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Effects of the Quality of Science and Innovation on Venture Finance: Evidence from University Spinoffs in Japan

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Effects of the quality of science and innovation on venture finance: Evidence from university spinoffs in Japan[1]

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Abstract

University spinoffs build on strong science, which allows them to create radical innovation. Radical innovation entails uncertainty in entrepreneurial outcomes, necessitating the participation of individuals and organizations that bridge the gap between science and the market. Recognizing that the commercial success of university spinoffs hinges on the entrepreneurial ecosystems they are embedded in, this study establishes unbalanced panel data (2015-2020) to examine the relationships among the key factors in university spinoff ecosystems: scientific productivity of academic researchers associated with university spinoffs, radicalness of the innovation created by the university spinoff, and entrepreneurial intermediaries who bridge the gap between science and the market. Estimation results reveal that h5-index positively affects venture capital funding. The quality of innovation does not affect the probability of university spinoffs receiving venture financing, negating the scout function of entrepreneurial intermediaries. Venture capital financing positively affects sales growth of university spinoffs, corroborating the coach function of entrepreneurial intermediaries.

Keywords: business angels, entrepreneurship, Japan, radical innovation, university spinoffs, venture capital

JEL: D22; G32; M13; L26; O16; O31; O34

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1. Introduction

Japan is under the third crisis. Fukao (2020) argues that the living standard (real GDP per capita) gap between Japan and a benchmark country (UK in the 19th century and US in the 20th and 21st century) has been expanding since the 1990s. Such a long-term decline in relative living standard took place first in the late 19th century due to the closure policy and lack of knowledge spillover from foreign countries. The second crisis occurred during and after the WWII. The third crisis stems from labor productivity decline since the 1990s which resulted from low total factor productivity (TFP) growth and stagnant capital deepening. TFP slowdown is a product of inactive industrial innovation and metabolism. Compared to other OECD member states, Japan's business ecosystem is occupied by older firms (Jones and Jin 2017) and they fail to grow both in the manufacturing and service sector (Criscuolo et al. 2014). Poor industrial metabolism is more salient among SMEs that account for 99% of firms in Japan, of which managers are rapidly aging (Hong et al., 2020). The business ecosystem characterized by old firms and aged managers ends up with less investment into new technologies, such as digital transformation, which ultimately results in low labor productivity growth (Hong et al., 2020).

Japan needs to bolster both entrepreneurship and innovation to overcome the third crisis. The knowledge spillover theory of entrepreneurship (KSTE) links innovation with entrepreneurship through spillovers. KSTE argues that innovative activities by firms, universities, and public research institutes endogenously create entrepreneurial opportunities (Acs et al. 2013). This is because large firms who want to have their employees focus on core task do not appreciate their serendipitous ideas, which encourages employees to start their own businesses. Furthermore, research universities generate undeveloped inventions due to their embryonic nature and difficulty in establishing licensing agreements. Therefore, knowledge-based economies endogenously create greater entrepreneurial opportunities. This makes the creation of new technology-based firms, such as university spinoffs, particularly important in knowledge-based economies, such as Japan.

Japan had made a series of attempts to promote university spillover since the 1990s by expanding university spillover pool (enhancing basic research), activating extant spillover channels (increasing university-industry joint research), and exploring new spillover channels. The last attempt includes legal reforms to foster university patent licensing, consultation, and academic entrepreneurship. The initial policy to promote academic entrepreneurship was the Hiranuma (Minister of Economy, Trade and Industry then) Plan of 2001 that aimed to establish 1,000 university spinoffs within three years (Walsh et al., 2008). As a result, by 2020, 2,901 university spinoffs were generated (Ministry of Economy, Trade and Industry [METI], 2021). There are some successful cases, the most distinguished example of which is PeptiDream, which developed a novel drug discovery system based on a special peptide invented by a University of Tokyo professor, went public and recorded a high market value (METI, 2020). Meanwhile, more than three-quarters of the university spinoffs remained commercially unsuccessful (METI, 2019), which is no wonder considering that university spinoffs are inherently associated with the difficulty in managing the commercialization of science (François & Philippart, 2019).

The successful commercialization of science through academic entrepreneurship hinges on the ecosystem university spinoffs are embedded in. The concept of entrepreneurial ecosystem draws on a biological metaphor, with an understanding that elements, functions, and dynamics of communities are key factors enabling a number of innovative startups that emerge, grow, and develop into self-sustainable industrial agglomerations (Nishizawa 2018). Central to this concept is the presence of an intermediary who leads the creation of meso-level institutions (small i), determining winners and losers among ecosystems (Storper 2013).

This study postulates that three factors shape entrepreneurial ecosystems in which university spinoffs are embedded: science, innovation, and entrepreneurial intermediaries. Radical innovation that generates a broad societal impact tends to build on strong science. One of the examples is the clustered regularly interspaced short palindromic repeats (CRISPR) and the CRISPR-associated protein9 (Cas9). This novel tool is applicable to a broad range of fields based on genetic modification. However, the markets for radical innovation may not preexist due to its disruptive nature. It is normally difficult for academic inventors to find commercial potential of their inventions and link it to entrepreneurial opportunity that is yet to exist. Intermediaries mitigate uncertainty in entrepreneurial opportunity associated with radical innovation. Intermediaries identify the commercial potential of upstream inventions, help CEOs improve entrepreneurial skills, and provide startups with resources to effectively diffuse radical innovation. On top of the creation of entrepreneurial opportunity, intermediaries bring an array of positive feedbacks to the teaching and research of home universities and attract knowledge-intensive business service providers required for the commercialization of academic inventions (e.g., patent attorneys), thereby further enriching university knowledge stock. These factors jointly form and strengthen local entrepreneurial ecosystems that are conducive to the creation of new industries. Three factors shaping entrepreneurial ecosystems that university spinoffs are embedded in are interrelated. Combining databases of publications, patents, and intermediaries for university spinoffs, this study makes the first attempt to elucidate the relationship among the three. This should derive policy and managerial implications on the successful commercialization of science through academic entrepreneurship.

