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Impacts of inter-firm relations on the adoption of remote work: Evidence from a survey in Japan during the COVID-19 pandemic*

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Abstract

During the COVID-19 pandemic, remote work suddenly attracted attention. This paper focuses on inter-firm relations, as the costs and benefits of introducing remote work are likely to differ depending on the firms' relationships with other firms. We combine our unique survey on the responses of Japanese manufacturers or wholesalers to the COVID-19 pandemic with transaction relation data. We find that firms sourcing from more suppliers before the pandemic are significantly more likely to adopt remote work during the pandemic even after controlling for firm size. Wholesalers selling to more customers appear to be less likely to shift to remote work.

Keywords: Remote work; COVID-19; transaction networks; firm-level data
JEL classification: F23, F61, M16, O33

*This study is conducted as a part of the Project "Empirical analysis of firms amidst globalization, digitization and the COVID-19 pandemic" undertaken at the Research Institute of Economy, Trade, and Industry (RIETI). This study utilizes "Survey of Globalization and Reduced Face-to-face Contacts during the COVID-19 Pandemic" and "TSR inter-firm relation database" and "TSR firm information database" provided by RIETI. The authors are grateful for helpful comments and suggestions by Discussion Paper seminar participants at RIETI, especially Makoto Yano and Masayuki Morikawa.
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1. Introduction

The adoption of a new working arrangement requires firms to coordinate with their transaction partners. Remote work[1] has been regarded as a new and flexible working style made feasible by information and communication technologies (ICT) but has not yet been widely adopted despite the COVID-19 pandemic.[2] This paper examines the introduction of remote work in the context of technology adoption, as Bloom et al. (2015) on an experimental introduction of work-from-home in a Chinese firm. The decision of a firm on remote work should depend on the adoption cost, which is likely to vary across firms. As a classic study of technology diffusion, Griliches (1957) finds that the profitability variations across regions had significant impacts on the adoption of hybrid seed corn in the U.S.[3] As pointed out by Erikson and Norlander (2022), the adoption of remote work is likely to be influenced by similar factors as outsourcing decisions across firm boundaries. As adoption costs for remote work are expected to decline with past experiences in coordination across firm boundaries, this paper examines whether the inter-firm relations before the pandemic is related with each firm's decision of introducing remote work during the COVID-19 pandemic. To investigate this issue, we combine our unique survey on the Japanese firms' responses to the COVID-19 pandemic with inter-firm transaction relation data in Japan.

Remote work has been expected to have many positive effects both on employees and employers. Remote work facilitates the labor market participation of wider people, as some of them may have difficulties physically commuting to their workplaces. Remote work improves the

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[1] Although other various expressions have been used, "remote work" is best suited to describe working from workers' home, satellite offices, coworking spaces, cafes or anywhere remotely from their offices. In contrast, "work from home" is limited to work exclusively from the workers' home, not anywhere else. "Telework" emphasizes the workers' use of telecommunication technologies, not working places. "Telecommuting" refers to work without commuting aided by telecommunication technologies. We will explain the expression used in our survey in Section 2.

[2] Economic analyses of COVID-19 have been accumulated, as surveyed by Brodeur et al. (2021) for instance.

[3] See Foster and Rosenzweig (2010), for example, for a survey of previous discussions of technology adoption though mainly in the development context.

efficiency or performances of workers through instant long-distance communications. Remote work helps mitigate the spread of contagion in the pandemic by reducing face-to-face contact. If all workers are required to commute to their offices/plants, the operations of their workplaces may be disrupted by the pandemic through widespread contagion or precautious lockdown measures.[4]

Despite these merits, many firms remain to ask their employees to commute even after the pandemic. Managers worry that workers would shirk at home, while workers worry that supervisors may not notice their performances (e.g., Burbano and Chiles 2022). CEOs may avoid the risks associated with changing work conditions. A randomized experiment in a Chinese firm, though before the COVID-19 pandemic, by Bloom et al. (2015) shows evidence of slow diffusion and gradual learning among employees in the adoption of work-from-home. In our sample of Japanese mid- or large-sized firms, more than one-third of them asked basically all their employees to commute even during the state of emergency in the spring of 2020.[5] Various factors are likely to prevent firms from introducing remote work. For example, some of the tasks performed by workers include non-codifiable contents and thus make face-to-face contact important. Some of the workers handle tangible goods in manufacturing or transportation. In addition to these characteristics of task content, customer relation is one of the frequently cited reasons for not introducing remote work, according to a survey by the government in Japan.[6]

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[4] Barry et al. (2022) argue that the ability of employees to work remotely is related to employment recovery from the pandemic and automation investment.

