)	(0.239)
REL_W	0.242	1.001**	1.218***	0.218	1.005**	1.135***	0.265	1.015**	1.231***
	(0.312)	(0.456)	(0.418)	(0.306)	(0.449)	(0.410)	(0.307)	(0.455)	(0.414)
$PINN$	0.714***	1.396***	1.123***	0.728***	1.384***	1.234***	0.701***	1.390***	1.119***
	(0.244)	(0.288)	(0.253)	(0.241)	(0.288)	(0.250)	(0.242)	(0.286)	(0.251)
REG_W	-0.250	0.048	-0.573	-0.249	0.058	-0.515	-0.278	0.035	-0.580
	(0.390)	(0.562)	(0.454)	(0.388)	(0.564)	(0.449)	(0.393)	(0.567)	(0.457)
$MEXP$	0.021	0.204	0.085	0.004	0.205	0.044	0.039	0.210	0.088
	(0.234)	(0.284)	(0.252)	(0.234)	(0.285)	(0.250)	(0.231)	(0.285)	(0.250)
$EAGE$	-0.957**	-0.958	-1.013**	-0.937**	-0.984	-0.869*	-0.878**	-0.904	-0.968*
	(0.444)	(0.610)	(0.503)	(0.439)	(0.601)	(0.494)	(0.446)	(0.609)	(0.502)
$ACAD$	0.287	-0.257	1.029***				0.298	-0.250	1.038***
	(0.361)	(0.505)	(0.337)				(0.360)	(0.504)	(0.335)
(Other characteristics)									
IF	0.187***	0.109	0.087	0.190***	0.112	0.094			
	(0.067)	(0.096)	(0.092)	(0.067)	(0.098)	(0.089)			
$FAGE$	-0.129	0.427	-0.060	-0.124	0.428	-0.025	-0.159	0.416	-0.065
	(0.278)	(0.387)	(0.331)	(0.279)	(0.388)	(0.323)	(0.279)	(0.385)	(0.331)
$SIZE$	0.089	0.153	0.397***	0.091	0.141	0.426***	0.140	0.180	0.416***
	(0.143)	(0.179)	(0.152)	(0.142)	(0.180)	(0.151)	(0.142)	(0.175)	(0.148)
$MFOUN$	-0.134	0.271	0.068	-0.141	0.290	0.018	-0.136	0.269	0.067
	(0.220)	(0.288)	(0.241)	(0.219)	(0.286)	(0.238)	(0.221)	(0.288)	(0.241)
$COMP$	-0.012	0.000	-0.303***	-0.015	0.007	-0.338***	-0.024	-0.007	-0.309***
	(0.079)	(0.100)	(0.086)	(0.078)	(0.100)	(0.085)	(0.079)	(0.100)	(0.086)
Constant term	2.380	-0.450	2.091	2.304	-0.385	1.479	3.152*	-0.050	2.395
	(1.900)	(2.607)	(2.373)	(1.883)	(2.573)	(2.334)	(1.890)	(2.590)	(2.348)
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations		715			715			715	
Log pseudolikelihood		-875.469			-883.269			-878.348	
Pseudo R^2		0.095			0.087			0.092	

Note: The reference group is firms that engage in neither internal R&D nor external knowledge acquisition (NO_RD). Robust standard errors are in parentheses. ***, ** and * indicate 1%, 5% and 10% significance levels, respectively.

Table 7: Estimation results (marginal effects): Innovation outcomes.

Variable	Probit model		Probit model	
	(i) INN	(ii) PAT	(iii) INN	(iv) PAT
(Non-exclusive strategies)				
INT	0.112**	0.140***		
	(0.048)	(0.039)		
EXT	0.215***	0.157***		
	(0.044)	(0.033)		
(Exclusive strategies)				
INT_only			0.058	0.097*
			(0.063)	(0.057)
EXT_only			0.135*	0.101
			(0.077)	(0.065)
INT_EXT			0.318***	0.273***
			(0.059)	(0.051)
Sector dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of observations	422	422	422	422
Log pseudolikelihood	-267.393	-162.052	-266.561	-161.610
Pseudo R^2	0.079	0.123	0.082	0.125

Note: Robust standard errors are in parentheses. ***, ** and * indicate 1%, 5% and 10% significance levels, respectively.

Table A. Correlation matrix of variables

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) INT	1.000													
(2) EXT	0.140	1.000												
(3) EDU	0.130	0.070	1.000											
(4) REL_W	0.043	0.103	0.030	1.000										
(5) $PINN$	0.125	0.231	0.077	-0.006	1.000									
(6) REG_W	0.013	0.046	0.181	0.228	0.140	1.000								
(7) $MEXP$	-0.014	0.015	0.007	-0.143	-0.039	-0.193	1.000							
(8) $EAGE$	0.014	0.074	0.104	-0.108	0.248	0.082	0.167	1.000						
(9) $ACAD$	0.177	0.160	0.235	-0.029	0.227	0.101	-0.047	0.148	1.000					
(10) IF	0.114	0.066	0.106	0.012	0.039	0.004	0.082	0.137	0.072	1.000				
(11) $FAGE$	0.085	0.157	-0.002	0.052	0.029	0.036	-0.010	0.035	0.059	0.059	1.000			
(12) $SIZE$	0.070	0.132	-0.083	-0.021	0.021	0.027	0.122	0.073	0.039	0.215	0.201	1.000		
(13) $MFOUN$	-0.032	0.044	-0.075	-0.149	-0.055	-0.076	0.124	0.024	-0.075	0.056	0.034	0.334	1.000	
(14) $COMP$	-0.099	-0.101	-0.063	0.135	-0.130	0.028	-0.016	-0.176	-0.196	-0.041	0.025	0.160	0.117	1.000