The reminder of this paper is organized as follows. Section 2 lays out theoretical framework and proposes hypotheses by reviewing previous literature on scientific productivity, radical innovation, and entrepreneurial intermediaries. Section 3 describes estimation strategy, data, and variables employed in empirical analysis. Section 4 presents estimation results and discusses their implications. Section 5 concludes by summarizing the results and referring to limitations of this study and agendas for future research.

2. Literature review

Strong science that university spinoffs build on attracts risk money. This tendency is salient in biotechnology of which industrial innovation builds on the advancement of scientific research (Narin and Olivastro 1992; Tamada et al. 2004). In fact, star scientists in biomedicine, such as Nobel

Prize laureates and members of the National Academy of Sciences, receive risk money from venture capitalists whereas productive scientists without such prestigious awards and elite status do not (Roche et al. 2020). This suggests that scientific eminence of biomedicine university spinoffs acts as a signal for investors to assess growth potential of university startups. Moreover, biopharmaceutical university spinoffs involving scientists with outstanding productivity, measured by citation and co-authorship networks, tend to attract funding from venture capitalists (Goji et al., 2020). This positive relation between scientific quality and venture financing is salient for researchers engaged in general research topics, such as CRISPR Cas9. However, the relationship is much weaker for specific research topics, such as Zika fever. These findings suggest that bioscientific research of general relevance leads to radical innovation associated with a wide social impact.

University spinoffs are expected to create radical innovation for two reasons. First, radical innovation prefers entrepreneurship. Established firms are unlikely to introduce radical innovations as they suffer more from cannibalizing currently lucrative lines of business (Shane, 2004). Entrepreneurial firms are exempt from rent dissipation, rendering them a key source of radical innovation. Second, radical innovation builds on a close linkage to scientific advancement (Gubitta et al., 2016). This is because university scientists engage in upstream research of which outcomes (inventions) tend to be embryonic and widely applicable. This nature of upstream inventions endows radical innovation with potential not only for direct impacts on productivity growth, but also for far-reaching impacts on the whole economy (Maine & Thomas, 2017; Acemoglu et al., forthcoming). In fact, university spinoffs, in comparison with new technology-based firms, are superior in introducing radical innovations (Stephan, 2014).

Radical innovation is associated with uncertainty in entrepreneurial opportunity. This is because there are no existing markets for such innovation to target (Kalantaridis & Küttim, 2021). This necessitates the creation, rather than the discovery, of entrepreneurial opportunity. Superstar scientists may retain dynamic capabilities (Teece 2007) in uncertain circumstances to sense, shape, and seize opportunities that enable their university spinoffs to outperform competitors (Thomas et al. 2020). However, it is normally difficult for academic inventors to undertake such a task. Entrepreneurial intermediaries, such as venture capitalists, “judge the hidden quality of entrepreneurial projects (Colombo and Grilli 2010, 613)” and cross the chasm between radical innovation and entrepreneurial opportunity. First, intermediaries act as a “scout” who is alert to signal that university spinoffs send via scientific productivity and technological excellence (Engel and Keilbach 2002; Baum and Silverman 2004; Conti et al. 2013; Hsu and Ziedonis 2013; Haeussler et al. 2014; Wry et al. 2014, Bertoni and Tykvova 2015; Hoenig and Henkel 2015; Lahr and Mina 2016; Yamauchi and Nagaoka 2017).

Second, intermediaries provide CEOs of university spinoffs with knowledge, financial, and physical resources. They act as a “guide” who provides CEOs with hands-on support, thereby endogenizing the growth potential of university spinoffs (Hellmann and Puri 2000; Hellmann and Puri 2002; Colombo and Grilli 2010; Balboa et al. 2011; Bertoni et al. 2011; Bertoni et al. 2013;

Bock et al. 2018). Meta analysis (984 effect sizes in 15 countries, 71 studies, 1964-2014) of venture capital involvement and firm performance reveals that venture capital advantages stems from both scout and guide functions (Lohwasser 2020). The positive relation between the two is contingent on institutional factors in that quality formal institutions and the efficiency of the financial market in the startups' home countries strengthen the relationship. This finding corroborates the view of KSTE that institutions matter for the promotion of entrepreneurship. They argue that even though knowledge-based economies endogenously create greater entrepreneurial opportunities, the economy will show a low level of opportunity-driven entrepreneurship if the formal (e.g., laws) or informal (e.g., norms) factors that shape the incentives and behavior of people are unfavorable to potential entrepreneurs. Intermediaries are a key actor in an entrepreneurial ecosystem to mitigate hard and soft institutional failure (Klerkx et al. 2012; Fukugawa 2021).

