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# Determinants of ICT and Smart Farming Technology Adoption by Agricultural Corporations in Japan

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This study identified the determinants of ICT and smart farming (ICT&SF) technology adoption intensity by Japanese agricultural corporations. Primary data were collected from a Japan nationwide questionnaire survey on "Business Development and Innovation in Agricultural Corporation Management" in 2019. Data of 183 agricultural corporations in Japan were analyzed through descriptive analysis and negative binomial modeling. The results showed that 175 out of 183 corporations had adopted at least one ICT&SF technology until 2019, indicating an overall adoption rate of 95.6%. Majority (84.7%) of corporations were limited companies and stock companies, and 86.9% of the corporations were qualified to own farmlands. Regarding the profile of corporate representatives, over one third of the representatives graduated from universities. Based on the empirical results, corporate forms, eligibility to own farmland, sales targets, profit targets, main product and self–evaluation of ICT utilization and information management significantly affected the adoption of ICT&SF technologies adoption. In terms of the characteristics of corporate representatives, those who graduated from specialized schools and vocational colleges tended to adopt more ICT&SF technologies.

**Key words**: adoption intensity, agricultural corporations, determinants, ICT, smart farming technologies

## INTRODUCTION

Many scholars discussed that acute labor shortage due to shrinking and aging of farmers has become one of the critical constraints of agricultural development in Japan. According to census by the Ministry of Agriculture, Forestry and Fisheries (MAFF), the labor force primarily engaged in agriculture has decreased from 1.76 million in 2015 to 1.36 million in 2020. Alarmingly, more than 70% of farmers were above the age of 65 years in 2020, compared with 65% in 2015 (MAFF, 2020). Under these circumstances, the Japanese government has encouraged the vigorous development of smart agriculture to overcome the disadvantages of agricultural labor shortage, improve agricultural production efficiency, and revitalize the progress of agriculture and rural areas (MAFF, 2022). Moreover, the widespread application of information and communication technology (ICT) in agriculture has proven crucial for optimizing the market activities, promoting the succession of agricultural skills, and boosting the development of agricultural informatization in Japan.

Meanwhile, a structural change toward consolidation is ongoing in Japanese agriculture, with the decline of agricultural households but the rise of large–scale farming and agricultural corporations in recent decades (Nanseki, 2021; EU–JAPAN CENTRE FOR INDUSTRIAL COOPERATION ECOS GmbH, 2021). The emergence of agricultural corporations has become the backbone of realizing large–scale production, heightening the strategic management of agribusiness and accelerating industrial clusters. Intensive adoption of ICT and smart farming (SF) by corporations is anticipated to allow for the technical optimization of agricultural production systems and food value chains, ultimately contributing positively to agricultural development. Ogata *et al*. (2019) analyzed the cost–effectiveness of ICTs for agricultural corporations using factor analysis and observed that the factors for production and accounting visualization are related to human resource development. Their factor scores comparisons by farm characteristics revealed three points: (1) ICT cost–effectiveness is greater for livestock farms than for farms producing other goods in terms of enhancing the profitability factor; (2) farms with higher sales place a greater value on production and accounting visualization factors than those with lower sales; and (3) farms with more employees place a higher value on production visualization factors than those with fewer employees. Nanseki (2019) and Nanseki *et al*. (2016) reported on interdisciplinary aspects based on ICT and smart farming technology by focusing on rice farming. Bucci *et al*. (2021) discussed factors affecting ICT adoption in Italian agriculture and reported Internet access, web pages, production standards, age, and educational background as the factors affecting successful adoption of management information systems on farms. However, the determinants of ICT and smart farming (ICT&SF) technology adoption by agricultural corporations in Japan remain unclear.

To this end, the objective of this study was to identify the determining factors of ICT&SF technologies

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adoption by Japanese agricultural corporations. Section 2 outlines empirical models, followed by a description of data sources and variables used in econometric analysis. Section 3 discusses the empirical results, and section 4 presents the key conclusions.

## METHODOLOGY AND DATA

### Methodology

Previous studies have analyzed the adoption of a particular or several agricultural technologies by applying ordered probit models, multinomial logit regressions, and double–hurdle models (Knowler and Bradshaw, 2007; Zhang *et al*., 2020). In this study, we investigated the intensity of ICT&SF technologies adopted by agricultural corporations. Accordingly, the dependent variable is a count variable taking a non–negative integer value from 0 to 21. Thus, count data models were deemed appropriate to estimate the effect of potential influencing factors on the number of technologies adopted (Cameron and Trivedi, 1986; Rahelizatovo and Gillespie, 2004; Isgin *et al*., 2008). Count integer values were assumed to follow a compound Poisson regression, in which the number of technologies adopted and the probability density function of $Y$ can be given as follows:

$$f(y_i|x_i) = P(Yi = y_i) = \frac{e^{\lambda}\,\lambda_i^{\,y_i}}{y_i!},\ y_i = 0, 1, 2, 3\ldots \quad (1)$$

where $y_i$ is the total number of technologies adopted by the agricultural corporation $i$ and $x_i$ is the expected determinant of ICT&SF technology adoption. The expected mean parameter ($\lambda$) of this function is defined as $\lambda_i = \exp(x_i'\beta)$, where $\beta$ can be estimated using maximum likelihood.

The Poisson model assumes that the mean and variance of the dependent variable are equal, that is, $\lambda_i$ = mean $(y_i|x_i)$ = variance $(y_i|x_i)$. However, when the conditional variance is greater than the conditional mean, overdispersion is the most likely situation (Ehiakpor *et al*., 2021). Thus, a negative binomial (of which Poisson is a special case) may be an appropriate count data handling procedure to accommodate the overdispersion issue by modeling variance as a function of mean. The variance in negative binomial model is given as follows:

$$Var(Y_i|x_i) = \lambda_i + \alpha\lambda_i^2 \quad (2)$$

where $\alpha$ is the dispersion parameter to be estimated. If $\alpha$ is zero, the negative binomial model is the same as the Poisson regression model, and the corresponding log–likelihood is $\log L = \sum_i log[\Pr(y_i)]$. In this study, the test indicated the presence of overdispersion, which led to the selection of a negative binomial model[1].

### Data

*Data collection*

The data used in this study were obtained from the "Business Development and Innovation in Agricultural Corporation Management" survey conducted by the Laboratory of Farm and Management at Kyushu University in 2019 (Nanseki, 2021). Information was gathered through mail questionnaires sent to agricultural corporations across Japan. The names of agricultural corporations were collected from the relevant publications, reports, and website of the Japan Agricultural Corporations Association (https://hojin.or.jp/).

In the survey, respondents were asked questions covering six parts: (1) basic information and operating policy of the corporation, such as corporate form, location, establishment year, development stage, annual sales/profit margin, operating targets in the next 5 years, and so on; (2) innovative realization of corporations within the past 3 years; (3) current status of ICT&SF technologies adoption; (4) detailed business content, management strategy, and self–evaluation; (5) social contribution and perception of the Free Trade Agreement (FTA); and (6) profile of corporate representatives, such as age and education.

The questionnaires were sent to 2,885 corporations, and 505 corporations provided valid answers, resulting in the effective response rate of 18% (Nanseki, 2021). The outline and basic survey results is shown in Nanseki (2021). In this study, we eliminated the observations without sufficient supporting information on questions of technology adoption and deleted the missing data of corporate and representative attributes. After screening for the missing data of all variables, most respondents made a single selection for the indicators of corporate attributes, and only one respondent made multiple selections for corporation's establishment background. Finally, 183 valid observations were used for further analyses[2].

*Variable description*

The dependent variable used in this study was the number of technologies adopted by an agricultural corporation. It is a count variable that can be used to estimate the intensity of technology adoption. Specifically, we counted the number of combined technology categories involved in both ICT and SF technologies. According to the Food and Agriculture Organization of the United Nations (FAO), ICT is defined as "a broader term for information technology (IT), which refers to all communication technologies, including the Internet, wireless networks, cell phones, computers, software, middleware, video–conferencing, social networking, and other media applications and services enabling users to access, retrieve, store, transmit, and manipulate information in a digital form.[3]" According to MAFF (2022),

[1] Variance of the dependent variable was approximately 15.907, which is nearly two–times greater than mean (6.623), implying that the count data present overdispersion.

[2] The results of analysis including 195 observations (12 missing data were replaced by 0 in independent variables; See APPENDIX for details) were previously presented orally at the 10th Asian Society of Agricultural Economics International Conference (Mi *et al*., 2021).

