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Yuji Honjo, Masatoshi Kato and
Hiroyuki Okamuro

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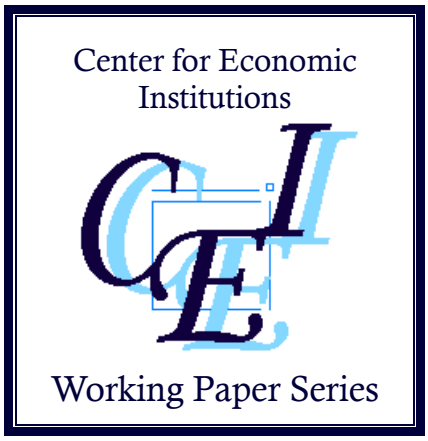

Institute of Economic Research
Hitotsubashi University
2-1 Naka, Kunitachi, Tokyo, 186-8603 JAPAN
http://cei.ier.hit-u.ac.jp/English/index.html
Tel:+81-42-580-8405/Fax:+81-42-580-8333

R&D financing of start-up firms: How much does founders' human capital matter?*

Yuji Honjo†

Masatoshi Kato‡

Hiroyuki Okamuro§

Abstract

This paper explores research and development (R&D) financing of start-up firms. Using a sample from an original survey conducted in 2008, we identify whether initial funds and founder-specific characteristics relate to R&D investment of start-up firms in Japan. It is found that internal finance is positively associated with R&D investment. It is also found that founders with higher educational background, prior innovation output and academic affiliation tend to raise more funds for R&D. On the other hand, we provide evidence that the effects of founders' human capital are mediated by investment opportunities, which would indicate that R&D investment of start-up firms depends heavily on investment opportunities.

JEL classification: G30; M13; O32.

Keywords: Founder; Human capital; Internal finance; R&D; Start-up.

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†Faculty of Commerce, Chuo University
Address : 742-1 Higashinakano, Hachioji, Tokyo 192-0393, Japan
E-mail : yhonjo@tamacc.chuo-u.ac.jp

‡Institute of Economic Research, Hitotsubashi University
E-mail : mkato@ier.hit-u.ac.jp

§Graduate School of Economics, Hitotsubashi University
E-mail : okamuro@econ.hit-u.ac.jp

1. Introduction

When founders start businesses, financing is essential to the success of the businesses. At start-up, most, if not all, firms have access not only to internal but also to external capital. However, some cannot obtain sufficient funds for investment from external capital markets due to information asymmetries between founders and providers of external capital. Especially for high-tech start-ups, financing of research and development (R&D) is critical, and financial constraints often discourage investment in R&D projects. The lack of funds for R&D may sometimes threaten the solvency of the firms.

Whereas physical capital of start-up firms tends to be scarce, founders' human capital plays a crucial role as valuable resources of start-up firms. Founders' human capital may have a significant impact on R&D financing. Founders with high human capital are expected to succeed in R&D projects, which would yield large profits. Such firms may tend to raise more funds for investment from external capital markets. Even though, in practice, capital markets are not perfect, founders' human capital may signal their potential capabilities to providers of external capital. For these reasons, it is conceivable that R&D investment decisions depend on the founder's human capital. Nevertheless, the effects of human capital of founders on R&D investment have been largely ignored in previous literature. One reason is that there are few data sources including R&D investment and financing of start-up firms.

This paper explores R&D financing of start-up firms. Using a sample from an original survey conducted in 2008, we identify whether initial funds and founder-specific characteristics relate to R&D investment of start-up firms in Japan. It is found that internal finance is positively associated with R&D investment. It is also found that founders with higher educational background,

prior innovation output and academic affiliation tend to raise more funds for R&D. On the other hand, R&D investment may depend heavily on investment opportunities. Therefore, we estimate the determinants of R&D investment, taking into account the demand for R&D.

The remainder of the paper is organized as follows. In the following section, we review related literature. Section 3 discusses the theoretical background for understanding R&D financing of start-up firms, and shows our analytical framework. Section 4 describes the data used in the analysis. The estimation methods and results are presented in Section 5. The final section includes some concluding remarks.

2. Literature review

A large number of studies have argued that firms face difficulties in their access to external capital markets (e.g., Leland and Pyle, 1977; Myers and Majluf, 1984). Even though a firm with high growth potential starts a business, providers of external capital, such as banks and investors, cannot accurately assess the potentiality. This is due to capital market imperfections stemming from information asymmetries between firms and providers of external capital. It is often argued that the cost of external finance increases by monitoring cost and risk premium. Also, as Carpenter and Petersen (2002a) emphasize, because of adverse selection and moral hazard problems, external finance is more expensive than internal finance. More specifically, information asymmetries are relatively large at start-up, since start-up firms lack track records. These firms are likely to face difficulties in financing, and funding gaps would arise from imperfections in capital markets.[1]

[1]For an overview of entrepreneurial finance, see, for example, Denis (2004).