Third, entrepreneurial intermediaries connect university spinoffs with other entrepreneurial ecosystem stakeholders, otherwise would have been fragmented (Clayton et al., 2018). Enhanced networks offer easier access to distribution channels, brand, production capacity, and complementary technological competencies for startups to scale. Startups backed by corporate venture capital (CVC) obtain access to the specialized irreproducible resources and distinctive competencies of the CVC's parent company (Block and MacMillan 1993, Dushnitsky 2004). This function represents reputation effect of entrepreneurial intermediaries, which should contribute to growth of startups. In summary, entrepreneurial intermediaries play roles as a scout who identifies commercial applications of radical innovation, a guide who helps CEOs learn entrepreneurial skills, and a mediator who helps university spinoffs expand entrepreneurial network (Fukugawa, 2021). Figure 1 summarizes key factors and their linkages that shape the entrepreneurial ecosystem that university spinoffs are embedded in.

Figure 1

Guided by the framework laid out in Figure 1, this study proposes the following hypotheses.

H1: The quality of science of university spinoffs positively affects venture finance.

H2: The quality of innovation of university spinoffs positively affects venture finance (scout function).

H3: Venture finance has a positive effect on growth of university spinoffs (guide function).

3. Method

Model

This study tests H1 using logistic regression model of which dependent variable is a binary dummy that represents whether university spinoffs received risk money from venture capitalists or business angels in the year that the survey was made. Due to the limitation of the data, it is not possible to identify the actual timing investment was made and amount of investment, which was employed by previous literature (Yamauchi and Nagaoka 2017). Independent variables are the quality of scientific publications, which are described in detail below. Similarly, the logistic regression model is employed to test H2. Independent variables are the quality of innovation. To test H3, this study estimates fixed-effects regression model of which dependent variable is logged sales and independent variables are dummy variables for venture financing status. Control variables are entrepreneurial ecosystem, firm age, firm size, technological field dummies, business stage dummies, and a top university dummy to capture reputation effect.

Estimation strategy

University spinoffs that switch the venture finance status (e.g., obtaining venture capital funds) at least once in the empirical period represents a minority (150/1186=12.6%) of the sample. Therefore, the use of fixed effect estimators is inefficient as it greatly reduces the sample. The use of random effect estimators hinges on the assumption of independence between individual effects and independent variables. It is desirable if we can rule out the presence of correlation between the two by adding pre-sample information representative of university spinoffs' ability to receive venture financing (Blundell et al. 1995; Bertoni et al. 2010). However, due to the characteristics of the data, it is not possible for this study to incorporate the pre-sample history variable. Therefore, to test H1 and H2, this study employs the Hausman test to select either fixed-effects or random-effects model, of which results are presented in Tables 7 to 9.

Data

This study established unbalanced panel that consists of 2433 university spinoffs using the METI University Spinoff Database (METI USO DB). The survey began in 2002 after the Hiranuma Plan was implemented, suspended from 2009 to 2013, and resumed in 2014. The number of university spinoffs included in the data is 312 in 2015, 332 in 2016, 421 in 2017, 523 in 2018, 413 in 2019, and 432 in 2020.

The METI USO DB defines university spinoff as firms that were established in collaboration with university-based scientists. It classifies university spinoffs into five categories according to the association with home universities. Firms that (1) were established to commercialize patents, technologies, and business models generated as outcomes of university research; (2) obtained technology licenses from universities to develop a business within five years of establishment; (3) were established by undergraduates or graduate students; (4) collaborated with universities to commercialize the founder's technologies and know-how within five years of establishment; and (5) were invested in by universities. Type 1, which accounts for 53% of the observations, corresponds to a 'new company founded to exploit a piece of intellectual property created in an academic institution' (Shane 2004, p.4).

METI investigated the population of university spinoffs through postal, email, and fax surveys in

2019, retrieving 851 responses from 1,092 inquiries (77.9%). Based on the responses, METI conducted another survey on the status quo of university spinoffs, obtaining 413 responses (16.5%) out of 2,505 inquiries, which includes inquiries that the potential respondents had not received. Only firms that METI could identify and have survived up to the survey date were included in the sample. Moreover, better performing firms are more likely to respond to the survey and agree to disclose their information online. Therefore, the results should be interpreted with caution that there is a sample selection bias that may distort the estimates.

Dependent variables (*VC dummy, BA dummy, ln sales*)

Dependent variables of logistic regression model to test H1 and H2 are binary dummies to represent the status that university spinoffs receive venture financing. A dependent variable of fixed-effects regression model to test H3 is log of sales.

The quality of science (*scholarly output, FWCI, citation count, h5-index*)

Proxy variables for the quality of science are taken from *SciVal*, a web-based analytical tool that builds on the world's largest scientific publication and citation database, Elsevier's *Scopus*. *SciVal* provides various indicators of the research performance of over 20,000 research institutions and their associated researchers from 230 countries. If more than one scientist is associated with university spinoffs, this study assumes that the scientist listed first is the most influential scientist for the university spinoff in terms of science base and uses information of that person in regression analysis. The data were retrieved in the last week of January 2022.