Note: The number of observations is 715.

Table B. Estimation results: Internal R&D (INT), licensing-in ($LICEN$), and joint R&D (JO_RD).

	Multivariate probit model			Multivariate probit model			Multivariate probit model		
Variable	(i) INT	(ii) $LICEN$	(iii) JO_RD	(iv) INT	(v) $LICEN$	(vi) JO_RD	(vii) INT	(viii) $LICEN$	(ix) JO_RD
(Entrepreneur-specific characteristics)									
EDU	0.252**	0.192	0.059	0.319***	0.223	0.111	0.271***	0.188	0.068
	(0.105)	(0.156)	(0.109)	(0.104)	(0.153)	(0.106)	(0.104)	(0.155)	(0.108)
REL_W	0.206	0.263	0.566***	0.168	0.258	0.541***	0.216	0.260	0.576***
	(0.165)	(0.240)	(0.183)	(0.161)	(0.244)	(0.184)	(0.164)	(0.242)	(0.183)
$PINN$	0.221**	0.051	0.536***	0.264**	0.083	0.576***	0.216**	0.051	0.534***
	(0.107)	(0.153)	(0.108)	(0.105)	(0.150)	(0.107)	(0.107)	(0.153)	(0.108)
REG_W	-0.242	-0.629**	0.106	-0.230	-0.619**	0.126	-0.253	-0.626**	0.093
	(0.202)	(0.244)	(0.224)	(0.201)	(0.244)	(0.224)	(0.202)	(0.245)	(0.226)
$MEXP$	-0.011	0.153	-0.009	-0.035	0.150	-0.021	-0.003	0.153	-0.004
	(0.112)	(0.148)	(0.116)	(0.112)	(0.147)	(0.116)	(0.111)	(0.148)	(0.116)
$EAGE$	-0.411*	-0.123	-0.162	-0.364*	-0.091	-0.130	-0.384*	-0.127	-0.152
	(0.219)	(0.330)	(0.234)	(0.217)	(0.330)	(0.232)	(0.219)	(0.328)	(0.233)
$ACAD$	0.500***	0.239	0.365**				0.499***	0.237	0.367**
	(0.158)	(0.194)	(0.151)				(0.158)	(0.194)	(0.151)
(Other characteristics)									
IF	0.068*	-0.011	0.034	0.069*	-0.009	0.035			
	(0.038)	(0.051)	(0.043)	(0.038)	(0.052)	(0.042)			
$FAGE$	-0.133	-0.100	0.181	-0.121	-0.090	0.189	-0.145	-0.098	0.174
	(0.143)	(0.216)	(0.162)	(0.142)	(0.216)	(0.160)	(0.143)	(0.216)	(0.161)
$SIZE$	0.101	0.170**	0.144**	0.115*	0.182**	0.157**	0.123*	0.166**	0.154**
	(0.065)	(0.085)	(0.067)	(0.064)	(0.086)	(0.067)	(0.064)	(0.083)	(0.065)
$MFOUN$	-0.087	0.306**	0.041	-0.110	0.288**	0.023	-0.091	0.305**	0.039
	(0.107)	(0.143)	(0.111)	(0.106)	(0.143)	(0.111)	(0.107)	(0.143)	(0.111)
$COMP$	-0.091**	-0.084	-0.100***	-0.107***	-0.092*	-0.114***	-0.095**	-0.083	-0.101***
	(0.038)	(0.053)	(0.039)	(0.037)	(0.052)	(0.038)	(0.038)	(0.053)	(0.038)
Constant term	1.480	-0.601	-1.182	1.317	-0.758	-1.310	1.768*	-0.649	-1.021
	(0.972)	(1.520)	(1.072)	(0.965)	(1.522)	(1.066)	(0.961)	(1.510)	(1.064)
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ρ_{21}		0.081			0.092			0.080	
		(0.081)			(0.079)			(0.081)	
ρ_{31}		0.110*			0.123**			0.113*	
		(0.063)			(0.062)			(0.063)	
ρ_{32}		0.088			0.093			0.088	
		(0.076)			(0.076)			(0.076)	
Number of observations		715			715			715	
Log pseudolikelihood		-1068.039			-1075.779			-1069.945	
Loglikelihood ratio test (ρ=0)		5.171			6.412*			5.348	

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% significance level, respectively.