[3] http://aims.fao.org/information-and-communication-technologies-ict

"smart agriculture" or "smart farming" refers to the utilization of cutting–edge technologies, such as robots, artificial intelligence (AI), and the Internet of Things (IoT), in agricultural or farm management. Recent studies have distinguished SF technologies into the following types: (1) recording and mapping technologies, which collect precise data for subsequent site–specific application; (2) tractor GPS and connected tools, which use real–time kinetics to appropriately apply variable rates of inputs and accurately guide tractors; (3) apps and farm management and information systems, which integrate and connect mobile devices for easier monitoring and management; and (4) autonomously operating machines, such as weeding and harvesting robots (Fountas *et al*., 2017; Knierim *et al*., 2019). In this study, the ICT&SF technologies adopted by Japanese agricultural corporations are tentatively identified as two types. One refers to the smart farming technologies (SFTs) contained ICT and (2) common ICTs applied in SF.

The definitions and adoption rates of each technology categories are shown in Table 1. Three aspects including data monitoring and collection, operation automatization, and robotization, and business management, were involved, and 21 ICT&SF technology categories were described. The most frequently adopted technology category was financial management systems, such as bookkeeping and accounting, with an adoption rate of 84.2%. Advertisement for companies and products was a relatively frequently used technology category with an adoption rate of 65.0%. The third most frequently adopted technology category was sales information management, with an adoption rate of 61.7%. In

**Table 1.** Definitions and adoption rates of ICT&SF technologies

| Technology categories | Type [1] | Frequency | Adoption rate (%) |
|---|---|---|---|
| *Data monitoring and collection technologies* | | | |
| 1–Measurement of environmental information of crops and livestock (temperature, water temperature, soil moisture, solar radiation, and so on) | ICTs applied in SF | 56 | 30.601 |
| 2–Measurement of biological information of crops and livestock (growth status, livestock estrus, body temperature, and so on) | SFTs contained ICTs | 52 | 28.415 |
| 3–Collection of work information from each field (recorded using a personal computer, smartphone, camera, GPS, and so on) | ICTs applied in SF | 76 | 41.530 |
| 4–Automatic measurement of product harvest (combined with sensor and so on) | SFTs contained ICTs | 14 | 7.650 |
| 5–Automatic measurement of product quality (livestock milk/meat quality, crop sugar content/acidity, and so on) | SFTs contained ICTs | 16 | 8.743 |
| 6–Browsing of farming information on smartphones (weather information, crop growth status, farm work amount, and so on) | ICTs applied in SF | 80 | 43.716 |
| 7–Measurement of crop growth using drones and artificial satellites (leaf color, pests, and so on) | ICTs applied in SF | 10 | 5.464 |
| *Robotization technologies and autonomously operating machines* | | | |
| 8–Automatic detection/notification of abnormal information (temperature, humidity, soil moisture, livestock estrus, body temperature, and so on) | SFTs contained ICTs | 25 | 13.661 |
| 9–Automation of agricultural land irrigation and water supply (paddy pipelines, open waterways, upland fields, and so on) | SFTs contained ICTs | 32 | 17.486 |
| 10–Agricultural machinery with operation assist function (straight–ahead assist function and so on) | SFTs contained ICTs | 17 | 9.290 |
| 11–Automatic environmental controls of greenhouses and barns (temperature, humidity, soil moisture, $CO_2$ concentration, and so on) | SFTs contained ICTs | 40 | 21.858 |
| 12–Livestock feeding, manure cleaning, and milking automation and robotization | SFTs contained ICTs | 19 | 10.383 |
| 13–Automation of crop cultivation machines/robots [plowing, fertilization, control (including drone), harvest, and so on] | SFTs contained ICTs | 15 | 8.197 |
| 14–Automatic sorting of harvested products (weight/shape sorting, color sorting, sugar content sorting, and so on) | SFTs contained ICTs | 41 | 22.404 |
| *Business management technologies* | | | |
| 15–Management of production record information (including data analysis such as tabulation and graphing) | ICTs applied in SF | 100 | 54.645 |
| 16–Provision of production information to business partners and consumers (product quality, production history, and so on) | ICTs applied in SF | 78 | 42.623 |
| 17–Sales information management (including customer management and internet sales) | ICTs applied in SF | 113 | 61.749 |
| 18–Inventory management of materials, such as pesticides and fertilizers (recorded using a personal computer, smartphone, and so on) | ICTs applied in SF | 83 | 45.355 |
| 19–Financial management systems, such as bookkeeping and accounting (settlement, management diagnosis, payroll, and so on) | ICTs applied in SF | 154 | 84.153 |
| 20–Planning of business strategy and creation of business plan (simulation on a personal computer and so on) | ICTs applied in SF | 72 | 39.344 |
| 21–Advertisement for companies and products (information on homepage and so on) | ICTs applied in SF | 119 | 65.027 |

Note: [1] Types of technology categories are tentative. ICTs and SFTs are broad concepts, they intersect with each other. With the development of each technology category, the types may be updated.

contrast, technologies with relatively low adoption rates included "automation of crop cultivation machines/robots", "automatic measurement of product harvest", and "measurement of crop growth using drones and artificial satellites", with adoption rates of 8.2%, 7.7%, and 5.5%, respectively. These trends are consistent with the statistics reported by Nanseki (2021).

The independent variables in our count data modeling covered a wide range of corporation attributes and representative characteristics, classified into the following 17 groups: (1) corporate form; (2) eligibility to own farmland; (3) location of corporation; (4) age of corporation; (5) establishment background; (6) human capital; (7) annual sales; (8) profit margin; (9) development stage of the corporation; (10) sales target for the next 5 years; (11) profit target for the next 5 years; (12) major product; (13) self–evaluation of ICT utilization and information management; (14) perception of the FTA participation of Japan; (15) age of representatives; (16) educational background of representatives; and (17) non–agricultural experience of representatives. The definitions, along with the unit and expected signs, are listed in Table 2.

**Table 2.** Definitions of variables in estimation

| Variables | Definition | Unit |
|---|---|---|
| *TECH (dependent)* | Number of ICT&SF technologies adopted (values ranging from 0 to 21) | Number |
| 1. Corporate form (+/–) | | |
| *CFORM_1* | 1 if the corporation is a limited company; 0 otherwise | Dummy |
| *CFORM_2* | 1 if the corporation is a stock company; 0 otherwise | |
| *CFORM_3* | 1 if the corporation is an agricultural cooperative corporation; 0 otherwise | |
| *CFORM_4* | 1 if the corporation form is others; 0 otherwise | |
| 2. Eligibility to own farmland (+) | | |
| *FARML* | 1 if the corporation is judicially qualified to own farmland; 0 otherwise | Dummy |
| 3. Location of corporation (+/–) | | |
| *R_HKD* | 1 if the corporation located in Hokkaido; 0 otherwise | Dummy |
| *R_TH* | 1 if the corporation located in Tohoku; 0 otherwise | |
| *R_KT* | 1 if the corporation located in Kanto; 0 otherwise | |
| *R_HR* | 1 if the corporation located in Hokuriku; 0 otherwise | |
| *R_KKTK* | 1 if the corporation located in Kinki Tokai; 0 otherwise | |
| *R_CHSK* | 1 if the corporation located in Chugoku and Shikoku; 0 otherwise | |
| *R_KSON* | 1 if the corporation located in Kyushu and Okinawa; 0 otherwise | |
| 4. Age of corporation (+/–) | | |
| *AGE_C* | 2019 – establishment year | Year |
| 5. Establishment background (+/–) | | |
| *ESTAB_1* | 1 if a farmer established a solely owned corporation; 0 otherwise | Dummy |
| *ESTAB_2* | 1 if a farmer established a joint corporation with other members; 0 otherwise | |
| *ESTAB_3* | 1 if a farmer has established corporations in collaboration with non–farmers and companies from other industries; 0 otherwise | |
| *ESTAB_4* | 1 if a non–farmer entered agriculture as an individual and established a corporation; 0 otherwise | |
| *ESTAB_5* | 1 if the company's main business is non–agriculture, but they have entered agriculture as a new business; 0 otherwise | |
| *ESTAB_6* | 1 if the parent corporation/main or group company has established a new corporation and entered agriculture; 0 otherwise | |
| *ESTAB_7* | 1 if the establishment background of a corporation is others; 0 otherwise | |
| 6. Human capital (+) | | |
| *BM* | Total number of board members | Persons |
| *RE* | Total number of regular employees | |
| 7. Annual sales (+) | | |
| *SALE* | Categorical variable of corporations' annual sales: 1 = <30 million yen; 2 = 30–50 million yen; 3 = 50–100 million yen; 4= 100–300 million yen; 5 = 300–500 million yen; 6 = 500–1000 million yen; 7 = 1000–1500 million yen; 8 = 1500–2000 million yen; 9 = >2000 million yen | Category |
| 8. Profit margin (+) | | |
| *PROF_1* | 1 if the profit margin of the corporation is 0% (break–even); 0 otherwise | Dummy |
| *PROF_2* | 1 if the profit margin of the corporation is 1%–5%; 0 otherwise | |
| *PROF_3* | 1 if the profit margin of the corporation is 5%–10%; 0 otherwise | |
| *PROF_4* | 1 if the profit margin of the corporation is 10%–15%; 0 otherwise | |
| *PROF_5* | 1 if the profit margin of the corporation is 15%–20%; 0 otherwise | |
| *PROF_6* | 1 if the profit margin of the corporation is >20%; 0 otherwise | |
| *PROF_7* | 1 if there is deficit; 0 otherwise | |