This study employs four indicators of publication and citation impacts. *Scholarly output* indicates the number of publications authored by a university-based scientist and indexed in Scopus. The value of x_s in 2015 means that a scientist *s* published *x* papers in 2015. *Field-weighted citation impact* (*FWCI*) denotes citations received by a paper *i* in the publication year and following three years divided by expected number of citations per paper received in the same period by "similar" publications. Similar publications to the paper *i* is defined by all publications that are in the same All Science Journal Classification category as *i* (Purkayastha et al. 2019). The value of $a(=x/y)_{si}$ in 2015 means that the papers that a scientist *s* published in 2015 received *x* citations from 2015 to 2018 and an average paper published in 2015 in the same discipline and the same type of document (research article, review, etc.) would receive *y* citations in the same period. *FWCI* is not calculated if the scientist *s* did not publish any paper in 2015. *FWCI* is zero if the paper *i* received no citations from 2015 to 2018. *Citation count* indicates the number of total citations the paper received. The value of x_i in 2015 means that a paper *i* published in 2015 received *x* citations by the latest week *Scopus* has updated. The *h-index* of a paper is *x* if the top *x* most-cited publications have each received at least *x* citations. Based on the same calculation method as *h-index*, the *h5-index* limits a publication and citation window to in the publication year plus last four years. The value of x_s in 2015 means that among the papers a scientist *s* published from 2011 to 2015, *x* papers received at least *x* citations in the same period.

The quality of innovation (*technical quality*, *market attractiveness*)

This study proxies the radicalness of innovation using information compiled by Bureau van Dijk's *Orbis Intellectual Property*. This database provides patent quality indicators developed by IP Business Information's *emposis patent valuation platform*. *Technical quality* represents the degree of innovation that can be derived from a company's IP. Specifically, it sums up technical coverage (scope), the detectability of infringement (the number of claims), the differentiation to state of the art (difficulty in inventing around), the technical relevance (external forward citations), etc. *Market attractiveness* indicates, from an IP point of view, how many competitors are active and innovations are made in the different technical fields of the company.

Patents are valuable to science-based university spinoffs and to their investors when they are broad (wide range of applications), blocking, and relevant (stimulating follow-on research) (Maine and Thomas 2017). Therefore, a range of aspects of patents, such as generality, international application, claims, legal strength, examiner citation, and non-self forward citation are considered to jointly constitute the radicalness of innovation. First, using information of backward and forward citations, Hirschey and Richardson (2001) develop the current impact index (CII), technology cycle time (TCT), and science linkage (SL). CII has positive impacts on firm's market value in the US, but has no impacts in Japan. TCT and SL has larger impacts on firm value in the US than in Japan, which suggests regional differences in access to university knowledge and spillover speed. These results imply cross-country differences in patent effect. Another strand of research operationalizes the radicalness (creativity) of innovation using superstar fraction, tail innovation, and generality of patents. A superstar inventor is defined as an inventor who surpasses his or her peers in the quality of patents generated as observed in the sample (Acemoglu et al. forthcoming). Tail innovation index is defined as the fraction of a firm's patents that receive more than a certain number of citations (Acemoglu et al. forthcoming). The generality of patents is the Herfindahl concentration index that aggregates the percentage of citations received by patent i that belongs to international patent classification (IPC) j, out of n_i IPCs (Hall et al. 2001). Second, valuable inventions tend to be patented globally (Patnum 1996). Fischer and Leidinger (2014) find that family size of patents and forward citations have positive effects on the probability of the patent being sold on Ocean Tomo (patent auctions) and its price. Third, firms are motivated to request for invalidation against competitors when they have a patent that undermines competitors' competitiveness in hope that the patent will be invalidated. Nakanishi and Yamada (2007) find that patent objection divided by patent stock and forward citations have positive effects on firm value. Fourth, integrating abovementioned patent indicators, Lanjouw and Schankerman (2004) develop a composite indicator (*Quality Measure*) that consists of forward citations, backward citations, patent family, and claims, with each item being differently weighed. *Quality Measure* has a positive effect on firm's market value and the probability of the patent being renewed that represents commercial value of patents. The positive effect of *Quality Measure* on firm value is more salient in biotechnology, such as health care and drugs. Sectoral patterns of patent effect (simple patent count and patent stock) are confirmed in the drug industry of the US (Hall et al., 2005) and Japan (Haneda and Odagiri, 1998). Guided by these findings, *technical quality* is expected to reflect the radicalness of innovation, with national and sectoral patterns of patent effect controlled for.

Control variables

Entrepreneurial ecosystem (*agglomeration*)

KSTE posits that personal interactions are central to entrepreneurship. Therefore, KSTE highlights the geographical nature of entrepreneurial opportunities and activities as personal interactions are promoted when economic actors are located closely. This implies that a key unit of entrepreneurial ecosystem analysis is cities and their greater regions. Table 1 shows geographical distribution of university spinoffs at the postal code level, which shows that they are located in university-based incubators. Figure 2 presents the geographical distribution at the postal code level, which clearly shows regional concentration in prefectures that have top universities (Hokkaido, Miyagi, Tokyo, Aichi, Osaka, Kyoto, and Fukuoka) defined below.

Table 1

Figure 2

Knowledge about new opportunities and resource requirements tends to be tacit. This suggests that entrepreneurial opportunities are localized as spillover is constrained by geographical distance. The geographic concentration of entrepreneurial activities enhances the local knowledge pool, which includes information about previous entrepreneurs' success, failure, and their reasons, thereby generating a demonstration effect for local entrepreneurs to learn from. Furthermore, entrepreneurial agglomerations attract providers of knowledge-intensive business services, such as patent attorneys, which in turn encourages new firms to locate nearby. Such characteristics of localized spillover, competition, and entrepreneurial activities shape the self-reinforcing nature of the ecosystem of entrepreneurship and innovation.

