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ARTICLE

The Relationship Between Innovation and Corporate Performance in Japanese SMEs by Two-Stage Panel Data Analysis: Focusing on the Joint Effect of ICT and R&D

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Abstract
The final aim of innovation is not innovation itself but enhancing profits or sales. To complete the theory of innovation, it is required to show whether innovation contributed to improvements in business performance. A further focus of this paper is on the role of ICT and R&D in the innovation process. ICT plays a vital role in absorbing information from outside the firm, while R&D is essential for assimilating obtained information with existing resources to create something novel. The focus of this paper is on the joint effect of these two factors. The estimation is based on a two-stage probit instrumental variable (IV) panel model and the authors' own survey data of 2012 and 2018. The dependent variables are innovation in the first equation and sales in the second. The results obtained show that (i) innovation enhances sales; (ii) R&D is significant for innovation; (iii) ICT is not significant for either of the equations; and (iv) the cross term of R&D and ICT is significant for innovation, implying that ICT is an enabler of innovation. These are novel results.

Keywords Open innovation · Instrumental variable · Mediation · Cross term · Enabler

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1 Introduction

The COVID-19 pandemic has caused a deterioration of the global economy due to the destruction of supply chains or shortages of semi-conductors, for example. Business activities also have been greatly affected by lockdowns, along with movement or quarantine restrictions, which reduced consumption demand. ICT (information and communications technology) such as telework, on the other hand, was widely utilized, substituting for face-to-face communications, Apedo-Amah et al. [3] observed that ICT investment increased in many economies to strengthen network and digital environments as well as information sharing during the COVID-19 pandemic. However, since ICT could not assist directly in manufacturing or distribution, its increase could not necessarily prevent economic activities from deteriorating. Innovation activities also have been disrupted; according to the authors' interviews with SMEs (small and medium-sized enterprises), communications with business partners, which can convey useful information on technologies, consumers, or markets, have been affected greatly. These are important sources of innovation for SMEs.

Most innovation models thus far have attempted to explore the innovation process to indicate how innovation capability achieves innovation. Innovation capability includes human resources, R&D, the level of technology, the ability of the top management, and so forth. However, the final aim of innovation is not innovation itself but enhancing a firm's performance, such as by increasing sales volumes and profits to achieve growth. Innovation is one of means for enhancing business performance. To complete the theory of innovation, it is therefore required to show whether innovation contributes to improvements in business performance. Innovation is thus one process that leads to increases in profits by creating new products which are of higher quality and cheaper or by improving current products. This paper examines two processes for enhancing profits—firms make use of all resources to achieve profits through both usual business activities and innovation activities. These two processes conclude the whole process that begins from ideas or the seeds of business or innovation, finally ending up with profit. The framework of the model is shown Fig. 1.

Another focus of this paper is on the role of ICT and R&D in the innovation process. ICT plays a vital role in absorbing information from outside the firm, as already mentioned, while R&D is essential for assimilating obtained information with existing resources to create something novel. The focus of this paper is on the joint effect of these two factors. Traditional studies on innovation in general have focused thematically on individual factors such as absorptive capability, R&D, HR (human resources), managerial capability, technology management, ICT, and so on. Although this approach has its advantages, it is critical to consider innovation as a single process from a broad perspective and framework, and analyze how SMEs obtain new information and ideas as sources of innovation, organize and conduct R&D to assimilate these ideas with management resources within the firm, and finally develop new products [12, 13, 48]. One particular factor is focused on at each step of the process. ICT, for example, plays a vital role in