| | | |
|---|---|---|
| 9. Development stage of corporations (+/–) | | |
| *STAGE_1* | 1 if the development stage is "starting"; 0 otherwise | |
| *STAGE_2* | 1 if the development stage is "growing"; 0 otherwise | |
| *STAGE_3* | 1 if the development stage is "mature"; 0 otherwise | |
| *STAGE_4* | 1 if the development stage is "recession"; 0 otherwise | |
| *STAGE_5* | 1 if the development stage is the second period of "starting"; 0 otherwise | Dummy |
| *STAGE_6* | 1 if the development stage is the second period of "growing"; 0 otherwise | |
| *STAGE_7* | 1 if the development stage is the second period of "mature"; 0 otherwise | |
| *STAGE_8* | 1 if the development stage is the second period "recession"; 0 otherwise | |
| *STAGE_9* | 1 if others | |
| 10. Sales target for the next 5 years (+) | | |
| *TSALE_1* | 1 if the sales target for the next 5 years is "maintain"; 0 otherwise | |
| *TSALE_2* | 1 if the sales target for the next 5 years is "1.2 times"; 0 otherwise | |
| *TSALE_3* | 1 if the sales target for the next 5 years is "1.5 times"; 0 otherwise | |
| *TSALE_4* | 1 if the sales target for the next 5 years is "1.8 times"; 0 otherwise | |
| *TSALE_5* | 1 if the sales target for the next 5 years is "2.0 times"; 0 otherwise | Dummy |
| *TSALE_6* | 1 if the sales target for the next 5 years is "2.0–3.0 times"; 0 otherwise | |
| *TSALE_7* | 1 if the sales target for the next 5 years is "over 3 times"; 0 otherwise | |
| *TSALE_8* | 1 if the sales target for the next 5 years is "decrease"; 0 otherwise | |
| *TSALE_9* | 1 if no target; 0 otherwise | |
| 11. Profit target for the next 5 years (+) | | |
| *TPROF_1* | 1 if the profit target for the next 5 years is "0%"; 0 otherwise | |
| *TPROF_2* | 1 if the profit target for the next 5 years is "1%–5%"; 0 otherwise | |
| *TPROF_3* | 1 if the profit target for the next 5 years is "5%–10%"; 0 otherwise | |
| *TPROF_4* | 1 if the profit target for the next 5 years is "10%–15%";0 otherwise | Dummy |
| *TPROF_5* | 1 if the profit target for the next 5 years is "15%–20%";0 otherwise | |
| *TPROF_6* | 1 if the profit target for the next 5 years is "over20%"; 0 otherwise | |
| *TPROF_7* | 1 if no margin; 0 otherwise | |
| 12. Major product 1 (+/–) | | |
| *PROD_1* | 1 if the major product is "paddy rice"; 0 otherwise | |
| *PROD_2* | 1 if the major product is "wheat"; 0 otherwise | |
| *PROD_3* | 1 if the major product is "beans and coarse cereals"; 0 otherwise | |
| *PROD_4* | 1 if the major product is "open–ground vegetables"; 0 otherwise | |
| *PROD_5* | 1 if the major product is "house vegetables"; 0 otherwise | |
| *PROD_6* | 1 if the major product is "flowers and foliage plants"; 0 otherwise | |
| *PROD_7* | 1 if the major product p is "fruit"; 0 otherwise | Dummy |
| *PROD_8* | 1 if the major product is "mushrooms"; 0 otherwise | |
| *PROD_9* | 1 if the major product is "dairy"; 0 otherwise | |
| *PROD_10* | 1 if the major product is "beef cattle"; 0 otherwise | |
| *PROD_11* | 1 if the major product is "swine"; 0 otherwise | |
| *PROD_12* | 1 if the major product is "poultry (meat/eggs)"; 0 otherwise | |
| *PROD_13* | 1 if the major product is "others"; 0 otherwise | |
| *PROD_14* | 1 if the major product is "multiple crops"; 0 otherwise | |
| 13. Self–evaluation of ICT utilization and information management (+) | | |
| *SELF_U* | 1 = weaker than others; 2 = slightly weaker than others; 3 = neither weaker nor stronger than others; 4 = slightly stronger than others; 5 = stronger than others | Likert scale |
| 14. Perception of the FTA participation of Japan (+) | | |
| *FTA* | Respondents' perception of the FTA participation of Japan: 1 = major crisis; 2 = crisis; 3 = neutral; 4 = opportunity; 5 = great opportunity | Likert scale |
| 15. Age of representatives (+/–) | | |
| *AGE_R* | Value ranging from 1 to 7: 1 = 10–20–year old; 2 = 20–30–year old; 3 = 30–40–year old; 4 = 40–50–year old; 5 = 50–60–year old; 6 = 60–70–year old; 7 = >70–year old | Category |
| 16. Educational background of representatives (+) | | |
| *EDU_1* | 1 if the representative graduated from a high school; 0 otherwise | |
| *EDU_2* | 1 if the representative graduated from a specialized school; 0 otherwise | |
| *EDU_3* | 1 if the representative graduated from a vocational college; 0 otherwise | |
| *EDU_4* | 1 if the representative graduated from a junior college; 0 otherwise | Dummy |
| *EDU_5* | 1 if the representative graduated from a university; 0 otherwise | |
| *EDU_6* | 1 if the representative graduated from a graduate school; 0 otherwise | |
| *EDU_7* | 1 if others | |
| 17. Non–agricultural experience of representatives (+/–) | | |
| *NAGRI* | Values ranging from 1 to 6: 1 = none; 2 = 1–5 years; 3 = 5–10 years; 4 = 10–15 years; 5 = 15–20 years; 6 = >20 years | Category |

Source: Nanseki (2021)
Note: (1) major crop of an agricultural corporation is classified as a crop that accounts for over 60% of that corporation's annual sales. (2) Symbols in parentheses denote the expected signs of each category of independent variables.

## RESULT AND DISCUSSION

### Descriptive results

*Distribution of ICT&SF technology adoption*

Fig. 1 presents the distribution of the ICT&SF technology adoption rates by Japanese agricultural corporations. Of the 183, 175 corporations had adopted at least one ICT&SF technology category until 2019, indicating an overall adoption rate of 95.6%. In contrast, 4.4% corporations implemented none of these technologies. Majority (82.0%) of the corporations adopted 10 or fewer technologies, and only 18.0% adopted 11 or more technologies. Moreover, the observed Japanese agricultural corporations adopted nearly 6.6 technologies on average.

*Summary of descriptive statistics*

Table 3 depicts the summary of descriptive statistics for all variables. Majority (84.7%) of the corporations are limited and stock companies. Approximately 86.9% corporations are judicially qualified to own farmland. Nearly 24.6% corporations are located in Tohoku, 23.5% are located in Kyushu and Okinawa, and only 1.6% are located in Hokkaido. The average age of the sampled corporations is approximately 19.0 years. Regarding establishment background, approximately 47.5% are solely owned corporation, established by a farmer and 26.8% are joint corporations founded by several farmers. Regarding human capital, the number of board members is approximately 3.6 on average, and the number of regular employees is approximately 11 on average. Nearly half of the corporations have a profit margin between 1% and 10%, while 20.8% are running in financial deficit. Regarding development stage, approximately 40.4% corporations are at the "growing stage," compared with 16.4% and 6.0% corporations at the "mature" and "recession" stages, respectively. Regarding the operating target, the largest proportion of companies (approximately 29.5%) have set the target of 1.5 times sales growth in the next 5 years. Moreover, 83.6% corporations have set the target of 1%–20% profit growth, compared with 10.4% corporations with a target of over 20% profit growth in the next 5 years. Regarding the major product, the corporations with major products as 'paddy rice' account for the largest proportion (18.0%), whereas the 'beans and coarse cereals' accounted the least, only for 1.1%. Moreover, approximately 8.7% corporations follow multiple crop farming. Regarding the profile of corporate representatives, over half of the representatives (54.6%) graduated from high schools and 36.6% from universities. Of the corporate representatives, 2.7% held a postgraduate degree.