University spillover also tends to be localized (Fukugawa 2013; Ghio et al. 2016), which suggests the significance of spillover channels other than publications. Localization stems from characteristics of knowledge to be transferred from universities to firms. Academic inventions that are potentially valuable for industrial innovations tend to be embryonic and contain tacit knowledge of academic inventors (Agrawal 2006). Therefore, entrepreneurial firms that commercialize academic inventions need to interact closely with university scientists in order to identify practical applications of the invention. Guided by insights from previous literature, this study represents local entrepreneurial ecosystems using the number of university spinoffs at the postal code level. Entrepreneurial agglomeration is expected to positively affect the probability of university spinoffs receiving venture financing due to its self-reinforcing nature stated above.

Type of university spinoffs (*type1*)

As discussed above, Type 1 university spinoffs are characterized by the firm technological linkage between startups and home universities. Other types of university spinoffs are more loosely linked with science as their definition focuses on human and financial linkages with home universities (Smilor et al. 1990; Roberts 1991; Steffensen et al. 2000). Therefore, a binary dummy variable to represent Type 1 university spinoffs is incorporated in the regression model to control for firm level differences in the significance of science linkage in innovative activities, which should affect needs to externally finance risky ventures.

Firm age (*firm age*) and firm size (*ln employees*)

The probability of university spinoffs receiving venture financing is affected firm level heterogeneity. This study controls for unobserved heterogeneity, at least partially, by adding the following variables. Firm size and firm age are closely correlated with business stages, and thus should affect external financial resources that startups count on (Berger and Udell 1998). Information about the year of establishment of university spinoffs is taken from the METI USO DB. Firm size is measured by log of the number of employees.

University reputation (*top university dummy*)

Venture capitalists may use the reputation of the home university of academic researchers as a signal of the quality of the university spinoff they are affiliated with. In fact, they use information demonstrating scientific eminence, such as academic researchers' being a Nobel Prize laureate and a member of prestigious academic societies, in investing into university spinoffs (Roche et al., 2020). Kato and Odagiri (2012) control for firms' propensity to access to prestigious universities using scores required for high-school students to pass the entrance exam. However, the database includes graduate schools and technical colleges that do not have undergraduate departments, which makes it impossible to collect information of academic skills of undergraduate enrollees. Therefore, this study controls for university quality by incorporating a binary dummy variable for seven ex-imperial universities (Hokkaido University, Kyoto University, Kyushu University, Nagoya University, Osaka University, Tohoku University, and University of Tokyo). Imperial universities, *kyu-teidai*, in prewar Japan have historically been top research universities that acted as the most important source of academic advancement and industrial innovation. Therefore, this variable is appropriate to capture the reputation effect of home universities.

Technological fields (*technology dummy*)

Table 2 presents the distribution of university spinoffs across technological fields. The necessity for university spinoffs to finance research activities from external sources may vary across technological fields (Honjo & Nagaoka, 2018). To control for differences in financing methods across technological fields, this study incorporates technology dummies in regression models. They include biotechnology and health care, medical devices, artificial intelligence (AI) and Internet of things (IoT), software and apps, robotics, space and aviation, electronics, environment and energy, and materials. This study bundles biotechnology, health care, and medical device into the category of biotechnology.

Table 2

Business stages (*business stage dummy*)

Business stages startups are in should affect the type of and dependence on external financial resources. Table 3 presents the financial structure of university spinoffs. 3F consisting of family, friend, and founder is the most important source of financial resource for university spinoffs. University spinoffs in Japan are financed exclusively by domestic actors. Table 4 presents the distribution of university spinoffs across growth stages. The METI USO DB classifies five stages that new businesses go through. Previous literature terms Stages 1 and 2 as seed and Stages 3 to 5 as startup, early, and later growth (Mason and Harrison, 1999; Sohl 1999; Van Osnabrugge and Robinson 2000). Figure 1 shows that 3F remains the most important source of financial resource across growth stages. What is characteristic to the university spinoff ecosystem is the presence of venture capital in the seed stage, which is even greater than that of business angels. This suggests the immature ecosystem in terms of individuals who invest in high-tech, risky business venture. Business corporations invest more into university spinoffs in the startup stage while the presence of venture capital sharply decreases in the growth stage. This study employs business stage dummies to control for variations in the significance of external financial sources across business stages.

Table 3

Table 4

Figure 2

Instrument variable (*patent attorney*)

Previous literature on the effect of intellectual property on venture finance addresses endogeneity by identifying appropriate instrument variables. Farre-Mensa et al. (2016) employ the probability of examiners granting patents as an instrument variable, given that the probability has to do with the number of patents granted to the firm whereas it does not affect firms' sales and financing. Yamauchi et al. (2016) use the distance to the nearest patent attorney office as an instrument variable based on the same assumption as Farre-Mensa et al. (2016) and find a positive impact of patents on value-added productivity. Following these studies, to test H2, this study introduces the number of patent attorney offices in a region as an instrument variable. This variable is expected to positively affect patenting activities, both filing and registration, by university spinoffs in the region whereas it does not correlate with venture financing. Information of regional distribution of patent attorney offices from 2015 to 2020 was collected from the "White Paper on Patent Attorneys" compiled by the Japan Patent Attorneys Association. This instrument is introduced in the regression models of which dependent variable is share of venture finance.