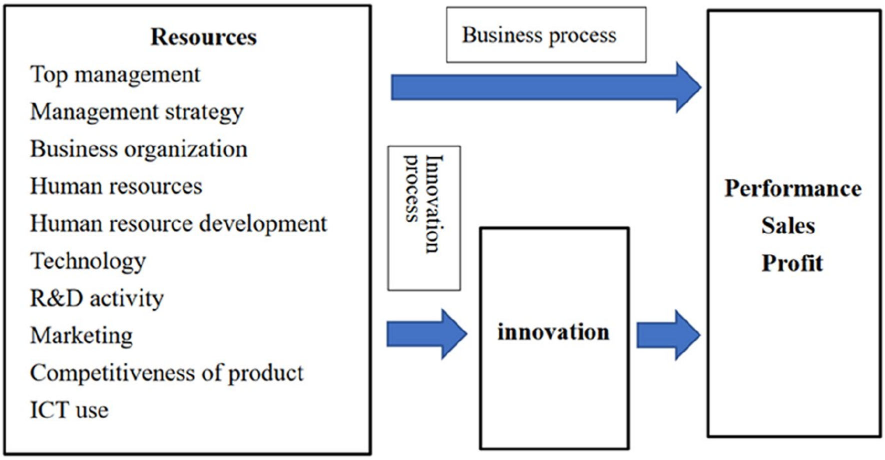

Fig. 1 Framework of the model

absorbing information from outside the firm, while R&D is essential for assimilating information obtained with existing resources to create something novel. As R&D is recognized as risky and having a high failure rate, a great amount of diverse research on R&D has been published since the 1980s. ICT, on the other hand, is a general-purpose technology that has various roles [8]. ICT has created opportunities for assessing and sharing information, both within and outside the firm, reducing related costs and improving efficiency in the business process, including innovation activities. However, only a handful of papers have provided evidence of the joint activity of R&D and ICT in this respect. Tsoukatos et al. [43], using original survey data on 405 Greek manufacturing SMEs, is one example. The point in which this study differs from that of Tsoukatos et al. [43] and other traditional studies lies in the following two aspects: (i) the roles of R&D and ICT are analyzed together, namely, the focus of this study is on how these two elements jointly promote innovation. In contrast, in their empirical model, Tsoukatos et al. [43] control R&D and ICT separately as variables, (ii) this paper focuses on the functionalities of R&D and ICT, which leads to an exploration of how these promote innovation. Most previous papers have used the amounts of R&D or ICT investment as a proxy of R&D or ICT, but in this setting, it is difficult to grasp the roles of R&D and ICT in innovation, namely, how and why they promote innovation. This study, on the other hand, focuses on the concrete functionalities of R&D and ICT as variables, which makes it possible to clarify their essential roles in the innovation process.

From the above discussions, the RQs of this paper are summarized as follows:

RQ1: How SMEs promote product innovation by using the kinds of innovation capabilities they own?

RQ2: Whether product innovation enhances corporate performance?
RQ3: How ICT and R&D jointly affect the innovation process?

With these questions in mind, the paper is structured as follows to shed light on the mechanisms of innovation in SMEs. Section 2 surveys related literature, and data obtained from the questionnaire, and the model for analysis is presented in Sect. 3. Section 4 shows the results from the two-stage panel data model. Discussion and conclusion are provided in Sect. 5. In this paper, the innovation process and innovation performance are integrated into one model, the aim being to explore the real objective of innovation.

2 Literature Survey

2.1 Uses of ICT for Innovation

ICT can contribute to the promotion of innovations though the following two functions: firstly, SMEs can utilize ICT to search for and access cutting-edge information outside the firm. One example of this channel is open innovation [11], which is a key factor for SME innovation, these channels consisting of intellectual and transaction channels [45, 46]. The former is used for collaboration with universities and research institutions, whereas the latter is for obtaining information from customers and suppliers via the supply chain [37], enabling information flows through orders, claims or improvements to interact more efficiently [42]. Secondly, SMEs assimilate information obtained through managerial resources they own and transform it into new knowledge, this process being referred to as “knowledge management.” ICT can support the sharing of information among R&D teams, which may shorten the R&D period or transform tacit knowledge into explicit knowledge. These functions of ICT are termed “IT capability” [21]. Recent developments in various ICTs that can assist innovation are as follows:

The Internet of Things (IoT) is transforming the traditional innovation process into a novel one in which big data on consumers, firms, and markets is utilized in real time. IoT could never have been realized without ICT development. Equipment and machinery in the factory are operated without human assistance, and robots equipped with AI can replace human engineers and workers everywhere in the economy, which is resulting in a digital transformation even in traditional process innovation [5]. Agriculture has been transformed into a high-tech industry due to ICT [2, 31]. These observations show that IoT enhances innovation.