### Empirical results

We applied a negative binomial model to identify the potential determinants of ICT&SF technologies adoption by Japanese agricultural corporations. We tested two non–nested forms of the negative binomial model denoted NB1 (which is a negative binomial model with constant dispersion) and NB2 (which is a negative binomial model with no constant dispersion) and compared their estimates according to Akaike's information criterion (AIC) and Bayesian information criterion (BIC). The results are presented in Table 4.

Table 4 displays the results of negative binomial regression models with 183 observations. In addition to the estimated parameters, the marginal effect of each explanatory variable on the response variable is presented. The fitness of NB1 was better than that of NB2 (the AIC/BIC of NB1 was lower than that of NB2). The

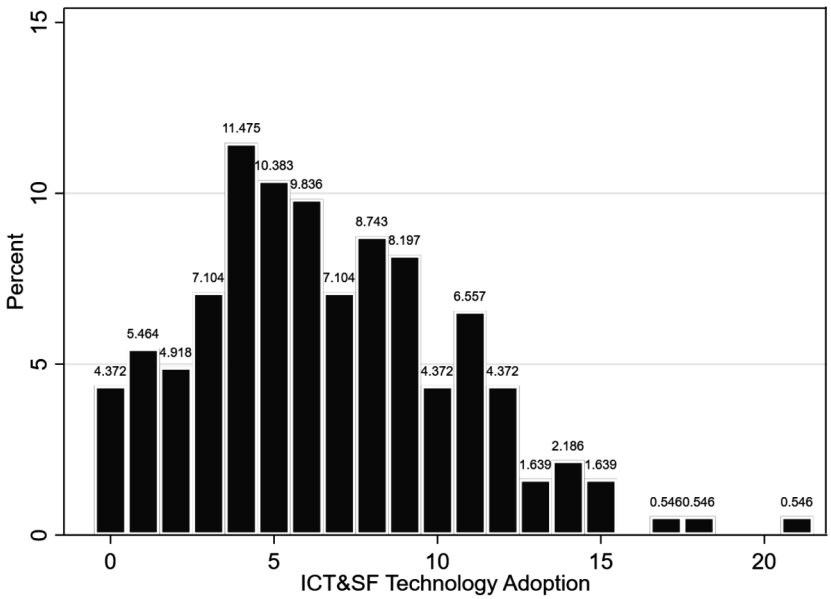


**Fig. 1.** Distribution of the technology adoption frequency of agricultural corporations (N=183).
Source: Questionnaire Survey on Business Development and Innovation in Agricultural Corporation Management in 2019

**Table 3.** Result of descriptive statistics

| Variables | Mean | SD | Min | Max | Obs. |
|---|---|---|---|---|---|
| *TECH (dependent)* | 6.623 | 3.988 | 0 | 21 | – |
| 1. Corporate form | | | | | |
| *CFORM_1* | 0.410 | 0.493 | 0 | 1 | 75 |
| *CFORM_2* | 0.437 | 0.497 | 0 | 1 | 80 |
| *CFORM_3* | 0.137 | 0.344 | 0 | 1 | 25 |
| *CFORM_4* | 0.016 | 0.127 | 0 | 1 | 3 |
| 2. Eligibility to own farmland | | | | | |
| *FARML* | 0.869 | 0.338 | 0 | 1 | – |
| 3. Location of corporation | | | | | |
| *R_HKD* | 0.016 | 0.127 | 0 | 1 | 3 |
| *R_TH* | 0.246 | 0.432 | 0 | 1 | 45 |
| *R_KT* | 0.137 | 0.344 | 0 | 1 | 25 |
| *R_HR* | 0.087 | 0.283 | 0 | 1 | 16 |
| *R_KKTK* | 0.137 | 0.344 | 0 | 1 | 25 |
| *R_CHSK* | 0.142 | 0.350 | 0 | 1 | 26 |
| *R_KSON* | 0.235 | 0.425 | 0 | 1 | 43 |
| 4. Age of corporation | | | | | |
| *AGE_C* | 19.071 | 12.516 | 2 | 76 | – |
| 5. Establishment background | | | | | |
| *ESTAB_1* | 0.475 | 0.501 | 0 | 1 | 87 |
| *ESTAB_2* | 0.268 | 0.444 | 0 | 1 | 49 |
| *ESTAB_3* | 0.044 | 0.205 | 0 | 1 | 8 |
| *ESTAB_4* | 0.055 | 0.228 | 0 | 1 | 10 |
| *ESTAB_5* | 0.044 | 0.205 | 0 | 1 | 8 |
| *ESTAB_6* | 0.060 | 0.238 | 0 | 1 | 11 |
| *ESTAB_7* | 0.060 | 0.238 | 0 | 1 | 11 |
| 6. Human capital | | | | | |
| *BM* | 3.552 | 2.394 | 1 | 20 | – |
| *RE* | 11.055 | 21.956 | 0 | 238 | – |
| 7. Annual sales | | | | | |
| *SALE* | 3.760 | 1.741 | 1 | 9 | – |
| 8. Profit margin | | | | | |
| *PROF_1* | 0.087 | 0.283 | 0 | 1 | 16 |
| *PROF_2* | 0.322 | 0.469 | 0 | 1 | 59 |
| *PROF_3* | 0.191 | 0.394 | 0 | 1 | 35 |
| *PROF_4* | 0.098 | 0.299 | 0 | 1 | 18 |
| *PROF_5* | 0.071 | 0.258 | 0 | 1 | 13 |
| *PROF_6* | 0.022 | 0.147 | 0 | 1 | 4 |
| *PROF_7* | 0.208 | 0.407 | 0 | 1 | 38 |
| 9. Development stage of the corporation | | | | | |
| *STAGE_1* | 0.066 | 0.248 | 0 | 1 | 12 |
| *STAGE_2* | 0.404 | 0.492 | 0 | 1 | 74 |
| *STAGE_3* | 0.164 | 0.371 | 0 | 1 | 30 |
| *STAGE_4* | 0.060 | 0.238 | 0 | 1 | 11 |
| *STAGE_5* | 0.169 | 0.376 | 0 | 1 | 31 |
| *STAGE_6* | 0.104 | 0.306 | 0 | 1 | 19 |
| *STAGE_7* | 0.027 | 0.163 | 0 | 1 | 5 |
| *STAGE_8* | 0.000 | 0.000 | 0 | 0 | 0 |
| *STAGE_9* | 0.005 | 0.074 | 0 | 1 | 1 |
| 10. Sales target for the next 5 years | | | | | |
| *TSALE_1* | 0.126 | 0.332 | 0 | 1 | 23 |
| *TSALE_2* | 0.284 | 0.452 | 0 | 1 | 52 |
| *TSALE_3* | 0.295 | 0.457 | 0 | 1 | 54 |
| *TSALE_4* | 0.038 | 0.192 | 0 | 1 | 7 |
| *TSALE_5* | 0.137 | 0.344 | 0 | 1 | 25 |
| *TSALE_6* | 0.060 | 0.238 | 0 | 1 | 11 |
| *TSALE_7* | 0.055 | 0.228 | 0 | 1 | 10 |
| *TSALE_8* | 0.005 | 0.074 | 0 | 1 | 1 |
| *TSALE_9* | 0.000 | 0.000 | 0 | 0 | 0 |
| 11. Profit target for the next 5 years | | | | | |
| *TPROF_1* | 0.038 | 0.192 | 0 | 1 | 7 |
| *TPROF_2* | 0.213 | 0.411 | 0 | 1 | 39 |
| *TPROF_3* | 0.350 | 0.478 | 0 | 1 | 64 |
| *TPROF_4* | 0.158 | 0.366 | 0 | 1 | 29 |
| *TPROF_5* | 0.115 | 0.320 | 0 | 1 | 21 |
| *TPROF_6* | 0.104 | 0.306 | 0 | 1 | 19 |
| *TPROF_7* | 0.022 | 0.147 | 0 | 1 | 4 |
| 12. Major product | | | | | |
| *PROD_1* | 0.180 | 0.386 | 0 | 1 | 33 |
| *PROD_2* | 0.000 | 0.000 | 0 | 0 | 0 |
| *PROD_3* | 0.011 | 0.104 | 0 | 1 | 2 |
| *PROD_4* | 0.077 | 0.267 | 0 | 1 | 14 |
| *PROD_5* | 0.115 | 0.320 | 0 | 1 | 21 |
| *PROD_6* | 0.038 | 0.192 | 0 | 1 | 7 |
| *PROD_7* | 0.137 | 0.344 | 0 | 1 | 25 |
| *PROD_8* | 0.033 | 0.179 | 0 | 1 | 6 |
| *PROD_9* | 0.022 | 0.147 | 0 | 1 | 4 |
| *PROD_10* | 0.049 | 0.217 | 0 | 1 | 9 |
| *PROD_11* | 0.044 | 0.205 | 0 | 1 | 8 |
| *PROD_12* | 0.049 | 0.217 | 0 | 1 | 9 |
| *PROD_13* | 0.158 | 0.366 | 0 | 1 | 29 |
| *PROD_14* | 0.087 | 0.283 | 0 | 1 | 16 |
| 13. Self–evaluation of ICT utilization and information management | | | | | |
| *SELF_U* | 2.628 | 0.985 | 1 | 5 | – |
| 14. Perception of the FTA participation of Japan | | | | | |
| *FTA* | 2.891 | 1.010 | 1 | 5 | – |
| 15. Age of representatives | | | | | |
| *AGE_R* | 5.098 | 1.158 | 2 | 7 | – |
| 16. Educational background of representatives | | | | | |
| *EDU_1* | 0.546 | 0.499 | 0 | 1 | 100 |
| *EDU_2* | 0.077 | 0.267 | 0 | 1 | 14 |
| *EDU_3* | 0.142 | 0.350 | 0 | 1 | 26 |
| *EDU_4* | 0.055 | 0.228 | 0 | 1 | 10 |
| *EDU_5* | 0.366 | 0.483 | 0 | 1 | 67 |
| *EDU_6* | 0.027 | 0.163 | 0 | 1 | 5 |
| *EDU_7* | 0.027 | 0.163 | 0 | 1 | 5 |
| 17. Non–agricultural experience of representatives | | | | | |
| *NAGRI* | 3.186 | 1.980 | 1 | 6 | – |