4. Results

Tables 5 and 6 present descriptive statistics and correlation matrix of the variables used in regression analysis. Both quantity and quality of innovation are positively correlated with investment by business angels whereas only quantitative aspect of innovation is positively correlated with investment by venture capitalists. Indicators of scientific productivity are significantly correlated with each other. Therefore, they are incorporated into regression models alternatively. *FWCI* is not correlated with the quality and quantity of innovation whereas *h5-index* positively correlates with both. The quantitative indicator of scientific production, *scholarly output*, is positively correlated with the quality and quantity of innovation.

Table 5

Table 6

Table 7 presents estimation results regarding H1. Only *h5-index* exhibits a positive effect on the probability of university spinoffs receiving risk money from venture capitalists. Unlike *FWCI*, *h5-index* does not control for differences in publication and citation practices across scientific disciplines (Hirsch 2005). Therefore, the result needs to be interpreted with caution even though technological fields are controlled for. Other scientific productivity indicators are not significantly associated with venture finance. The results are robust when the sample is limited to Type 1 university spinoffs that aim to commercialize university patents and thus are expected to be affected by the quality of university research. Furthermore, the results do not change when the fixed-effects regression models are estimated using share of venture finance as dependent variables. Therefore, the data provide weak support to H1. The result suggests the possibility that the effective use of publication database helps investors and policymakers identify potential investees and recipients, even though the nature of the quality indicator needs to be adequately understood.

The citation window of *FWCI* after 2019 is less than four years, which makes the value smaller. For instance, *FWCI* in 2020 builds on citations that a paper received from 2020 to now, of which citation window is half of *FWCI* before 2019. Considering that one third of the sample comes from the METI USO surveys after 2019, I ran the same regression model using the subsample before 2019, of which results remained the same.

Table 7

Table 8 presents estimation results regarding H2. None of the innovation quality indicators are positively associated with the probability of university spinoffs receiving risk money from venture capitalists and business angels. The results are robust after controlling for endogeneity. The absence of signaling effect of innovation quality contradicts to the finding of Haeussler et al. (2014) that patent citations speed up the time to receiving venture capital funding. Therefore, the data do not support H2. The number of patents granted and filed positively affects the probability of university spinoffs receiving venture financing, which corroborates the finding of Yamauchi and Nagaoka (2017) that patent application and patent grant speed up the timing of venture financing, of which effect varies across technological fields. However, after controlling for endogeneity, the quantitative measure of innovation does not affect share of venture finance. Overall, the results suggest the absence of scout function of entrepreneurial intermediaries in the ecosystem the university spinoffs are embedded in. The key results remain the same when the fixed-effects regression models are estimated using share of venture finance as dependent variables.

Table 8

Table 9 presents estimation results regarding H3. Venture capital funding positively affects sales growth of university spinoffs. Venture capitalists provide CEOs of university spinoffs with hands-on support so that they can grow faster. However, no guide effect is confirmed for angel investing. Therefore, the data provide partial support to H3.

Table 9

5. Conclusion

This study examined the relationship among three factors that shaped entrepreneurial ecosystems that university spinoffs were embedded in: science, innovation, and entrepreneurial intermediaries. The key findings from panel analysis are as follows. First, the quality of science measured by *h5-index* is positively associated with the probability of university spinoffs receiving venture capital funding. Second, none of the innovation quality indicators are associated with the probability of university spinoffs receiving venture financing. Third, receiving venture capital financing positively affects sales growth of university spinoffs, which corroborates previous findings on hands-on support provided by venture capitalists. The guide effect is not observed for angel investing. The scout effect in terms of the quantity of innovation disappears when endogeneity is controlled for.

I conclude the paper by referring to agendas of future research suggested by estimation results. First, the absence of scout effect in terms of the quality of innovation suggests that the patent indicators employed by this study may not capture the radicalness of innovation. Future research should operationalize the radicalness of innovation using alternative indicators, such as superstar fraction, tail innovation, and generality of patents. Second, considering that venture capital occupies a surprisingly large share in the seed stage (Figure 2), future research should investigate what support measures that venture capitalists offer are more effective than others in the entrepreneurial ecosystem for university spinoffs. Third, heterogeneity among venture capitalists (Hellmann 1998; Bottazzi et al. 2004; Bertoni et al. 2013) in terms of economic incentives and behavior should be incorporated into regression analysis in future research.

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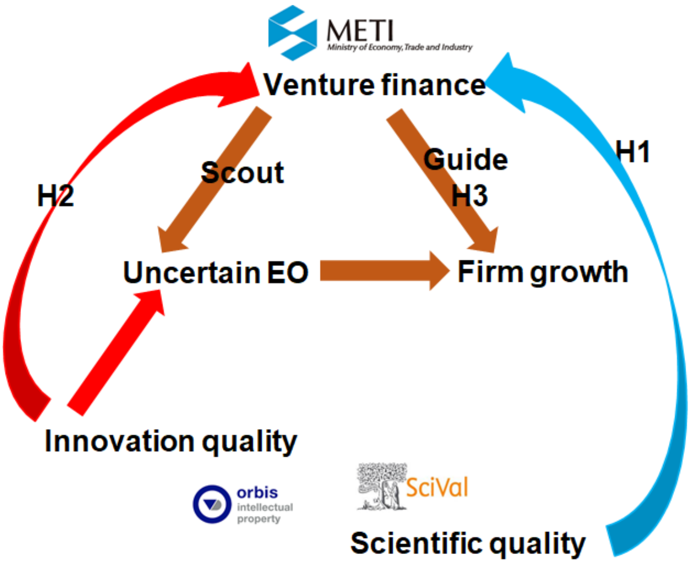
Figure 1 Theoretical framework and hypotheses