Huge amounts of data can be saved and stored to be subsequently utilized for business purposes. Such big data is allowing firms to create new business models to serve customers in new ways. The so-called GAFA (Google, Apple, Facebook, and Amazon) are typical examples of the expansion of new business models. The kinds of characteristics of big data that enhance core competency or innovation have become the focus of research, Lee [24], Maryam and Goran [29], and Jaime et al. [20] identifying these as the three Vs of big data, Volume, Velocity, and Variety. Zhan et al. [49] analyze the merits of big data, finding that they reduce lead time and costs of innovation through efficient transactions with consumers and trade partners. Blackburn et al. [6] focus on how big data transforms the R&D process through interviews and case studies. Big data is relevant not only for large firms but also SMEs, since the latter can access big data through open innovation with large firms or universities [36]. Since the age of big data has just begun, new ICTs will surely bring about a transformation to the data-driven economy [44].

Social media such as Twitter, blogs, Facebook, Instagram, and others have become popular in all kinds of businesses. Firms have come to recognize that the use of social media is a strategic measure not only for the collection of information on promoting marketing but also for developing new goods and services [18, 19]. Consumer involvement in social media has the three dimensions of consumer brand engagement, cognitive processing, and affection and activation [7].

2.2 R&D and ICT

Previous research has mainly addressed R&D from the perspective of organizational theory, focusing on areas such as acquisition of new information through the R&D organization, sharing of the information among R&D team members, and the conversion of the information to knowledge, and furthermore, from tacit knowledge to codified/explicit knowledge. Accordingly, two roles are considered critical in the R&D process: the gatekeeper, the key person who incorporates new information, and the transformer, who converts the acquired information into knowledge and transmits it to other members of the organization [15, 45]. To convey information smoothly, trustworthiness among R&D members is a prerequisite [14, 26]. Many of these discussions on R&D consider R&D's success or failure as the outcome of their analyses.

As discussed earlier, in knowledge management, ICT offers effective measures for the promotion of R&D and innovations. The uses of ICTs are categorized according to their functionalities: (1) ICT used for obtaining external information on new technologies; (2) ICT used for sharing internal knowledge on products and production; and (3) ICT used for sharing internal knowledge on the market and consumers. ICT can also contribute to all aspects of the above innovation process; acquisition, assimilation, transformation, and exploitation [47]. In particular, ICT can activate and make these more efficient [32, 34, 35]. Information networks inside the firm promote the sharing of necessary information among R&D team members and other teams, which may shorten the time required for decision-making, or assist in the transformation of tacit knowledge to explicit knowledge [33, 38]. ICT thus transforms information to knowledge efficiently and encourages innovation. Tsoukatos et al. [43] examined the role of R&D and ICT using their survey data of 405 Greek manufacturing SMEs. They used ERP (Enterprise Resource Planning) and TQM (Total Quality Management) as variables to represent ICT and R&D investment. Least square regression showed that only TQM is significant.