Note: N=183

likelihood–ratio chi–square test of NB1 rejected the null hypothesis of "variance = mean" (Indelta = –1.882, at 5% significance level). Therefore, we summarize detailed analysis of NB1 results below.

The result of NB1 revealed corporate form, eligibility to own farmland, sales targets, profit target, major product, self–evaluation of ICT utilization and information management, and educational background of representatives as the potential determinants of ICT&SF technologies adoption by Japanese agricultural corporations. Here we mainly discuss these indicators with parameters at 1% and 5% significance levels. First, the marginal effect of *CFORM_3* on ICT&SF technology adoption was –2.431 at 5% significance level, indicating that cooperative agricultural corporations tend to adopt fewer technologies than limited companies. Second, the coefficient of *FARML* was positive and statistically significant at 5% level, indicating that corporations eligible to own farm-

**Table 4.** Result of negative binomial regression model

| | NB2 | | NB1 | |
|---|---|---|---|---|
| | Parameter | Marginal effect | Parameter | Marginal effect |
| 1.Corporate form (benchmark: *CFORM_1*, limited company) | | | | |
| *CFORM_2* | –0.046 | –0.306 | –0.049 | –0.323 |
| *CFORM_3* | –0.361** | –2.391** | –0.367** | –2.431** |
| *CFORM_4* | –0.273 | –1.805 | –0.290 | –1.923 |
| 2. Eligibility to own farmland | | | | |
| *FARML* | 0.246** | 1.627** | 0.257** | 1.700** |
| 3. Location of corporation (benchmark: *R_HKD*, Hokkaido) | | | | |
| *R_TH* | –0.032 | –0.209 | –0.021 | –0.141 |
| *R_KT* | –0.040 | –0.265 | –0.031 | –0.204 |
| *R_HR* | 0.030 | 0.201 | 0.036 | 0.240 |
| *R_KKTK* | 0.380 | 2.516 | 0.395 | 2.616 |
| *R_CHSK* | –0.083 | –0.547 | –0.078 | –0.516 |
| *R_KSON* | –0.088 | –0.581 | –0.080 | –0.532 |
| 4. Age of corporation | | | | |
| *AGE_C* | 0.001 | 0.009 | 0.001 | 0.008 |
| 5. Establishment background (benchmark: *ESTAB_1*, a farmer established a solely owned corporation) | | | | |
| *ESTAB_2* | 0.014 | 0.091 | 0.020 | 0.131 |
| *ESTAB_3* | 0.218 | 1.442 | 0.219 | 1.453 |
| *ESTAB_4* | 0.029 | 0.193 | 0.046 | 0.305 |
| *ESTAB_5* | 0.115 | 0.764 | 0.127 | 0.842 |
| *ESTAB_6* | 0.107 | 0.707 | 0.115 | 0.764 |
| *ESTAB_7* | –0.179 | –1.184 | –0.166 | –1.097 |
| 6. Human capital | | | | |
| *BM* | 0.038* | 0.249* | 0.038 | 0.252 |
| *RE* | 0.000 | –0.002 | 0.000 | –0.002 |
| 7. Annual sales | | | | |
| *SALE* | –0.016 | –0.107 | –0.017 | –0.110 |
| 8. Profit margin (benchmark: *PROF_1*, 0%)) | | | | |
| *PROF_2* | 0.012 | 0.078 | 0.011 | 0.075 |
| *PROF_3* | –0.136 | –0.900 | –0.138 | –0.916 |
| *PROF_4* | 0.041 | 0.271 | 0.053 | 0.354 |
| *PROF_5* | –0.139 | –0.921 | –0.129 | –0.855 |
| *PROF_6* | –0.267 | –1.770 | –0.251 | –1.665 |
| *PROF_7* | 0.073 | 0.486 | 0.075 | 0.495 |
| 9. Development stage of the corporation (benchmark: *STAGE_1*, starting) | | | | |
| *STAGE_2* | 0.079 | 0.522 | 0.096 | 0.634 |
| *STAGE_3* | 0.186 | 1.233 | 0.205 | 1.358 |
| *STAGE_4* | –0.029 | –0.193 | –0.004 | –0.025 |
| *STAGE_5* | 0.186 | 1.234 | 0.212 | 1.403 |
| *STAGE_6* | 0.313 | 2.075 | 0.331 | 2.195 |
| *STAGE_7* | 0.165 | 1.095 | 0.160 | 1.059 |
| *STAGE_8* | (omitted) | 0.000 | (omitted) | 0.000 |
| *STAGE_9* | –0.245 | –1.620 | –0.203 | –1.342 |
| 10. Sales target for the next 5 years (benchmark: *TSALE_1*, maintain) | | | | |
| *TSALE_2* | 0.241* | 1.595* | 0.247* | 1.637* |
| *TSALE_3* | 0.110 | 0.728 | 0.114 | 0.753 |
| *TSALE_4* | 0.318 | 2.105 | 0.340 | 2.249 |
| *TSALE_5* | –0.020 | –0.135 | –0.011 | –0.076 |
| *TSALE_6* | 0.107 | 0.711 | 0.124 | 0.818 |
| *TSALE_7* | 0.114 | 0.754 | 0.125 | 0.826 |
| *TSALE_8* | 0.042 | 0.280 | 0.090 | 0.595 |
| *TSALE_9* | (omitted) | 0.000 | (omitted) | 0.000 |
| 11. Profit target for the next 5 years (benchmark: *TPROF_1*, 0%) | | | | |
| *TPROF_2* | 0.262 | 1.736 | 0.268 | 1.776 |
| *TPROF_3* | 0.419* | 2.778* | 0.414 | 2.739 |
| *TPROF_4* | 0.319 | 2.111 | 0.314 | 2.079 |
| *TPROF_5* | 0.528** | 3.494** | 0.520* | 3.443* |
| *TPROF_6* | 0.475* | 3.149* | 0.469 | 3.104 |
| *TPROF_7* | –0.724 | –4.795 | –0.731 | –4.844 |