EO: entrepreneurial opportunities

Table 1 Geographical distribution of university spinoffs at the postal code level

Postal code	N	VC dummy	BA dummy	IPO dummy	M&A dummy
1130033	42	0.214	0.238	0.547	0.047
9808579	40	0.5	0	0.425	0.125
5650871	29	0.379	0.068	0.413	0.034
6068501	28	0.571	0.428	0.607	0.107
2770882	24	0.458	0.125	0.291	0.333
5670085	17	0.470	0.235	0.294	0.235
2600856	15	0.266	0.2	0.333	0
6158245	13	0.153	0.153	0.307	0
1030023	12	0.75	0.083	0.583	0
1050001	12	0.083	0.083	0.333	0
2130012	12	0	0.166	0	0
8140001	12	0	0	0	0.083

* IPO dummy takes a value of one when CEO of university spinoff intends to take the university spinoff public. M&A dummy takes a value of one when CEO of university spinoff intends to sell the firm.

Figure 2 Geographical distribution of university spinoffs

Table 2 Distribution of university spinoffs across technological fields

	Freq.	%
Biotechnology, healthcare, medical device	689	28.3
Others	369	15.1
Software, application	250	10.3
Environment, energy	204	8.3
Chemicals and material other than biotechnology	151	6.2
Electronics	144	5.9
AI, IoT	115	4.7
Robotics	60	2.5
Manufacturing other than ICT hardware	46	1.9
Aviation, space	17	0.7
ICT hardware	13	0.5
Total	2,433	100

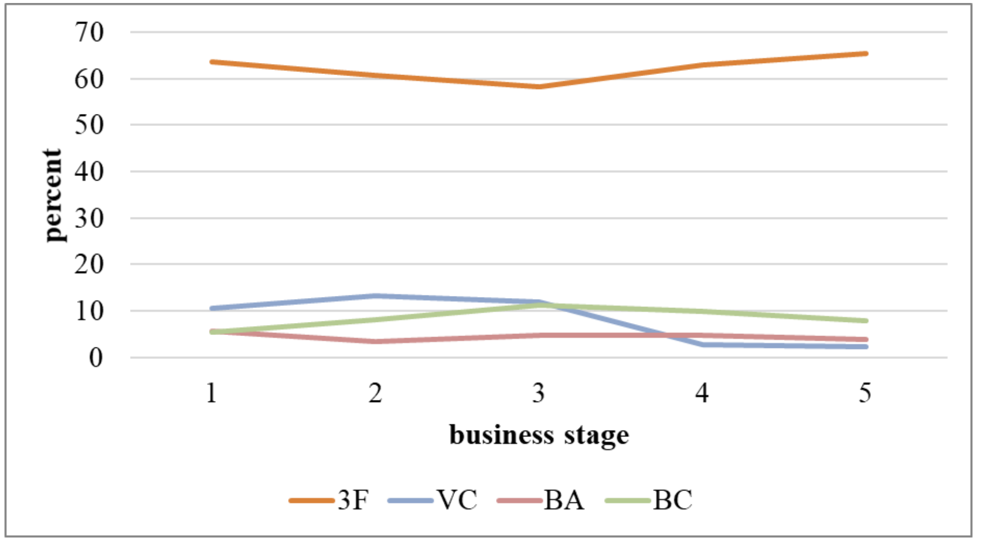
Table 3 Financial structure of university spinoffs

	%
Founder	56.1
Founder’s family, etc.	8.4
Board members and employees	15.3
Business angels	1.7
Corporate venture capital	2.7
University venture capital	1.8
Other venture capital	1.8
Business corporation	7.8
Bank	0.3
University	0.8
Foreign	1.1

Table 4 Distribution of university spinoffs across business stages

	# of USOs	%
1. No salable products, before proof of concept	262	12.7
2. No salable products, after proof of concept	299	14.5
3. Report deficit in a single fiscal year	532	25.8
4. Report surplus in a single fiscal year	360	17.5
5. Eliminate cumulative deficit	459	22.3

Figure 3 The dynamics of venture finance for university spinoffs



1. See Table 3 for the definitions of business stages.
2. 3F: family, founder, friends
3. VC: venture capital
4. BA: business angels
5. BC: business corporations

Table 5 Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Dummy VC	2,432	.143	.351	0	1
Dummy angel	2,432	.097	.296	0	1
Scholarly output	1,712	6.927	10.084	0	103
FWCI	1,459	.885	1.455	0	37.02
Citation counts	1,459	127.2	598.7	0	11647
h5-index	1,653	5.926	5.454	0	40
Technical quality	1,084	76.804	15.843	8	100
Market attractiveness	1,084	70.284	26.136	0	100
Ln patents	2,106	1.392	1.320	0	6.089
Ln employees	2,317	1.929	.917	0	5.398
Firm age	2,431	9.069	6.511	0	56
Agglomeration	2,431	1.665	1.624	1	10
Patent attorney	2430	1526.4	2372.2	2	6275