3 Methodology

3.1 Questionnaire Survey

This model is based on two surveys conducted in February 2012 and February 2018. The samples were selected as follows: in the first survey, from the lists of the Teikoku Databank, 3959 firms were selected from the manufacturing, construction, information and communications, and service industries. The criteria of the selection were that sample firms have to satisfy the following conditions: the firm (i) is unlisted; (ii) employs more than 20 workers, (iii) has earned positive profits in the most recent three terms, that is, in the last 18 months, and (iv) is experiencing increasing sales. The reason for these limitations was to reduce the number of samples to an appropriate size. The valid number of responses to the first survey was 647, a response rate of 16.2%).[1] The second survey was conducted in February 2018 with 620 of the above 647 SMEs which responded to the first survey, 27 being unable to participate due to bankruptcy, change of address, or rejection of the survey. 122 SMEs among the 620 replied, the valid response rate being 19.7%. Summary statistics of the pooled data are shown in Table 1.

3.2 Selected Firm Characteristics

The main industry the sample firms were engaged in was manufacturing, amounting to 60% of the total, followed by construction. Regarding the trend of sales in the past three years, in 2012, almost two-thirds of the firms, whether they succeeded in innovation or not, had increased their sales amounts, which may have been due to recovery from the Lehman Shock. In 2018, on the other hand, the percentage of "Increasing" sales declined and those of "Almost the same" increased. The ratios of R&D to sales indicate that SMEs that achieved innovation tended to have a higher R&D ratio than those that did not achieve innovation. The ratio for more than half of the former was 0.1–0.3, whereas more than half (2012) or two thirds (2018) of the latter had no R&D expenditures, a substantially large contrast. Similar phenomena are also seen in the trends in R&D over the past three years; about 50% of SMEs that achieved innovation and 80% of SMEs that showed no innovation maintained the same R&D ratio in both the first and second surveys.

3.3 Dependent Variable

The number of SMEs which achieved innovation in the questionnaire is taken in this paper as an outcome variable. That is, respondents were asked whether they supplied a new product or service to the market during 2006–2010 and during 2013–2017

[1] Idota et al. [17] is based on the first survey, but the method of analysis is SEM (Structural Equation Modelling), which is different from this paper.

Table 1 Descriptive statistics and correlation matrix

	Mean	SD	1	2	3	4	5	6	7	8	9
1. Sales	0.562	0.498	1								
2. Number of transaction partners	0.414	0.494	0.221**	1.000							
3. Employee (log)	3.677	0.640	0.092	0.091	1.000						
4. Open innovation	0.740	1.521	0.075	− 0.171*	− 0.092	1.000					
5. Innovation	0.627	0.485	0.076	0.114	0.075	0.090	1.000				
6. ICT	0.397	0.490	0.039	0.0358	0.250**	− 0.071	0.175**	1.000			
7. R&D organization	0.007	0.885	0.163*	0.234**	0.107	0.093	0.371**	0.099	1.000		
8. ICT*R&D autonomy	0.603	3.320	0.065	0.045	0.069	0.035	0.415**	0.116*	0.053	1.000	
9. Subsidy	0.065	0.247	− 0.001	− 0.113	0.094	− 0.105	0.149*	0.190**	− 0.015	0.039	1.000

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

Table 2 Distribution of replies

2012	2018
Achieved innovation: 80 (66.7)	Achieved: 52 (65.0)
	Not at all: 28 (35.0)
Not at all: 40 (33.3)	Achieved: 5 (12.5)
	Not at all: 33(82.5)
	No reply: 2 (5)

(QII.1). Firms were asked to reply "yes" or "no," and these are taken as explained variables for estimation. The numbers of replies to the two surveys are shown in Table 2. About two thirds of respondents answered positively in both surveys, these firms being genuinely innovative. The variable of "Innovation" is thus constructed.

In VIII.9 in the questionnaire, it was asked whether another dependent variable, sales, are increasing or not. If SMEs reply "yes," it takes 1, and otherwise 0. More than half the samples firms replied "yes." Innovation is not the sole objective of firms, but profit or sales; innovation is one means of obtaining profit or sales. Many patents do not necessarily yield profits automatically. To make the whole process of innovation worthwhile, profit should accrue from the outcome. The hypothesis this paper is seeking to substantiate is related to innovation, and innovation is one variable that explains profit or sales. In addition, one further equation, which defines a firm's profits, is required. Innovation, which is examined in this study, is included as one variable that explains profit or sales. A two-stage estimation model is thus a better formulation for examining the innovation process [22].