| | | | | |
|---|---|---|---|---|
| 12. Major product (benchmark: *PROD_1*, paddy rice) | | | | |
| *PROD_2* | (omitted) | 0.000 | (omitted) | 0.000 |
| *PROD_3* | –0.031 | –0.206 | –0.048 | –0.317 |
| *PROD_4* | 0.030 | 0.201 | 0.038 | 0.255 |
| *PROD_5* | 0.042 | 0.275 | 0.036 | 0.241 |
| *PROD_6* | –0.452** | –2.996** | –0.475* | –3.144* |
| *PROD_7* | –0.072 | –0.474 | –0.064 | –0.425 |
| *PROD_8* | –0.253 | –1.675 | –0.240 | –1.587 |
| *PROD_9* | –0.026 | –0.169 | –0.022 | –0.145 |
| *PROD_10* | –0.139 | –0.922 | –0.133 | –0.882 |
| *PROD_11* | 0.343 | 2.269 | 0.365 | 2.415 |
| *PROD_12* | 0.364* | 2.413* | 0.376* | 2.493* |
| *PROD_13* | –0.045 | –0.296 | –0.051 | –0.341 |
| *PROD_14* | 0.003 | 0.017 | 0.014 | 0.092 |
| 13. Self–evaluation of ICT utilization and information management | | | | |
| *SELF_U* | 0.344*** | 2.279*** | 0.345*** | 2.287*** |
| 14. Perception of the FTA participation of Japan | | | | |
| *FTA* | 0.058 | 0.386 | 0.059 | 0.394 |
| 15. Age of representatives | | | | |
| *AGE_R* | –0.035 | –0.232 | –0.036 | –0.237 |
| 16. Educational background of representatives | | | | |
| *EDU_2* | 0.287** | 1.901** | 0.293** | 1.939** |
| *EDU_3* | 0.287** | 1.900** | 0.289** | 1.913** |
| *EDU_4* | –0.179 | –1.188 | –0.198 | –1.309 |
| *EDU_5* | –0.027 | –0.177 | –0.033 | –0.217 |
| *EDU_6* | –0.153 | –1.012 | –0.156 | –1.031 |
| *EDU_7* | –0.010 | –0.068 | –0.002 | –0.017 |
| 17. Non–agricultural experience of representatives | | | | |
| *NAGRI* | 0.020 | 0.135 | 0.021 | 0.142 |
| *_cons* | –0.045 | | –0.092 | |
| N | 183 | | 183 | |
| Pseudo–$R^2$ | 0.145 | | 0.146 | |
| Log likelihood | –433.160 | | –432.347 | |
| lnalpha | –15.603 | | | |
| lndelta | | | –1.882** | |
| AIC | 1006.319 | | 1004.694 | |
| BIC | 1230.983 | | 1229.358 | |

Note: (1) ***, **, and * represent statistically significant at the 1%, 5%, and 10% levels, respectively; (2) The parameter here can be interpreted as semi–elasticity; the marginal effect is calculated at the mean of the dependent variable (Paxton *et al.*, 2011)

land were likely to adopt two more technologies. Third, the self–evaluation of ICT utilization and information management significantly and positively affected technology adoption ($p < 0.01$). It demonstrated that corporations with a higher self–evaluation of ICT utilization and information management tended to use more ICT&SF technologies. Finally, the marginal effect of *EDU_2* and *EDU_3* are both positive statistically significant at 5% level, indicating the representatives who graduated from specialized schools and vocational colleges were more likely to adopt ICT&SF technologies. These results differ from the finding of Carrer *et al.*, (2017), who demonstrated that university–level education positively affected the likelihood of technology adoption in farm management. This discrepancy may be explained by the fact that representatives who graduate from specialized schools and vocational colleges have more opportunities to receive specific agricultural knowledge and training lessons on farming skills and are, therefore, more willing to adopt technologies.

With regard to the empirical results at 10% significance level, first, the marginal effect of *TSALE_2* was 1.637, indicating that corporations targeting 1.2 times sales growth in the next 5 years were likely to use two more technologies than corporations aiming to maintain the current sales. Second, the marginal effect of *TPROF_5* was 3.443, indicating that corporations targeting 15%–20% profit growth in the next 5 years were likely to use three more technologies than corporations that aimed to maintain the profit. Finally, the marginal effects of *PROD_6* and *PROD_12* were –3.144 and 2.493, respectively. Compared with the benchmark major product "paddy rice", corporations operating "flowers and foliage plants" were likely to use three less technologies, whereas corporations operating "poultry" were likely to use two more technologies.

In particular, indicators with estimated parameters at 10% significance level were slightly different from the previous results, which based on 193 samples (see Table A3 in Appendix). Some variables with 10% significance level in the previous version, such as the number of board members and representatives' age, were altered.

As shown in Table 4, the number of board members promoted ICT&SF technologies adoption even the marginal effect is not significant. Similarly, the coefficient of *AGE_R* was insignificant as well, but still, it revealed a negative sign. This is also consistent with a previously reported finding from the adoption literature, which demonstrated a negative association between the age of decision–makers and technology adoption (Simmons *et al*., 2005).

## CONCLUSIONS

Through a national questionnaire survey of "Business Development and Innovation in Agricultural Corporation Management", this study identified the determinants of ICT&SF technology adoption by Japanese agricultural corporations. Negative binomial models were employed to examine the relevant corporate attributes and representative characteristics potentially affecting the technology adoption by agricultural corporations.

The results revealed that, of the 183 sampled corporations, 175 had adopted at least one ICT&SF technology until 2019, indicating an overall adoption rate of 95.6%. Among the 21 ICT&SF technologies, the most frequently adopted component was financial management systems, such as bookkeeping and accounting, with an adoption rate of 84.2%, whereas the least frequently adopted technology was the measurement of crop growth using drones and artificial satellites, with an adoption rate of 5.5%. Regarding the attributes of sampled corporations, majority (84.7%) of the corporations were limited and stock companies and 86.9% were qualified to own farmlands. In addition, 18.0% corporations operated paddy rice as major product and only 1.1% mainly operated beans and coarse cereals. Regarding the profile of corporate representatives, over half of the representatives (54.6%) graduated from high schools and 36.6% from universities.

The results of empirical models revealed corporate form, eligibility to own farmland, sales target, profit target, major product, self–evaluation of ICT utilization and information management, and educational background of representatives as the potential determinants of technologies adoption by Japanese agricultural corporations. Specifically, regarding corporate form, cooperative agricultural corporations tended to adopt fewer technologies than limited companies. Moreover, corporations eligible to own farmland were likely to adopt two more technologies. Regarding sales and profit targets, corporations aiming to increase their sales by 1.2 times the current value or raise their profits by 15%–20% of the current margin in the next 5 years were likely to adopt more technologies than those aiming to maintain the current status. Compared with corporations operating paddy rice as the major product, those mainly operating flowers and foliage plants were likely to use less technologies, whereas those targeting poultry were likely to adopt more technologies. Moreover, the self–valuation of ICT utilization and information management positively affected technology implementation. Finally, in terms of corporate representatives' characteristics, those who graduated from specialized schools and vocational colleges were more likely to adopt technologies.

## AUTHOR CONTRIBUTIONS

All listed authors have discussed the results and contributed to the final manuscript. Mi Jie conceived the original idea, performed empirical computations, and drafted the manuscript. Nanseki Teruaki devised the project, designed the questionnaire, collected the data, provided the data source, suggested the conceptual organization and data interpretation of this study, and supervised the findings of this work. Chomei Yosuke assisted in data collection and contributed to the editing and revision of the manuscript. Uenishi Yoshihiro suggested the conceptual organization of this study, aided in result interpretation, and edited the manuscript accordingly. Nguyen Thi Ly advised on the research design and data interpretation and edited the manuscript. All authors have reviewed the results and approved the final version of the manuscript.

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## APPENDIX

**Table A1.** Comparison of the adoption rates of ICT&SF technologies with different sample sizes

| Technology category | N=195 | | N=183 | |
|---|---|---|---|---|
| | Frequency | Adoption rate (%) | Frequency | Adoption rate (%) |
| | (1) | (2) | (3) | (4) |
| *Data monitoring and collection technologies* | | | | |
| 1–Measurement of environmental information of crops and livestock (temperature, water temperature, soil moisture, solar radiation, and so on) | 57 | 29.231 | 56 | 30.601 |
| 2–Measurement of biological information of crops and livestock (growth status, livestock estrus, body temperature, and so on) | 52 | 26.667 | 52 | 28.415 |
| 3–Collection of work information from each field (recorded using a personal computer, smartphone, camera, GPS, and so on) | 78 | 40.000 | 76 | 41.530 |
| 4–Automatic measurement of product harvest (combined with sensor and so on) | 16 | 8.205 | 14 | 7.650 |
| 5–Automatic measurement of product quality (livestock milk/meat quality, crop sugar content/acidity, and so on) | 19 | 9.744 | 16 | 8.743 |
| 6–Browsing of farming information on smartphones (weather information, crop growth status, farm work amount, and so on) | 86 | 44.103 | 80 | 43.716 |
| 7–Measurement of crop growth using drones and artificial satellites (leaf color, pests, and so on) | 10 | 5.128 | 10 | 5.464 |
| *Robotization technologies and autonomously operating machines* | | | | |
| 8–Automatic detection/notification of abnormal information (temperature, humidity, soil moisture, livestock estrus, body temperature, and so on) | 26 | 13.333 | 25 | 13.661 |
| 9–Automation of agricultural land irrigation and water supply (paddy pipelines, open waterways, upland fields, and so on) | 36 | 18.462 | 32 | 17.486 |
| 10–Agricultural machinery with operation assist function (straight–ahead assist function and so on) | 18 | 9.375 | 17 | 9.290 |
| 11–Automatic environmental controls of greenhouses and barns (temperature, humidity, soil moisture, $CO_2$ concentration, and so on) | 40 | 20.513 | 40 | 21.858 |
| 12–Livestock feeding, manure cleaning, and milking automation and robotization | 19 | 9.744 | 19 | 10.383 |
| 13–Automation of crop cultivation machines/robots [plowing, fertilization, control (including drone), harvest, and so on] | 15 | 7.692 | 15 | 8.197 |
| 14–Automatic sorting of harvested products (weight/shape sorting, color sorting, sugar content sorting, and so on) | 44 | 22.564 | 41 | 22.404 |
| *Business management technologies* | | | | |
| 15–Management of production record information (including data analysis such as tabulation and graphing) | 106 | 54.359 | 100 | 54.645 |
| 16–Provision of production information to business partners and consumers (product quality, production history, and so on) | 83 | 42.564 | 78 | 42.623 |
| 17–Sales information management (including customer management and internet sales) | 119 | 61.026 | 113 | 61.749 |
| 18–Inventory management of materials, such as pesticides and fertilizers (recorded using a personal computer, smartphone, and so on) | 87 | 44.615 | 83 | 45.355 |