For start-up firms, it may be more difficult to finance R&D from external capital markets. This is probably due to the features of R&D. Kamien and Schwartz (1978), for example, discuss two reasons. First, external financing is difficult to obtain without substantial related tangible collateral to be claimed by the lender if the project fails, and an R&D project that fails generally leaves behind few tangible assets of value.[2] Carpenter and Petersen (2002a) also pointed out that physical investments designed to embody R&D results are likely to be firm-specific and, therefore, have little collateral value. Second, the firm is reluctant to reveal detailed information about the project that would make it attractive to outsider lenders, fearing its disclosure to potential rivals. As Himmelberg and Petersen (1994) argued, adverse selection problems may be pronounced in high-tech industries because firms have to maintain information asymmetries actively to appropriate returns on innovation. In addition to these reasons, Carpenter and Petersen (2002a) argued that the returns to high-tech investment are skewed and highly uncertain, in part because R&D projects have low probability of financial success. As Colombo and Grilli (2007) emphasize, greater uncertainty deters investments, as there is greater risk of incurring sunk costs. Despite the high risk of R&D projects, most part of the investment is used to produce firm-specific equipment, which is less desirable as collateral. Consequently, the features of R&D would prevent start-up firms from accessing to external capital markets.

On the other hand, as Aghion et al. (2004) pointed out, more innovative firms are likely to generate more attractive investment opportunities than less innovative firms. If so, they are likely to be more reliant on external finance than less innovative firms. Although the demand for R&D investment appears

[2]Hall (2002) pointed out that 50% or more of R&D spending is the wages and salaries of highly educated scientists and engineers.

high for start-up firms pursuing innovation, it is not easy to raise funds for R&D from providers of external capital. In fact, Himmelberg and Petersen (1994) found a large, positive and statistically significant relationship between R&D investment and internal finance. They argued that the flow of internal finance is the principal determinant of the rate at which small, high-tech firms acquire technology through R&D. More recently, Brown et al. (2009) found the significant effects of cash flow on financing of R&D for young, but not mature, firms, using dynamic R&D models for high-tech firms. Given imperfections in capital markets, R&D investment—especially that of start-up firms—depends heavily on firms' financial conditions, including the sources of finance. The availability of internal capital, therefore, would affect the firm's decision on R&D investment.

As well as internal capital, human capital may have an impact on R&D financing at start-up. As Hall (2002) pointed out, the efforts of educated scientists and engineers create an intangible asset, from which profits in future years will be generated as the firm's knowledge. Also, Cressy (1996) emphasizes that human capital is the 'true' determinant of firm survival and that the correlation between financial capital and survival is spurious. Therefore, human capital, rather than financial capital, may relate to R&D output and post-entry performance. On the other hand, human capital may also affect the financing of R&D. Under imperfections in capital markets, human capital acts as a valid signal toward providers of external capital. Especially for start-up firms, the human capital of founders appears to play a key role in R&D financing. With respect to start-up financing, for example, Bates (1990) argued that owner educational background is a major determinant of the financial capital structure of small business start-ups. Åstebro and Bernhardt

(2005) also indicated that firm capital is generally increasing in human capital.[3] These findings imply that the founder's human capital exerts a positive effect on the R&D financing of start-up firms.

While a large number of previous studies have examined the determinant of R&D investment or start-up financing, little attention has been paid in previous studies to the relationship between R&D and human capital of start-up firms. As one of the few exceptions, Colombo and Grilli (2007) shed light on start-up financing of new technology-based firms, using young and independent Italian firms that operate in high-tech industries, both in manufacturing and services. They found that the level of financial leverage decreases with variables that are indicative of a greater amount of available personal wealth to finance firms' start-up. Although they analyzed access to the sources of start-up financing, such as personal capital and bank loans, they did not consider firms' investment decisions.[4] That is, it is still unclear whether founders' human capital affects the R&D investment decisions of start-up firms.

Whereas high-tech start-ups start businesses to drive innovation, the fact that R&D projects are difficult to finance is due in part to imperfections in capital markets. As Hall (2002) argued, this fact would result in under-provision of R&D investment in the economy. Since innovation driven by start-up firms is expected to contribute to future economic growth, further research on start-up financing and R&D investment would be needed to provide information to improve environment for start-up firms.

[3] In addition, Parker and van Praag (2006) and Honjo (2007) indicated that educational background is associated with lower financial constraints. In contrast, Cassar (2004) found that a major decision maker's characteristics do not have a significant influence upon start-up financing.

[4] Okamuro (2006) examined the effect of educational background on R&D intensity, but its effect was not significant.

3. Analytical framework

The premise of this paper is that imperfections in capital markets create a wedge between the costs of internal and external finance. As already argued, this is due to information asymmetries between founders and external suppliers of capital. Figure 1 portrays the supply of funds to a start-up firm and the demand for R&D investment by the firm. Following Hall (2002), the horizontal axis, k, measures R&D investment, while the vertical axis, ρ, measures the (marginal) cost of funds.[5]

First, the supply curve, S, is depicted in Figure 1, according to financing hierarchy.[6] ρ_{in} represents the cost of internal finance. It is assumed that the cost of external finance is higher than that of internal finance because of imperfections in capital markets due to information asymmetries between founders and external suppliers of capital. Also, the cost of external finance increases with k, partly because the risk premium increases with it. Therefore, the firm uses external finance after exhausting internal finance. In other words, external finance compensates for insufficient funds resulting from less internal finance. As shown in Figure 1, the supply curve is flat as long as the R&D investment is financed only by internal capital, k_{in}, and the curve slopes up over it.[7]

Then, the demand curve, D, which indicates the firm's marginal product of R&D investment, is drawn in Figure 1. The demand curve is negatively slope but highly elastic. One reason is that most start-up firms have trivial

[5] See also Hubbard (1998), and Carpenter and Petersen (2002a, b).