Table 6 Correlation matrix

	Dummy VC	Dummy angel	Scholarly output	FWCI	Citation counts	h5-index	Technical quality	Ln patents
Dummy VC	1							
Dummy angel	0.256*	1						
Scholarly output	0.108*	0.125*	1					
FWCI	0.078*	0.011	0.181*	1				
Citation counts	0.012	0.009	0.518*	0.325*	1			
h5-index	0.200*	0.173*	0.731*	0.274*	0.637*	1		
Technical quality	0.044	0.060*	0.080*	-0.010	0.020	0.209*	1	
Ln patents	0.144*	0.097*	0.213*	0.003	0.150*	0.254*	0.310*	1

1. The level of statistical significance: * 5%.

Table 7 Estimation results of logistic regression models regarding H1

N	1176	994	994	1130	133	115	115	130
Model	RE	RE	RE	RE	FE	FE	FE	FE
Dependent variable	VC dummy	VC dummy	VC dummy	VC dummy	BA dummy	BA dummy	BA dummy	BA dummy
Scholarly output	0.011				0.058			
FWCI		0.052				0.560		
Citation counts			0.000				0.000	
h5-index				0.104**				-0.007
Firm age	-0.131**	-0.143**	-0.144**	-0.122**	-15.898	2.128	2.115	-15.898
Ln employees	2.449***	2.324***	2.328***	2.343***	-0.306	-0.034	-0.148	-0.434
Agglomeration	0.290**	0.261**	0.269**	0.269**	-0.405	-0.337	-0.380	-0.393
Constant	-11.943***	-11.435***	-11.474***	-12.325***				
Business stage dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Technology dummies	Yes	Yes	Yes	Yes	No	No	No	No
Top university dummy	Yes	Yes	Yes	Yes	No	No	No	No
Type 1 USO dummy	Yes	Yes	Yes	Yes	No	No	No	No
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

1. RE: random-effects. FE: fixed-effects. The Hausman test was used for selection of the model.
2. The level of statistical significance: * 10%, ** 5%, *** 1%.

Table 8 Estimation results of logistic regression models regarding H2

N	752		659		1,456		1,328		104		659		1,456		1,330	
Model	RE		RE IV		RE		RE IV		FE		RE IV		RE		RE IV	
Dependent variable	VC dummy Coefficient	S.E.	VC share Coefficient	S.E.	VC dummy Coefficient	S.E.	VC share Coefficient	S.E.	BA dummy Coefficient	S.E.	BA share Coefficient	S.E.	BA dummy Coefficient	S.E.	BA share Coefficient	S.E.
Technical quality	0.011	0.019	-0.721	0.674					0.157	0.235	0.206	0.578				
Market attractiveness	-0.009	0.012							0.033	0.063						
Ln patents					0.750***	0.223	7.257	7.835					0.409**	0.181	2.401	6.552
Firm age	-0.187***	0.065	-0.137	0.359	-0.233***	0.058	-0.636*	0.340	-10.079	112.929	0.166	0.336	0.017	0.038	0.065	0.287
Ln employees	2.060***	0.436	5.211	1.678	2.904***	0.472	2.501	1.869	-3.667	2.743	0.042	1.410	0.775***	0.266	0.151	1.908
Agglomeration	0.261	0.171	0.593	0.462	0.305**	0.133	0.528	0.351	-1.649	1.775	0.039	0.449	0.076	0.122	0.074	0.404
Constant	-7.899***	2.452	51.411	46.236	-12.205***	1.894	-4.316	3.974			-21.160	38.914	-12.399***	2.140	-7.551**	2.980
Business stage dummies	Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Technology dummies	Yes		Yes		Yes		Yes		No		Yes		Yes		Yes	
Top university dummy	Yes		Yes		Yes		Yes		No		Yes		Yes		Yes	
Type 1 USO dummy	Yes		Yes		Yes		Yes		No		Yes		Yes		Yes	
Year dummies	Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	

1. RE: random-effects. FE: fixed-effects. The Hausman test was used for selection of the model.
2. IV: instrument variable method.
3. The level of statistical significance: * 10%, ** 5%, *** 1%.

Table 9 Estimation results of fixed-effects regression models regarding H3

N	1816		1613		1816		1613	
Model	FE		FE IV		FE		FE IV	
Dependent variable	Ln sales		Ln sales		Ln sales		Ln sales	
	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
VC dummy	1.815***	0.446	1.697**	0.680				
BA dummy					0.707	0.499	1.146	0.760
Firm age	-0.020	0.127	-0.001	0.141	-0.045	0.128	-0.004	0.141
Ln employees	1.289***	0.272	1.245***	0.446	1.500***	0.270	1.330***	0.456
Agglomeration	-0.268**	0.120	-0.268**	0.131	-0.235*	0.121	-0.263**	0.133
Ln patents			-0.330	3.948			1.003	3.870
Business stage dummies	Yes		Yes		Yes		Yes	
Technology dummies	No		No		No		No	
Top university dummy	No		No		No		No	
Type 1 USO dummy	No		No		No		No	
Year dummies	Yes		Yes		Yes		Yes	

1. FE: fixed-effects.
2. IV: instrument variable method.
3. The level of statistical significance: * 10%, ** 5%, *** 1%.