| | | | | |
|---|---|---|---|---|
| 19–Financial management systems, such as bookkeeping and accounting (settlement, management diagnosis, payroll, and so on) | 163 | 83.590 | 154 | 84.153 |
| 20–Planning of business strategy and creation of business plan (simulation on a personal computer and so on) | 76 | 38.974 | 72 | 39.344 |
| 21–Advertisement for companies and products (information on homepage and so on) | 126 | 64.615 | 119 | 65.027 |

**Table A2.** Result of descriptive statistics with 195 samples

| Variables | Mean | SD | Min | Max |
|---|---|---|---|---|
| *TECH (dependent)* | 6.544 | 3.976 | 0 | 21 |
| 1. Corporate form | | | | |
| *CFORM_1* | 0.395 | 0.490 | 0 | 1 |
| *CFORM_2* | 0.451 | 0.499 | 0 | 1 |
| *CFORM_3* | 0.138 | 0.346 | 0 | 1 |
| *CFORM_4* | 0.015 | 0.123 | 0 | 1 |
| 2. Eligibility to own farmland | | | | |
| *FARML* | 0.872 | 0.335 | 0 | 1 |
| 3. Location of corporation | | | | |
| *R_HKD* | 0.015 | 0.123 | 0 | 1 |
| *R_TH* | 0.236 | 0.426 | 0 | 1 |
| *R_KT* | 0.128 | 0.335 | 0 | 1 |
| *R_HR* | 0.092 | 0.290 | 0 | 1 |
| *R_KKTK* | 0.138 | 0.346 | 0 | 1 |
| *R_CHSK* | 0.138 | 0.346 | 0 | 1 |
| *R_KSON* | 0.246 | 0.432 | 0 | 1 |
| 4. Age of corporation | | | | |
| *AGE_C* | 18.436 | 12.455 | 1 | 76 |
| 5. Establishment background | | | | |
| *ESTAB_1* | *0.482* | *0.501* | *0* | *1* |
| *ESTAB_2* | *0.256* | *0.438* | *0* | *1* |
| *ESTAB_3* | *0.041* | *0.199* | *0* | *1* |
| *ESTAB_4* | *0.056* | *0.231* | *0* | *1* |
| *ESTAB_5* | *0.046* | *0.210* | *0* | *1* |
| *ESTAB_6* | *0.056* | *0.231* | *0* | *1* |
| *ESTAB_7* | *0.067* | *0.250* | *0* | *1* |
| 6. Human capital | | | | |
| *BM* | 3.544 | 2.392 | 1 | 20 |
| *RE* | 10.615 | 21.363 | 0 | 238 |
| 7. Annual sales | | | | |
| *SALE* | 3.708 | 1.718 | 1 | 9 |
| 8. Profit margin | | | | |
| *PROF_1* | 0.082 | 0.275 | 0 | 1 |
| *PROF_2* | 0.313 | 0.465 | 0 | 1 |
| *PROF_3* | 0.185 | 0.389 | 0 | 1 |
| *PROF_4* | 0.097 | 0.297 | 0 | 1 |
| *PROF_5* | 0.067 | 0.250 | 0 | 1 |
| *PROF_6* | 0.026 | 0.158 | 0 | 1 |
| *PROF_7* | 0.200 | 0.401 | 0 | 1 |
| 9. Development stage of the corporation | | | | |
| *STAGE_1* | 0.067 | 0.250 | 0 | 1 |
| *STAGE_2* | 0.415 | 0.494 | 0 | 1 |
| *STAGE_3* | 0.164 | 0.371 | 0 | 1 |
| *STAGE_4* | 0.056 | 0.231 | 0 | 1 |
| *STAGE_5* | 0.159 | 0.367 | 0 | 1 |
| *STAGE_6* | 0.103 | 0.304 | 0 | 1 |
| *STAGE_7* | 0.026 | 0.158 | 0 | 1 |
| *STAGE_8* | 0.005 | 0.072 | 0 | 1 |
| *STAGE_9* | 0.005 | 0.072 | 0 | 1 |

Note: N=195

| Variables | Mean | SD | Min | Max |
|---|---|---|---|---|
| 10. Sales target for the next 5 years | | | | |
| *TSALE_1* | 0.118 | 0.323 | 0 | 1 |
| *TSALE_2* | 0.282 | 0.451 | 0 | 1 |
| *TSALE_3* | 0.297 | 0.458 | 0 | 1 |
| *TSALE_4* | 0.036 | 0.187 | 0 | 1 |
| *TSALE_5* | 0.133 | 0.341 | 0 | 1 |
| *TSALE_6* | 0.062 | 0.241 | 0 | 1 |
| *TSALE_7* | 0.051 | 0.221 | 0 | 1 |
| *TSALE_8* | 0.005 | 0.072 | 0 | 1 |
| *TSALE_9* | 0.000 | 0.000 | 0 | 0 |
| 11. Profit target for the next 5 years | | | | |
| *TPROF_1* | 0.036 | 0.187 | 0 | 1 |
| *TPROF_2* | 0.205 | 0.405 | 0 | 1 |
| *TPROF_3* | 0.333 | 0.473 | 0 | 1 |
| *TPROF_4* | 0.149 | 0.357 | 0 | 1 |
| *TPROF_5* | 0.118 | 0.323 | 0 | 1 |
| *TPROF_6* | 0.118 | 0.323 | 0 | 1 |
| *TPROF_7* | 0.021 | 0.142 | 0 | 1 |
| 12. Major product | | | | |
| *PROD_1* | 0.174 | 0.380 | 0 | 1 |
| *PROD_2* | 0.000 | 0.000 | 0 | 0 |
| *PROD_3* | 0.010 | 0.101 | 0 | 1 |
| *PROD_4* | 0.092 | 0.290 | 0 | 1 |
| *PROD_5* | 0.113 | 0.317 | 0 | 1 |
| *PROD_6* | 0.036 | 0.187 | 0 | 1 |
| *PROD_7* | 0.128 | 0.335 | 0 | 1 |
| *PROD_8* | 0.031 | 0.173 | 0 | 1 |
| *PROD_9* | 0.021 | 0.142 | 0 | 1 |
| *PROD_10* | 0.046 | 0.210 | 0 | 1 |
| *PROD_11* | 0.041 | 0.199 | 0 | 1 |
| *PROD_12* | 0.046 | 0.210 | 0 | 1 |
| *PROD_13* | 0.103 | 0.304 | 0 | 1 |
| *PROD_14* | 0.092 | 0.290 | 0 | 1 |
| 13. Self-evaluation of ICT utilization and information management | | | | |
| *SELF_U* | 2.610 | 0.980 | 1 | 5 |
| 14. Perception of the FTA participation of Japan | | | | |
| *FTA* | 2.882 | 1.006 | 1 | 5 |
| 15. Age of representatives | | | | |
| *AGE_R* | 5.082 | 1.181 | 2 | 7 |
| 16. Educational background of representatives | | | | |
| *EDU_1* | 0.554 | 0.498 | 0 | 1 |
| *EDU_2* | 0.077 | 0.267 | 0 | 1 |
| *EDU_3* | 0.138 | 0.346 | 0 | 1 |
| *EDU_4* | 0.062 | 0.241 | 0 | 1 |
| *EDU_5* | 0.354 | 0.479 | 0 | 1 |
| *EDU_6* | 0.031 | 0.173 | 0 | 1 |
| *EDU_7* | 0.026 | 0.158 | 0 | 1 |
| 17. Non-agricultural experience of representatives | | | | |
| *NAGRI* | 3.164 | 1.983 | 0 | 6 |