[6] For more discussions on financing hierarchy, see, for example, Fazzari et al. (1988) and Berger and Udell (1998).

[7] Since we focus only on start-up financing, we do not take into account new equity financing. Therefore, we describe the supply curve with constantly increasing slope over the quantity of internal finance.

market shares and they do not have influence on product price. In addition, the firm's demand for R&D, which relates to the R&D investment decision, depends on the returns received from the R&D project and the probability of success of R&D. Even if the marginal return remarkably decreases with an increase in R&D investment, the marginal probability of the success does not sharply decrease with it. In Figure 1, without imperfections in external markets, the cost of funds equals the marginal product of R&D investment at k^*. However, information asymmetries indeed exist between the founder and external suppliers of capital. As a result, the firm invests in R&D at k_0.

On the other hand, especially for start-up firms, founders' human capital may play a major role in financing from external capital markets. Highly educated founders may be able to raise funds because they have more valuable knowledge and network for business. Such founders may also use their abilities to the application procedure of external finance. In addition, under imperfect information in the market, signaling is more likely to affect the cost of funds at start-up. High human capital may attract potential investors. From the viewpoint of investors, R&D projects undertaken by founders with high human capital, such as technologically trained founders, are expected to yield large returns. In Figure 1, the supply curve, S', applies to the founder who has high human capital. In this case, the founder with high human capital can raise funds at k_1.

Given the firm's demand for R&D, we consider that R&D investment is determined not only by the firm's internal finance but also by the founder's human capital. Let R denote R&D investment of a start-up firm, and K_0 and X represent the firm's internal finance for R&D and the founder's human capital, respectively. Using a function form, $f()$, we obtain the following

relationships:

$$R = f(K_0, X) + u \tag{1}$$

where u is an error term.

In Equation (1), we show our model to examine the effects of internal finance and human capital on R&D financing of start-up firms. However, the financing may depend heavily on investment opportunities for R&D. While some firms demand a small amount of investment, other firms require more funds for large R&D projects. Although the demand curve of R&D investment is described as fixed in Figure 1, the demand for R&D varies according to the firm's investment opportunities. In Figure 1, a firm has D as the demand curve, while another firm has D'. Thus, we take into account the difference not only of the supply curve but also of the demand curve between start-up firms. Given the demand for R&D, Q, we rewrite Equation (1) as follows:

$$R = g(K_0, X, Q) + v \tag{2}$$

where v is an error term.

With respect to the effects of internal finance and human capital, if internal finance forms a large part of financial resources for R&D, then R&D investment may increase with internal finance. Also, several previous studies have argued that founders are aware of the likelihood of their firms' success while potential investors are not (e.g., Leland and Pyle, 1977).[8] According to this argument, whereby the greater the initial funds provided by the founder, the greater the founder's perception of the likelihood of success. If so, internal finance induces external finance, and internal finance has a positive effect on R&D investment. On the other hand, as Cressy (1996) indicated, human capital

[8] Avery et al. (1998) pointed out that personal commitments may be important for firms seeking certain types of loans as they serve as a signal of the quality of firms.

may be the true factor affecting the success of R&D, and human capital, rather than financial capital, relates to R&D output. Based on this view, the founder's human capital has more impact on R&D investment. We thus hypothesize that founders with high human capital, other things being equal, tend to raise more funds for R&D.

On the other hand, founders' human capital may affect the demand for R&D, in addition to R&D investment. Founders with high human capital may tend to pursue large scale R&D projects, since they have abilities to conduct such projects. In this respect, there remains the possibility that the demand for R&D is endogenously determined by founders' human capital. When estimating the determinants of R&D investment, therefore, we take into account the endogeneity of the demand for R&D.[9]

In the following sections, using data on start-up firms in Japan, we attempt to identify what factors are associated with the R&D investment of start-up firms.

4. Data

4.1. Data sources

The sample used in this analysis comes from an original survey conducted in 2008.[10] By sending questionnaires to 13,582 firms in the Japanese manufacturing and software industries, which were incorporated between January 2007 and August 2008, we constructed the sample of start-up firms that pursue

[9]Similarly, we might be able to regard internal finance as endogenous. As discussed later, however, the correlation coefficients between the variables for internal finance and founder-specific characteristics are found to be low. In order to avoid the complexity of the estimation, therefore, we do not use a endogenous model for internal finance. In this regard, further investigation into how founders' human capital affects start-up financing may be warranted.

[10]For more details on this survey, see Okamuro et al. (2009).

R&D. The list of firms for the survey was obtained from a database complied by Tokyo Shoko Research (TSR) that is a major credit investigation company in Japan.