3.4 Explanatory Variable I: R&D

To construct variables related to R&D, suitable questions were chosen from QI and QIII of the questionnaire, as follows:

QI.1.3 Various basic technologies and know-how other than core technologies are owned.
QIII.1.3. R&D is directly connected to new products and services.
QI.1.5.5. Goals are assigned to employees, who are rewarded based on their achievements.
QI.1.5.8. The top manager takes the lead in new business.
QIII.1.4. Positive about offering owned technology to other firms.
QIII.2.1. Speedy decision-making.
QIII.2.2. Responsibility and authority are delegated to the R&D department.
QVIII.3. Number of employees.

The result of the factor analysis regarding R&D, shown in Table 3, extracts two factors which consist of two questions each. The first factor is named "R&D orientation," while the second factor is named "R&D autonomy." The first factor consists of "QIII.1.3. R&D is directly connected to new products and services." These factors

Table 3 Factor analysis of R&D

Observation variables	Factor 1	Factor 2	Communality
Positive about offering owned technology to other firms	**0.946**	0.222	0.945
R&D is directly connected to new products and services	**0.587**	0.476	0.572
Responsibility and authority are delegated to the R&D department	0.204	**0.836**	0.740
Speedy decision-making	0.341	**0.684**	0.585
Goals are assigned to employees, who are rewarded based on their achievements	0.194	0.215	0.084
The top manager takes the lead in new business	0.283	0.131	0.097
Various basic technologies and know-how other than core technologies are owned	0.235	0.266	0.126
Number of employees (log)	0.102	0.066	0.015
Variance	3.009	1.050	
Proportion	37.608	13.126	
Cumulative	37.608	50.734	

Note: The numbers in bold indicate that their factor loadings are greater than 0.5, showing a strong correlation with a common factor

indicate the direction and performance of R&D and, accordingly, the latent variable based on these observed variables is referred to as "R&D orientation." This variable, in other words, indicates whether R&D leads on to the achievement of innovation, which is an essential question for R&D. Various previous papers have also analyzed this aspect [16, 25, 41].

The second extracted factor contains "QIII.2.1: Speedy decision-making," and "QIII.2.2: Responsibility and authority are delegated to the R&D department." Particularly, the latter question 2.2 is related to the decentralization and autonomy of R&D units. From our field research, it is observed that the speed of decision-making is a characteristic merit of SMEs [46]. From these observations, it follows that the latent variable is referred to as "R&D autonomy." Previous papers also discussed autonomy and found from Japanese data that autonomy as a variable elevates innovation, whereas Argyres and Silverman [4] and Lerner and Wulf [23] claim that centralization in R&D organizations is better in the pursuit of innovation in terms of efficient allocation of resources and coping with shifts in technologies, markets, and other environments related to R&D. This study supports autonomy as a factor promoting innovation.

3.5 Explanatory Variable II: ICT

The RQs of this study are to examine how ICT contributes to R&D and innovation in SMEs. Although the authors' previous study adopted the number of ICT systems and practices, such as e-commerce, supply chain management, SNS, and so on as variables of ICT use, it is in line with the objective of this paper that the perceived effect of ICT is taken as a variable. In other words, instead of external differences, how successfully SMEs use ICT is evaluated in this analysis.

Table 4 Factor analysis of ICT

Observation variables	Factor 1
ICT shortens the development period for a new product	**0.452**
ICT improves the speed of decision-making	**0.442**
ICT assists in adverting products	0.237
Variance	2.025
Proportion	67.502
Cumulative	67.502

Note: The numbers in bold indicate that their factor loadings are greater than 0.5, showing a strong correlation with a common factor

The questionnaire contains questions on the effect of ICT on innovation, which were asked in QV.4. The questions used in this analysis are summarized as follows:

QV.4.2: ICT assists in advertising products.
QV.4.3: ICT improves the speed of decision-making.
QV.4.4: ICT shortens the development period for a new product.