Note: N=195

**Table A3.** Comparison of NB1 results with different sample sizes

| | N=195 | | N=183 | |
|---|---|---|---|---|
| | Parameter | Marginal effect | Parameter | Marginal effect |
| 1. Corporate form (benchmark: *CFORM_1*, limited company) | | | | |
| *CFORM_2* | –0.001 | –0.004 | –0.049 | –0.323 |
| *CFORM_3* (agricultural cooperative corporations) | –0.334** | –2.184 ** | –0.367** | –2.431** |
| *CFORM_4* | –0.249 | –1.627 | –0.290 | –1.923 |
| 2. Eligibility to own farmland | | | | |
| *FARML* | 0.195 | 1.274 | 0.257** | 1.700** |
| 3. Location of corporation (benchmark: *R_HKD*, Hokkaido) | | | | |
| *R_TH* | –0.292 | –1.908 | –0.021 | –0.141 |
| *R_KT* | –0.263 | –1.721 | –0.031 | –0.204 |
| *R_HR* | –0.203 | –1.328 | 0.036 | 0.240 |
| *R_KKTK* | 0.108 | 0.704 | 0.395 | 2.616 |
| *R_CHSK* | –0.276 | –1.808 | –0.078 | –0.516 |
| *R_KSON* | –0.276 | –1.808 | –0.080 | –0.532 |
| 4. Age of corporation | | | | |
| *AGE_C* | 0.003 | 0.017 | 0.001 | 0.008 |
| 5. Establishment background (benchmark: *ESTAB_1*, a farmer established a solely owned corporation) | | | | |
| *ESTAB_2* | 0.025 | 0.161 | 0.020 | 0.131 |
| *ESTAB_3* | 0.182 | 1.193 | 0.219 | 1.453 |
| *ESTAB_4* | 0.2 | 1.309 | 0.046 | 0.305 |
| *ESTAB_5* | 0.162 | 1.063 | 0.127 | 0.842 |
| *ESTAB_6* | 0.146 | 0.953 | 0.115 | 0.764 |
| *ESTAB_7* | –0.189 | –1.239 | –0.166 | –1.097 |
| 6. Human capital | | | | |
| *BM* (number of board members) | 0.041* | 0.270* | 0.038 | 0.252 |
| *RE* | 0.000 | –0.003 | 0.000 | –0.002 |
| 7. Annual sales | | | | |
| *SALE* | –0.024 | –0.157 | –0.017 | –0.110 |
| 8. Profit margin (benchmark: *PROF_1*, 0%) | | | | |
| *PROF_2* | 0.084 | 0.547 | 0.011 | 0.075 |
| *PROF_3* | –0.010 | –0.065 | –0.138 | –0.916 |
| *PROF_4* | 0.129 | 0.842 | 0.053 | 0.354 |
| *PROF_5* | –0.011 | –0.075 | –0.129 | –0.855 |
| *PROF_6* | –0.168 | –1.098 | –0.251 | –1.665 |
| *PROF_7* | 0.130 | 0.849 | 0.075 | 0.495 |
| 9. Development stage of the corporation (benchmark: *STAGE_1*, starting) | | | | |
| *STAGE_2* | 0.202 | 1.321 | 0.096 | 0.634 |
| *STAGE_3* | 0.261 | 1.710 | 0.205 | 1.358 |
| *STAGE_4* | 0.042 | 0.274 | –0.004 | –0.025 |
| *STAGE_5* | 0.252 | 1.648 | 0.212 | 1.403 |
| *STAGE_6* | 0.331 | 2.166 | 0.331 | 2.195 |
| *STAGE_7* | 0.215 | 1.407 | 0.160 | 1.059 |
| *STAGE_8* | –14.031 | –91.810 | (omitted) | 0.000 |
| *STAGE_9* | –0.065 | –0.427 | –0.203 | –1.342 |
| 10. Sales target for the next 5 years (benchmark: *TSALE_1*, maintain) | | | | |
| *TSALE_2* (1.2 times) | 0.149 | 0.978 | 0.247* | 1.637* |
| *TSALE_3* | 0.046 | 0.298 | 0.114 | 0.753 |
| *TSALE_4* | 0.313 | 2.045 | 0.340 | 2.249 |
| *TSALE_5* | –0.043 | –0.281 | –0.011 | –0.076 |
| *TSALE_6* | 0.042 | 0.275 | 0.124 | 0.818 |
| *TSALE_7* | 0.126 | 0.823 | 0.125 | 0.826 |
| *TSALE_8* | –0.101 | –0.659 | 0.090 | 0.595 |
| *TSALE_9* | (omitted) | 0.000 | (omitted) | 0.000 |
| 11. Profit target for the next 5 years (benchmark: *TPROF_1*, 0%) | | | | |
| *TPROF_2* | 0.095 | 0.622 | 0.268 | 1.776 |
| *TPROF_3* | 0.203 | 1.328 | 0.414 | 2.739 |
| *TPROF_4* | 0.092 | 0.603 | 0.314 | 2.079 |
| *TPROF_5* (10%–15%) | 0.279 | 1.828 | 0.520* | 3.443* |
| *TPROF_6* | 0.192 | 1.257 | 0.469 | 3.104 |
| *TPROF_7* (no target) | –0.926* | –6.060* | –0.731 | –4.844 |

| | | | | |
|---|---|---|---|---|
| 12. Major product (benchmark: *PROD_1*, paddy rice) | | | | |
| *PROD_2* | (omitted) | 0.000 | (omitted) | 0.000 |
| *PROD_3* | –0.034 | –0.220 | –0.048 | –0.317 |
| *PROD_4* | –0.012 | –0.080 | 0.038 | 0.255 |
| *PROD_5* | –0.065 | –0.428 | 0.036 | 0.241 |
| *PROD_6* (flowers and foliage plants) | –0.499** | –3.265** | –0.475* | –3.144* |
| *PROD_7* | –0.155 | –1.011 | –0.064 | –0.425 |
| *PROD_8* | –0.279 | –1.825 | –0.240 | –1.587 |
| *PROD_9* | –0.140 | –0.916 | –0.022 | –0.145 |
| *PROD_10* | –0.240 | –1.572 | –0.133 | –0.882 |
| *PROD_11* | 0.257 | 1.681 | 0.365 | 2.415 |
| *PROD_12 (poultry)* | 0.218 | 1.425 | 0.376* | 2.493* |
| *PROD_13* | –0.214 | –1.397 | –0.051 | –0.341 |
| *PROD_14* | –0.058 | –0.380 | 0.014 | 0.092 |
| 13. Self–evaluation of ICT utilization and information management | | | | |
| *SELF_U* | 0.328*** | 2.146*** | 0.345*** | 2.287*** |
| 14. Perception of the FTA participation of Japan | | | | |
| *FTA* | 0.045 | 0.293 | 0.059 | 0.394 |
| 15. Age of representatives | | | | |
| *AGE_R* | –0.065* | –0.425* | –0.036 | –0.237 |
| 16. Educational background of representatives | | | | |
| *EDU_2* (specialized schools) | 0.298** | 1.950** | 0.293** | 1.939** |
| *EDU_3* (vocational colleges) | 0.246* | 1.613* | 0.289** | 1.913** |
| *EDU_4* | –0.214 | –1.401 | –0.198 | –1.309 |
| *EDU_5* | –0.029 | –0.188 | –0.033 | –0.217 |
| *EDU_6* | –0.240 | –1.567 | –0.156 | –1.031 |
| *EDU_7* | 0.075 | 0.492 | –0.002 | –0.017 |
| 17. Non–agricultural experience of representatives | | | | |
| *NAGRI* | 0.006 | 0.038 | 0.021 | 0.142 |
| *_cons* | 0.641 | | –0.092 | |
| N | 195 | | 183 | |
| Pseudo–$R^2$ | 0.148 | | 0.146 | |
| Log likelihood | –459.061 | | –432.347 | |
| lndelta | –1.716** | | –1.882** | |
| AIC | 1060.122 | | 1004.694 | |
| BIC | 1292.505 | | 1229.358 | |

Note: (1) ***, **, and * represent statistically significant at the 1%, 5%, and 10% levels, respectively; (2) The parameter here can be interpreted as semi–elasticity; marginal effect is calculated at the mean of the dependent variable (Paxton *et al.*, 2011).