[5] Limited introduction of remote work in Japan during the COVID-19 pandemic has been reported in many surveys, such as Okubo (2022). Morikawa (2020) examined the impact of work-from-home on productivity in Japan based on a survey of individuals. Tanaka (2023) analyzed the factors hindering digital communications during the COVID-19 pandemic based on a survey of foreign firms in Japan.

[6] According to an annual survey of telework population in 2021 by the Ministry of Land, Infrastructure, Transport and Tourism, more than half of the respondents employed not allowed telework answered that their jobs are not suitable for telework. As the reasons for the non-suitability, customer service is chosen by 22.5% of them, followed by on-site manufacturing/construction jobs 22.1%, medical or elderly care 16.4%, and on-site transport/cleaning jobs 9.6%, although 24.4% choose a vague option of “the way of working”.

Since this suggests an important role of interactions across firm boundaries, limited adoption of remote work may share common problems such as the slow diffusion of new technology. Historical episodes show that it often takes very long time for new technology to be introduced by many firms, as Juhász et al (2020) compare COVID-19 with the Industrial Revolution.[7] Excess inertia due to coordination failure and positive network externality are among the factors behind slow adoption.

While it is difficult to precisely capture the task contents of individual workers, the use of firm-level data enables us to investigate the relationships of inter-firm relations with each firm's adoption of remote work. Remote work adoption is suitable for firm-level analysis, as the decisions are made at corporate level (Bartik et al. 2020 for example based on a firm survey in the U.S.). In Japan, the state of emergency was declared by the government as in many other countries but without penalties for violations (see OECD 2021, for example). The stringency of lockdown measures in Japan was among the lowest in the world, comparable with that of Sweden and New Zealand. This makes Japanese experiences suitable for firm-level analysis, as the adoption of remote work was based on voluntary cooperation by private firms. Some workers can choose between remote work and commuting, but the system of allowing employees to choose their work style is arranged by employers. Firms offering the choice of flexible work style including remote work will attract workers in the long run, but this paper focuses on the short-run reaction to the pandemic. In the case of Japan, no legally mandatory lockdown actions were taken during the COVID-19 pandemic, leaving the choice of remote work to individual firms. This paper is an attempt at exploring the effect of adoption costs for remote work, which vary across firms and are likely to depend on firms' experiences in inter-firm coordination.

[7] Bloom et al. (2019) discuss wide variations in management practices across firms based on their surveys.

Our primary focus is on the inter-firm transaction relations. The introduction of remote work is often discussed in the relationship with the ability of workers to work remotely based on the suitability of tasks for remote work.[8] As far as we know, however, no previous research has directly analyzed the impact of inter-firm relations on the adoption of remote work based on firm-level data. Firms may differ in their accumulation of experiences or skills for adjustments with other firms, as Bernard et al. (2022) formalize it as "relation-specific capability" of firms. Firms with rich experiences in coordinating with many other firms are likely to introduce remote work relatively smoothly during the pandemic. Customer relation concerns, however, may make sellers hesitate to shift to remote work as insufficient face-to-face contact will result in sales decline. We use the number of transaction partners as a proxy for such capability of firms. Supply-chain relationships with upstream and downstream firms are likely to affect the adoption of new technology, as Basker and Simcoe (2021) examine in the case of the Universal Product Code during the early years of the bar code system in the U.S. Fort (2017) finds supply-chain fragmentation is related with IT adoption of U.S. firms.[9] Atkin et al. (2017) emphasize organizational barriers to technology adoption in the case of soccer-ball producers in Pakistan. Lakhani et al. (2013) argue that human resource practices of lead firms influence those of suppliers through visits of specialists or standardized training. As pointed out by Erikson and Norlander (2022), we can discuss the future of remote work in the post-pandemic era from the literature on outsourcing because these past studies reveal how firms manage work beyond organizational boundaries. Our estimation results show that firms sourcing from many suppliers tend to adopt remote work relatively frequently even after controlling for their firm sizes. We also

[8] The measure of suitability for remote work by Dingel and Neiman (2020) has been often used to analyze remote work at the task or occupation level.
[9] Tomiura (2009) also reports that the choice between foreign versus domestic outsourcing is significantly related with the firm's R&D intensity.

find that wholesalers selling to many customers appear to hesitate to shift to remote work.

For our empirical analysis, we combine two different data sources. First, we conducted a unique survey for our research project at Japan's Research Institute of Economy, Trade, and Industry (RIETI). We distributed the questionnaires to virtually all medium or large-sized firms in manufacturing or wholesale industries in Japan. We collect information on firms' responses to the COVID-19 pandemic, including the introduction of remote work, at four points in time around the pandemic as a retrospective question. Second, we link this survey results with the inter-firm transaction relation database assembled by one of the major credit report agencies in Japan, Tokyo Shoko Research Co., Ltd. (TSR). The database covers firms without size thresholds in all industries in Japan and enables us to identify each firm's customers and suppliers. TSR database contains not only inter-firm transaction network data but also firm attributes, including personal characteristics of Chief Executive Officers (CEOs).