These questions required a response on the five-point Likert scale. Again, factor analysis is applied to extract latent variables. The results are shown in Table 4, which extracts one factor consisting of "QV.4.3: ICT improves the speed of decision-making" and "QV.4.4: ICT shortens the development period for a new product." Thus, the related latent variable is referred to as "ICT." These are consistent with assertions in previous research [9, 10].

3.6 Other Controls

- Number of transaction partners

  This variable explains the competitiveness of products. There are a large number of possible indicators which explain this characteristic, but the questionnaire asks whether the number of transaction partners is increasing (QI.4.2). If so, they are attracted by either the quality or the price of products, indicating the competitiveness of products. To those who answered affirmatively, another question was asked regarding whether new trade partners approached to initiate transactions. This question is also related to product competitiveness. The dummy variable of "Number of transaction partners" is thus constructed.

- Number of employees

  The number of employees is a proxy for the size of firm, which is asked by V.3.3. This question is used for individual firm characteristics. The logarithm is used for estimation.

- Open innovation

As presented in Sect. 2.1, collaboration with other firms, universities, and public research institutions is a vital factor for innovation and refers to open innovation. For Japanese SMEs, there are two channels of information flow through open innovation; intellectual and supply chains. The former is related to laboratories in universities or public research institutions, while the latter refers to customers or suppliers of transactions. Question IV. 2 asked whether SMEs own such collaboration. To elaborate collaborative behavior, Question III.1.7 asks to mark partners of open innovation, which include (1) Parent company, (2) Affiliated company, (3) Customer, (4) Supplier, (5) Competitor in the same industry, (6) Industry association, (7) Public research institution, (8) University inside the prefecture, (9) University outside the prefecture, (10) Local government, and (11) others. If respondents reply affirmatively to Question IV. 2 and mark partners in Question III.1.7, the dummy variable of "Open innovation" takes 1, otherwise 0.

- ICT*R&D autonomy

  This variable is constructed as the cross term of ICT use and R&D autonomy (latent variable), indicating whether the two variables together affect innovation. This variable is termed the mediation effect from the standpoint of ICT, explaining how ICT affects innovation via other variables. If ICT*R&D autonomy is positively significant, then ICT assists R&D autonomy to promote innovation, implying that ICT is "an enabler." This will be discussed in detail in what follows.

- Subsidies

  Question VI.1. asks whether the firms received public support for innovation such as financial assistances for R&D, investment, training, tax exemptions, patent registration, and participation in exhibitions and trade shows. If they received support for at least one of these, the variable takes 1, otherwise 0.

4 Estimation Methods and Results

4.1 Model

This paper at first conducts a probit estimation based on the pooled data (Model 1), and the second analysis is the examination of the relationship between innovation and sales with instrumental variables (IV) panel data regression, in which a variable of innovation is the instrument and the variable of sales is instrumented. A two-stage panel data estimation, which is an IV probit model consisting of a first and second estimation, is then performed. Here, the first equation estimates innovation with internal innovation capabilities such as R&D, ICT, and subsidies (SB), and the second equation estimates sales with competitiveness of products (Number of transaction partners: TP), collaboration with other entities (Open innovation), and innovation (Innovation), and the firm size (Number of employees) is controlled as a firm characteristic.