The number of effective responses was 1,516 (approximately 11% of the target). From among the responses, we identified 1,060 firms that had started their businesses during 2007 and 2008.[11] Also, 487 firms indeed required R&D investment, and these firms were selected as the sample for this analysis. As a result, we obtained 363 firms in the final sample because of missing values for some variables.[12]

We also used another data source to collect data on industry-specific characteristics. Data on the appropriability of innovation output and technological opportunities were taken and calculated from the Report on the Japanese National Innovation Survey 2003, compiled by the National Institute of Science and Technology Policy (NISTEP) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

4.2. R&D investment

In the questionnaire, we asked how much firms spend on R&D for one year. Here, R&D expenditures mean equipment and materials for R&D including outsourcing cost and labor cost. We define these expenditures as R&D investment.

Table 1 shows the descriptive statistics of R&D investment in the sample. While the average of R&D investment is about 6.8 million yen, the standard deviation appears very high. Among the 363 firms, 143 firms (39.4%) did

[11] We excluded firms that were established before December 2006 as sole proprietors and incorporated after January 2007.

[12] Among the firms, one firm that had no initial funds was excluded from the sample.

not actually spend on R&D, even though they required R&D investment. On the other hand, the sample includes not only independent firms but also subsidiaries and affiliated firms, which perhaps are financially supported by their parent firms. Therefore, Table 1 shows the descriptive statistics of R&D investment separately for independent firms, and subsidiaries and affiliated firms. Table 1 indicates that the R&D investment of subsidiaries and affiliated firms is distinctly larger than that of independent firms.

4.3. Internal finance: initial funds

In the traditional investment model, cash-flow has often been used to capture the access to internal finance that hypothetically mitigates financial constraints.[13] However, cash-flow is not appropriate as a proxy for the access to internal finance at start-up, since most start-up firms have not yet established cash-flow. In the questionnaire, we asked the amount of initial funds from each type of funding sources, such as founders, and family and friends, at start-up.[14] Instead of cash-flow, using the initial funds provided by founders, we measure the availability of internal finance at start-up. As well as the initial funds provided by the founders themselves, those provided by their family and friends may be essentially treated as internal finance. In this paper, therefore, the sum of the founder's own funds and their family's and friends' funds is defined as the variable for internal finance. For subsidiaries and affiliated firms, on the other hand, initial funds provided by their parent firms are also

[13] For the investment model, see, for example, Fazzari et al. (1988) and Hoshi et al. (1991).

[14] Several studies have focused on equity financing of R&D, and the cost of equity finance may differ from that of debt finance for start-up firms. For instance, Carpenter and Petersen (2002a) argued that new equity has many advantages over debt for financing high-tech investment. More recently, Müller and Zimmermann (2009) examined the importance of equity finance for the R&D activity of small- and medium-sized enterprises. However, we do not distinguish equity finance from debt finance because we did not ask equity and debt finance, separately, in order to reduce respondent burden in answering the questionnaire.

regarded as internal finance.

In Table 2, we show the ratio of firms financed by each type of funding sources at start-up. Table 2 also presents the descriptive statistics of the funding sources. In addition, Table 2 shows those of internal finance; that is, (1) + (2) and (1) + (2) + (6). As shown in Table 2, over 90% of the firms use founders' own funds at start-up, and most of them resort to internal capital. On the other hand, the average amount of initial funds from parent firms and private financial institutes (i.e., banks) is remarkably higher.

4.4. Human capital: founder-specific characteristics

Previous studies have attempted to capture the effects of founders' or entrepreneurs' human capital on the firm's behavior and post-entry performance (e.g., Åstebro and Bernhardt, 2003; Colombo and Grilli, 2007). In general, human capital has been measured by founders' personal attributes, which can be retrieved from the data source. Colombo and Grilli (2004), for example, argued that generic human capital is related to the general knowledge acquired by entrepreneurs both through formal education and professional experience. In fact, most studies have used educational background as a measure of founders' human capital (e.g., Bates, 1990; Åstebro and Bernhardt, 2005). Following these studies, we capture educational background of founders. The dummy variables, EDU_U and EDU_G, are used to examine the effects of educational level—undergraduate university education and graduate school education. As well as educational background, the dummy variables, EXP_W and EXP_M, are used to identify the effects of prior work experience in the related field and prior managerial experience, respectively.

In addition to educational background and work experience, founders'

prior research activities may relate to R&D investment. The dummy variable, $INNOV$, is used to measure product/process innovation experience. This variable indicates the degree of founders' technological capability. Also, the dummy variable, $ACAD$, is used to measure the affiliation to academic associations in the natural sciences. This variable may indicate the extent of founder's human network as well as technological capability.

Furthermore, we control the difference of age and generation between founders, by using the variable for founders' age, AGE.

4.5. Demand for R&D

In the traditional investment model, Tobin's q, which is often measured by the market value of equity plus the book value of debt, divided by the book value of total assets, is used as a proxy for investment opportunities (e.g., Fazzari et al., 1988; Hoshi et al., 1991). Needless to say, however, firms cannot go public immediately after starting their businesses, and hence it is difficult to measure their market values.