Table 5 Results of the estimation

	1	2	3
	Probit regression	Two stage probit regression	
		First	Second
Variables	Sales	Innovation	Sales
Innovation	0.263 (0.278)		1.037** (0.512)
Number of transaction partners	0.793*** (0.309)		0.832*** (0.320)
Open innovation	0.181* (0.105)		0.205** (0.104)
ICT	0.003 (0.283)		0.019 (0.292)
Employee (log)	0.380 (0.245)		0.306 (0.234)
ICT		0.221 (0.311)	
R&D orientation		0.645*** (0.216)	
ICT*R&D autonomy		0.2614*** (0.072)	
Subsidy		1.452* (0.805)	
Observations	182	168	168
Corr (e.innnovation,e.sales)			− 0.255 (0.397)
Corr (innovation[new_no],sales[new_no])			− 0.655* (0.392)
Log likelihood	− 115.53562		− 185.68869
Prob > χ^2	0.0959		0.0292

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

$$\text{Innovation} = a + b_1\text{R\&Do} + b_2\text{ICT} + b_3\text{SB} + b_4\text{ICT} * \text{R\&Da} + e_1 \quad (1)$$

$$\text{Sales} = c + d_1\text{Innovation} + d_2\text{TP} + d_3\text{OI} + d_4\text{ICT} + d_5\text{NE} + e_2, \quad (2)$$

where R&Do: R&D orientation, ICT*R&Da: cross term of ICT and R&D autonomy, SB: subsidies, TP: number of transaction partners, OI: Open innovation, NE: number of employees

4.2 Results

The results of the IV probit panel data estimation are shown in Table 5. In the first equation, R&D orientation ($p < 0.01$), ICT*R&D autonomy ($p < 0.01$), and Subsidies ($p < 0.1$) are found to be significant, but ICT itself is not significant. Among factors which affect innovation, two latent variables related to R&D strongly enhance innovation, which is consistent with the results of the previous studies listed in Sect. 2.1. In particular, it is natural that R&D orientation, which consists of the two characteristics "Positive about offering owned technology" and "R&D is directly connected to new products and services," promotes innovation, whereas R&D autonomy, consisting of "Give responsibility and authority to R&D department" and

"Decision-making is speedy," is not significant. However, R&D autonomy with the help of ICT, that is, the cross-term of ICT*R&D autonomy is significant for innovation. This is because ICT assists in facilitating faster decision-making, which is a natural feature of ICT. The role of ICT in this context will be discussed later.

In the second equation, Innovation ($p < 0.01$), Transaction channel ($p < 0.01$), and Open innovation ($p < 0.05$) are found to be significant. Innovative SMEs which own a competitive product due to collaboration with universities and research institutes tend to achieve increased sales. But this result was not found for profit. ICT is individually significant for neither sales nor innovation, whereas R&D is significant for innovation, but not for sales. ICT and R&D together promote innovation, but not sales. In other words, these two variables together directly promote innovation, but indirectly promote sales, since innovation raises sales.

These results answer the RQs posed in the Introduction: Regarding RQ1, innovation capabilities such as the numbers of trading partners (Transaction channel), open innovation, and R&D are identified as promoting innovation. Innovation undeniably promotes sales, which demonstrates RQ2, and ICT and R&D jointly affect the innovation process (RQ3).

5 Discussion and Conclusion

5.1 Role of ICT in the Innovation Process

To highlight the novelty of the above results, the concept of "ICT as an enabler of innovation" has been referred to earlier, for example, by Spiezia [40] and Scupola [39]. Regarding empirical studies, using cross-section data, Alam et al. [1] estimated the impact of ICT skills of workers on innovation and financial performance of regional SMEs in Queensland, Australia. In their two-stage estimation model, ICT has a significant effect on innovation but not on financial performance, which is similar to our results. They also use the cross-term of ICT skills and start-up as well as ICT skills, and obtain the result that both are significant to innovation, indicating that ICT skills are not simple enablers, but boost innovation itself, which is different from our results. Thus, to the best of our knowledge, the role of ICT as an enabler has not been demonstrated by rigorous empirical studies thus far.

This paper uses a two-stage panel data model with an instrumental variable, which is much more sophisticated. In Table 5, ICT is significant in neither the probit regression nor the two-stage IV model, indicating that ICT individually is significant neither for innovation nor sales. In this aspect, the role of ICT may differ slightly from that expected by earlier literature, such as Brynjolfsson and Hitt [9], Brynjolfsson and Saunders [10] and Ueki and Tsuji [47].

It follows from these results that ICT itself does not create innovation, but assists R&D teams in activating R&D functions such as "Speedy decision-making," and "Responsibility and authority are delegated to the R&D department." The former is precisely one of the merits of ICT and the latter enhances the motivation of R&D team members. These discussions lead to the answer for RQ3, that is, the roles of ICT and the autonomy of R&D teams in shortening decision-making are particularly important for innovation. Accordingly, this paper identifies the mediation effect of ICT on innovation via R&D autonomy. ICT itself may not necessarily create innovation, but it is an "innovation enabler" that supports other factors [28]. Taking the example of cloud computing, since cloud computing is a general-purpose ICT, combining this with mobile phones is what has brought smartphones to realization [27]. Thus, the mediation effect appears to be an essential nature of ICT, and this is what is demonstrated by the model in this paper.

5.2 Open Innovation

This model shows that Open innovation is significant in the second equation (Sales), but not in the first (innovation), which seems to differ from reality, as opposite results are obtained. This may come from its definition. In the questionnaire, Question III.1.7 in Sect. 3.6 lists the partners of open innovation such as (1) Parent company, (2) Affiliated company, (3) Customer, (4) Supplier, (5) Competitor in the same industry, (6) Industry association, (7) Public research institution, (8) University inside the prefecture, (9) University outside the prefecture, (10) Local government, and (11) others. In Sect. 3.6, they are classified into two categories of open innovation: supply chains (transaction channels), that is, (1)–(6) and intellectual channels, that is, (7)–(10). In the questionnaire survey, few respondents which marked intellectual channels are small, while many more marked supply chains. SMEs mainly connect to firms via the supply chain rather than intellectual channels, and the stronger connection with other firms may therefore raise sales. Large firms own more information on technologies and markets, from which SMEs can absorb cutting-edge information [46]. Because of this dual nature of supply chains, this estimation is more influenced by physical transactions than the flow of information via intellectual channels. However, to determine which is larger requires further analysis.

5.3 Further Research

The following are suggestions for further research. Most panel data analysis on R&D or ICT in the innovation process have employed data constructed by government or international organizations. These have merits such as containing a large number of samples and using international data, which makes for much more rigorous and in-depth analysis. In comparison with firm-level survey data, however, official data on R&D or ICT contain less firm-specific characteristics such as the implementation of R&D, organizational structure, information flow among different R&D departments, leadership of top management, and so on. This paper aims to explain the role of R&D and ICT in the innovation process of SMEs, and hypotheses are derived from the authors' in-depth field surveys [46]. Thus, it has been possible to include in this paper variables related to SME management, organization, implementation of R&D and ICT. Because of the sample number, it was not possible to incorporate all the variables into the analysis and the variables analyzed here are limited. While the model used in this paper has these shortcomings, to the authors' limited knowledge there has been no analysis employing robust panel data analysis thus far.

Another requirement for further study should be a focus on policy. The estimation shows that Subsidies is significant in the first equation (innovation). SMEs wanted small subsidies to support their investments in new fields, including funds for supporting consortia for the application of new technologies, exhibitions in trade shows, HRD (human resource development), and so on [30, 46]. Some SMEs may possess specific technologies, but are unable to develop them into final products due to a lack of manpower and financial capability. The above policies assist SMEs in stimulating their innovation. The amount of funds offered by policy measures is not of such great significance, what is much more important is the priority of policy targets.

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Data availability The content of the filed survey was published by [46].

Declarations

Conflict of interest The authors declare that they have no competing interests.

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