In the questionnaire, on the other hand, we asked how much firms require R&D investment for one year, in order to obtain sufficient R&D output. Using this value, we capture investment opportunities for R&D, and measure the demand for R&D investment, Q. Table 3 shows the descriptive statistics of the demand for R&D investment. According to Table 3, on average, the demand for R&D investment is larger than the actual R&D investment.

4.6. Others

In addition to the above variables, some variables are included in the model. First, since some start-up firms were established by multiple founders, the

dummy variable for multiple founders, $MFOUND$, is included as a control variable. Also, as shown in Tables 1 and 3, some start-up firms in the sample are founded by their parent firms, and the financial structure may be different from that of independent firms. Therefore, we use the dummy variable, SUB, to control the difference of the financial structure of subsidiaries and affiliated firms. Additionally, the subsample containing only independent firms will be, in part, used in the estimation model.

Then, as discussed later, there remains the probability that the demand for R&D investment depends on founders' human capital. For this reason, we attempt to use an endogenous model to estimate the parameters. As instruments, we measure the intention of an initial public offering (IPO), IPO, in order to capture founders' motivations for the access to external finance. Furthermore, the demand for R&D may differ between firms, according to the industry's characteristics. We thus include industry-specific variables that represent appropriability and technological opportunities, $APPRO$ and $TECOPP$, in the model.

5. Estimation methods and results

5.1. Methods

Based on Equations (1) and (2), we estimate the determinants of R&D investment, using data on start-up firms in Japan. Table 4 shows the definitions of variables, including instrumentals. As shown in Tables 1 and 3, R&D investment differs between independent firms and subsidiaries or affiliated firms. Not surprisingly, (parent) firms generally provide initial funds to their subsidiaries when founding new subsidiaries. Therefore, the financial structure of subsidiaries and affiliated firms seems to be considerably different from that of

independent firms. For this reason, the subsample consisting of independent firms is used for our estimation. Table 5 shows the descriptive statistics of the independent variables separately for all firms and independent firms. The correlation matrix for independent firms is shown in Table 6. As shown in Table 6, the correlation coefficients between the variables for internal finance and founder-specific characteristics are found to be low, which indicate that founders' human capital has less influence on internal capital.

In addition, as already mentioned, some start-up firms did not actually invest in R&D; that is, some observations take the value zero. Taking into account the truncated observations, therefore, we apply a type-I Tobit model to the estimation.

On the other hand, the demand for R&D is considered to be endogenously determined, and it may depend in part on founders' human capital. In order to take into account the endogeneity of Q, therefore, we also estimate Equation (2) as a type-I Tobit model with an endogenous regressor. As instruments, we additionally use IPO, $APPROP$ and $TECHOPP$.

5.2. Results

We show the estimation results for the determinants of R&D investment in Table 7. Table 7 shows the results when all the independent variables are exogenous. While Columns (i), (ii) and (iii) show the results for all firms, Columns (iv), (v) and (vi) show those only for independent firms. Columns (i) and (iv) show the results only with founder-specific characteristics and control variables. Also, Columns (ii) and (v) show the results including the variable for internal finance, and Columns (iii) and (vi) show those including the variables for internal finance and the demand for R&D investment.

Table 8 shows the estimation results when the demand for R&D is regarded as endogenous. In Table 8, we employ the maximum likelihood estimator. While Columns (i) and (ii) show the estimation results for all firms, Columns (iii) and (iv) show those only for independent firms. Columns (ii) and (iv) show the estimation results when the variable for internal finance is included in the model. While a Wald test of the exogeneity of the instruments was rejected at the 5% significance level for independent firms, it was not rejected at the 5% significance level for all firms in Columns (i) and (ii) of Table 8.[15] Therefore, we will discuss the determinants of R&D investment, including the results of Table 7. The determinants of the demand for R&D will be discussed in Appendix.

First, with respect to the effects of human capital, the coefficients of EDU_U and EDU_G are positive in Table 7.[16] In particular, EDU_G has a significantly positive effect on R&D investment. The results indicate that founders with higher educational background tend to raise more funds for R&D. On the other hand, the coefficients of EXP_W and EXP_M have a negative sign, but EXP_M does not have a significant effect on R&D investment. Regarding innovation experience, the coefficients of $INNOV$ are overall positive, indicating that founders with prior innovation experience are more likely to invest in R&D. In addition, $ACAD$ has a positive effect on R&D investment, indicating that founders who are members of academic associations are more likely to invest in R&D, although their effects are insignificant for independent firms. These results suggest that founders who have innovative or academic activities have an impact on R&D investment. The findings of this

[15] For independent firms, the Wald test was not rejected at the 1% significance level.

[16] By defining the ratio of R&D investment to total initial funds as the dependent variable, we indeed estimated the determinants of R&D investment as well. However, we did not obtain more significant results regarding the effects of human capital on R&D investment.

paper imply that founders' backgrounds, such as graduate school education, prior innovation experience and academic affiliation enable start-up firms to raise more funds for R&D. However, the effects of human capital become less significant in Columns (iii) and (iv) of Table 7 and all Columns of Table 8 when Q is included, and especially they tend to be significant for independent firms.

Then, with respect to the effects of internal finance, the coefficients of IF_FP and IF_F are positive and significant in Columns (ii) and (v) of Table 7. However, their effects do not consistently appear in Columns (iii) and (vi) of Table 7 when Q is included. This suggests that R&D investment depends more heavily on investment opportunities, rather than internal finance. From this finding, we may say that the availability of internal finance has no impact on R&D investment, and, hence, we cannot conclude severe financial constraints for R&D investment of start-up firms.

Overall, Q has a significantly positive effect on R&D investment. As already argued, when the demand for R&D investment is controlled, the effects of human capital become less significant. We provide evidence that the effects of founders' human capital are mediated by investment opportunities. The results indicate that founders who have these characteristics tend to raise more funds for R&D, perhaps because they have more investment opportunities for R&D. Previous studies have argued that credit to new-technology based firms is rationed because of imperfections in capital markets (e.g., Colombo and Grilli, 2007). However, the findings of this paper suggest that financing of high-tech start-ups may rather depend on investment opportunities. In this regard, research on start-up financing should not ignore the demand side in considering R&D investment. At least in stagnated countries like Japan, one

should take into account the demand for R&D investment more carefully.

6. Conclusions

This paper has explored R&D financing of start-up firms. Using a sample from an original survey conducted in 2008, we identified whether initial funds and founder-specific characteristics relate to R&D investment of start-up firms in Japan. It was found that internal finance is positively associated with R&D investment. It was also found that founders with higher educational background, prior innovation output and academic affiliation tend to raise more funds for R&D. On the other hand, we provided evidence that the effects of founders' human capital are mediated by investment opportunities, which would indicate that R&D investment of start-up firms depends heavily on investment opportunities.

Because high-tech start-ups are expected to stimulate future economic growth through innovation, much attention has recently been paid on innovation of firms—especially of start-up firms that invest heavily on R&D. If, as Brown et al. (2009) argued, young high-tech firms face binding financial constraints, then exogenous changes in the supply of internal or external finance leads to changes in R&D. In fact, previous studies have argued that financial constraints prevent start-up firms from investing in R&D. These studies tend to emphasize that the imperfections in external capital markets cause harm to start-up firms. However, sufficient attention has not been paid in these studies to the opportunities for R&D investment of start-up firms. In contrast, the findings of this paper indicate that R&D investment of start-up firms depends on investment opportunities. In order to understand how high-tech start-ups raise funds from capital markets, one needs to take into account the effects of

investment opportunities. This would be able to provide better insights not only into the strategic behavior of start-up firms, but also into the dynamics of competitive process and the evolution of market structure.

Appendix

In Table 8, it is assumed that the demand for R&D is endogenously determined by human capital, the IPO intention, appropriability and technological opportunities. In order to demonstrate the effects of human capital on the demand for R&D, we show the estimation results in Table A1 when estimating the determinants of the demand for R&D. As shown in Table A1, the coefficients of EDU_U and EDU_G are positive, although those of EXP_W are negative. This indicates that founders with high higher educational background tend to have larger demand for R&D. These findings are similar to those of Table 7, suggesting that founders' human capital that relates to R&D investment affects the demand for R&D.

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Table 1: Descriptive statistics of R&D investment

R&D investment	Mean	S.D.	25%	Median	75%	N
All	6.8	31.8	0.0	0.5	2.0	363
Independent firm	3.2	8.4	0.0	0.5	2.0	304
Subsidiary and affiliated firm	25.5	74.2	0.0	0.5	10.0	59

Notes: S.D. indicates the standard deviation. N indicates the number of observations.

The value of R&D investment is expressed in millions of yen.

Table 2: Sources of initial funding

Funding sources	Firms		Initial funds		
	M	Ratio (M/N)	Mean	S.D.	Median
(1) Founder's own funds	327	0.901	5.4	8.8	3.0
(2) Family and friends	101	0.278	4.4	6.5	2.0
(3) Individual investor	28	0.077	6.3	8.5	2.75
(4) Public financial institute	43	0.118	10.9	14.2	6.0
(5) Private financial institute	27	0.074	71.2	172.3	10.0
(6) Parent firm	43	0.118	140.8	431.5	14.0
(7) Subsidy	7	0.019	4.6	5.4	2.0
(8) Others	24	0.066	28.2	109.2	3.25
Total	363	1.000	31.8	163.3	5.0
(Internal finance)					
(1) + (2)	332	0.915	6.6	10.0	3.29
(1) + (2) +(6)	357	0.983	23.1	154.9	4.0

Notes: S.D. indicates the standard deviation. N indicates the number of observations, and $N = 363$. The value of internal finance is expressed in millions of yen.

Table 3: Descriptive statistics of the demand for R&D investment

Demand for R&D investment	Mean	S.D.	25%	Median	75%	N
All	17.9	68.0	1.0	5.0	10.0	363
Independent firm	10.4	19.2	1.0	4.0	10.0	304
Subsidiary and affiliated firm	56.7	158.5	2.0	6.0	40.0	59

Notes: S.D. indicates the standard deviation. N indicates the number of observations.

The value of R&D investment is expressed in millions of yen.

Table 4: Definitions of variables

Variables	Definitions
R	R&D investment (millions of yen)
(Founder-specific characteristics)	
EDU_U	Dummy variable: 1 if the founder has undergraduate education, 0 otherwise.
EDU_G	Dummy variable: 1 if the founder has graduate school education, 0 otherwise.
EXP_W	Dummy variable: 1 if the founder had prior work experience in the related field at start-up, 0 otherwise.
EXP_M	Dummy variable: 1 if the founder had prior managerial experience in other firms at start-up, 0 otherwise.
$INNOV$	Dummy variable: 1 if the founder has prior experience of product/process innovations at start-up, 0 otherwise.
$ACAD$	Dummy variable: 1 if the founder is a member of academic association in the natural sciences, 0 otherwise.
AGE	Logarithm of the founder's age at start-up.
(Internal finance)	
IF_FP	Founder's own funds plus his or her family's and friends' funds plus funds provided by the parent firm (millions of yen)
IF_F	Founder's own funds plus his or her family's and friends' funds (millions of yen)
(Demand for R&D)	
Q	Required R&D investment (millions of yen)
(Others: control variables)	
$MFOUND$	Dummy variable: 1 if the firm has multiple founders, 0 otherwise.
SUB	Dummy variable: 1 if the firm is founded as a subsidiary or affiliated firm, 0 otherwise (as an independent firm)
(Others: instruments)	
IPO	Dummy variable: 1 if the founder is willing to go public, 0 otherwise.
$APPROP$	Degree of appropriability (see Okamuro et al. (2009)).
$TECHOPP$	Degree of technological opportunities (see Okamuro et al. (2009)).

Table 5: Descriptive statistics of the variables

	All ($N = 363$)			Independent firm ($N = 304$)		
	Mean	S.D.	Median	Mean	S.D.	Median
EDU_U	0.512	—	—	0.503	—	—
EDU_G	0.113	—	—	0.115	—	—
EXP_W	0.857	—	—	0.855	—	—
EXP_M	0.372	—	—	0.339	—	—
$INNOV$	0.358	—	—	0.342	—	—
$ACAD$	0.146	—	—	0.138	—	—
AGE	3.824	0.252	3.850	3.810	0.256	3.850
IF_FP	22.738	153.630	4.000	—	—	—
IF_F	—	—	—	6.464	10.288	3.000
Q	17.931	68.006	5.000	10.412	19.176	4.000
$MFOUND$	0.482	—	—	0.457	—	—
SUB	0.163	—	—	—	—	—
IPO	0.281	—	—	0.306	—	—
$APPROP$	1.192	0.207	1.167	1.188	0.210	1.167
$TECHOPP$	0.892	0.173	0.853	0.900	0.173	0.940

Notes: S.D. indicates the standard deviation. N indicates the number of observations.

The value of internal finance is expressed in millions of yen.

Table 6: Correlation matrix (independent firm)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	R	1.000										
(2)	EDU_U	−0.016	1.000									
(3)	EDU_G	0.207	−0.363	1.000								
(4)	EXP_W	−0.063	0.040	0.090	1.000							
(5)	EXP_M	0.045	0.044	−0.084	−0.101	1.000						
(6)	$INNOV$	0.066	0.079	0.001	−0.038	−0.004	1.000					
(7)	$ACAD$	0.119	−0.003	0.363	0.002	−0.025	0.153	1.000				
(8)	AGE	−0.018	0.009	0.047	−0.071	0.165	0.229	0.173	1.000			
(9)	IF_F	0.292	0.076	0.030	−0.023	0.068	0.005	0.094	0.078	1.000		
(10)	Q	0.674	0.040	0.084	−0.052	0.098	0.033	0.038	−0.079	0.311	1.000	
(11)	$MFOUND$	0.150	−0.066	−0.021	−0.186	0.180	0.006	−0.023	0.057	0.128	0.239	1.000

Notes: The number of observations is 305.

Table 7: Determinants of R&D investment

	All			Independent firm		
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
EDU_U	9.679*	4.250	2.001	2.182	1.633	0.510
	(4.946)	(3.755)	(2.093)	(1.488)	(1.436)	(1.110)
EDU_G	24.978***	19.624***	6.879**	7.366***	6.948***	4.437**
	(8.044)	(6.071)	(3.447)	(2.436)	(2.346)	(1.811)
EXP_W	−21.486***	−13.124***	−5.151*	−2.428	−2.426	−1.836
	(6.291)	(4.792)	(2.698)	(1.928)	(1.851)	(1.427)
EXP_M	−1.708	−4.113	−2.044	1.164	0.908	−0.128
	(4.907)	(3.722)	(2.084)	(1.472)	(1.416)	(1.097)
$INNOV$	6.891	9.108**	4.011*	1.982	2.101	1.246
	(4.849)	(3.672)	(2.055)	(1.466)	(1.409)	(1.086)
$ACAD$	11.783*	11.708**	4.590	2.850	2.184	2.087
	(6.647)	(5.016)	(2.807)	(2.088)	(2.014)	(1.547)
AGE	0.518	−3.707	4.697	−3.764	−4.171	−0.480
	(9.403)	(7.114)	(4.010)	(2.781)	(2.676)	(2.091)
IF_FP		0.137***	−0.119***			
		(0.011)	(0.013)			
IF_F					0.237***	0.068
					(0.062)	(0.049)
Q			0.655***			0.308***
			(0.030)			(0.027)
$MFOUND$	8.381*	5.096	−2.386	3.565**	2.924**	0.077
	(4.655)	(3.525)	(1.994)	(1.398)	(1.353)	(1.068)
SUB	20.509***	6.986	2.622			
	(6.213)	(4.895)	(2.774)			
Constant	−9.587	6.944	−24.416	11.041	11.954	−1.205
	(36.152)	(27.327)	(15.416)	(10.641)	(10.235)	(7.997)
N	363	363	363	304	304	304
log-likelihood	−1201	−1139	−1008	−790	−783	−732
LR statistic	51.0***	176.4***	437.4***	27.1***	41.1***	143.6***

Notes: Standard errors are in parentheses. $***$, $**$ and $*$ indicate the 1%, 5% and 10% significance levels, respectively. N indicates the number of observations.

Table 8: Determinants of R&D investment: endogenous regressor

	All		Independent firm	
	(i)	(ii)	(iii)	(iv)
EDU_U	0.935	2.046	−0.283	−0.137
	(2.849)	(2.110)	(1.331)	(1.279)
EDU_G	8.509*	7.516	2.478	2.607
	(5.156)	(4.840)	(2.288)	(2.216)
EXP_W	−4.408	−5.479*	−1.509	−1.550
	(4.417)	(3.217)	(1.632)	(1.612)
EXP_M	−3.417	−2.148	−0.911	−0.851
	(2.518)	(2.159)	(1.306)	(1.275)
$INNOV$	6.426***	4.203*	0.671	0.641
	(2.478)	(2.299)	(1.257)	(1.252)
$ACAD$	6.914**	4.848	2.101	2.226
	(3.389)	(3.131)	(1.765)	(1.752)
AGE	0.551	4.327	2.048	2.144
	(4.799)	(4.474)	(2.626)	(2.648)
IF_FP		−0.104		
		(0.081)		
IF_F				−0.063
				(0.083)
Q	0.489***	0.616***	0.565***	0.557***
	(0.112)	(0.208)	(0.127)	(0.122)
$MFOUND$	−1.333	−2.040	−2.062	−1.832
	(2.917)	(2.720)	(1.640)	(1.497)
SUB	−1.161	2.912		
	(5.808)	(3.179)		
Constant	−10.087	−22.738	−11.327	−11.376
	(18.428)	(17.842)	(10.209)	(10.172)
N	363	363	304	304
log-likelihood	−3064	−2749	−2034	−2018
Wald statistic	168.1***	738.7***	52.2***	72.6***

Notes: Standard errors are in parentheses. $***$, $**$ and $*$ indicate the 1%, 5% and 10% significance levels, respectively. N indicates the number of observations. Q is an endogenous variables, and the additional instruments are IPO, $APPROP$ and $TECHOPP$.

Table A1: Determinants of the demand for R&D

	All		Independent firm	
	(i)	(ii)	(iii)	(iv)
EDU_U	12.508*	1.397	4.177*	3.010
	(7.353)	(3.427)	(2.265)	(2.170)
EDU_G	26.353**	15.605***	7.141*	6.314*
	(12.388)	(5.758)	(3.817)	(3.643)
EXP_W	−25.620**	−9.255**	−1.174	−1.231
	(10.065)	(4.694)	(3.101)	(2.957)
EXP_M	1.028	−3.180	2.770	2.159
	(7.443)	(3.457)	(2.283)	(2.180)
$INNOV$	−3.259	4.970	1.336	1.556
	(7.465)	(3.473)	(2.310)	(2.203)
$ACAD$	0.284	5.682	−0.581	−2.018
	(10.531)	(4.890)	(3.341)	(3.197)
AGE	10.747	−3.391	−5.256	−5.812
	(15.181)	(7.057)	(4.611)	(4.398)
IF_FP		0.384***		
		(0.011)		
IF_F				0.542***
				(0.099)
$MFOUND$	13.169*	7.523**	7.769***	6.108***
	(7.111)	(3.304)	(2.190)	(2.110)
SUB	46.613***	9.631**		
	(9.475)	(4.518)		
IPO	22.863***	9.582**	10.447***	10.953***
	(7.998)	(3.731)	(2.383)	(2.274)
$APPROP$	−15.309	−6.901	−5.382	−2.500
	(16.894)	(7.845)	(5.162)	(4.950)
$TECHOPP$	−11.436	9.162	−4.498	−2.223
	(21.672)	(10.076)	(6.653)	(6.357)
Constant	−1.760	18.356	30.900	25.708
	(66.500)	(30.871)	(20.049)	(19.141)
N	363	363	304	304
Adj. R^2	0.106	0.808	0.120	0.200

Notes: Standard errors are in parentheses. $***$, $**$ and $*$ indicate the 1%, 5% and 10% significance levels, respectively. N indicates the number of observations.

Figure 1: Financing of R&D investment