The remainder of this paper is organized as follows. Section 2 describes our dataset, especially our unique survey on the firms' responses to the pandemic. Section 3 examines whether a firm's adoption of remote work is related to the firm's transaction relationships based on inter-firm transaction network data. Section 4 reports results from robustness checks. Section 5 adds concluding comments.

2. Description of data

This section describes our dataset used for this research. We combine our original survey on the COVID-19 pandemic with firm-level data of inter-firm transaction networks. Each sub-section is devoted to brief descriptions of our RIETI COVID-19 survey and inter-firm transaction relation database.

2.1. RIETI COVID-19 survey

To collect information on remote work, we conducted a survey of firms in Japan.[10] We design our survey as covering virtually all large- and medium-sized firms in manufacturing and wholesale industries.[11] The sectors covered by our survey are listed in Appendix Table A1. We define large or medium-sized firms as 50 or more employees and capital of 30 million yen or more.[12] We distributed our survey questionnaires to 22,948 firms at the beginning of January 2021, and accepted responses until March 2021 from 6,722 firms with the response rate of 29.3%.

The survey asks each firm about the adoption of remote work at the following four points in time:[13] (i) before the pandemic (December 2019), (ii) under the state of emergency (April or May 2020), (iii) after the state of emergency lifted (September or October 2020), and (iv) at the time of the survey (January 2021). Although it was not originally intended, our survey was conducted amid the period when the government announced the state of emergency again.[14]

In answering the question on remote work, firms are requested to choose one from the following five options.

(A) Remote work has been introduced in principle to all employees in our firm.

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[10] The "Survey of Globalization and Reduced Face-to-face Contacts during the COVID-19 Pandemic" was conducted by TSR for our research project at RIETI.

[11] Service sector is omitted due to wide intra-industry heterogeneities in the amenability for remote work. Retail sector is omitted as firm's remote work decision is highly sensitive to its location in the case of COVID-19 with widely varying cross-regional rates of contagion. Though firms in other industries turn out to be also covered by the survey due to multiple lists prepared at different points in time for our survey, we drop these exceptional firms from our analysis. We also confirm the robustness of our main findings even if we concentrate on manufacturing firms in Section 4.

[12] This size threshold is motivated by our plan to match our survey results with firm-level data from the Ministry of Economy, Trade, and Industry's Basic Survey of Japanese Business Structure and Activities or *Keizaisangyousho Kigyo Katsudo Kihon Chosa* in Japanese for a different paper.

[13] In the questionnaire, we explicitly state that what we asked includes work from home, work from satellite offices, "workation" and other forms of remote work for at least a part of work hours. As the original survey was conducted in Japanese, we translate the text into English for this paper.

[14] The state of emergency was announced for eleven prefectures in January 2021, while it was declared for all 47 prefectures in April 2020. We will check whether firms operating plants/establishments in the eleven prefectures under the state of emergency differ in their adoption of remote work in Section 4.3.

(B) Remote work has been introduced widely in our firm though with exceptions.

(C) Remote work has been introduced in our firm but is limited to selected employees.

(D) All employees in our firm are in principle required to commute to their workplaces.

(E) Others.

While we will define the remote work adopters by firms introducing remote work to basically all employees or widely (A or B), we will alternatively include firms introducing remote work selectively (C) into remote work adopters in a wide definition for a robustness check purpose. Figure 1 visualizes the share of firms and the transition over periods about the introduction of remote work in our sample. The proportion of firms requiring all employees to commute to their workplaces declined sharply during the first state of emergency in the spring of 2020, but bounced back after the state of emergency was lifted in the autumn of the same year.

As shown in Table 1, merely around one-quarter of the surveyed firms introduced remote work even when the government declared the state of emergency during the first wave of COVID-19 pandemic in April 2020. After the first state of emergency was lifted, the share of firms adopting remote work further decreased.[15] As the remote work was introduced only in a limited portion of firms, characterizing these firms will be informative. Summary statistics of other variables captured by our RIETI survey, such as the firms' activities in digital data collection, are also displayed in the same table. More than seventy percent of the firms have a plant or establishment. Nearly a quarter of the firms regularly collect data from their daily business operations, though merely five percent of the firms use cloud computing. We will investigate whether inter-firm transaction relationships before the pandemic are associated with the

[15] Bloom et al. (2015) report that over half of the employees under a randomized experiment switch to work from home when they are allowed to reselect their work style.

introduction of remote work during the pandemic in Section 3.

2.2. TSR database of inter-firm transaction relations

To examine the relation between inter-firm networks and the firm's decision on the adoption of remote work, we derive transaction relation data assembled by TSR, which is one of the two major credit reporting agencies in Japan.[16] Both publicly listed and unlisted firms of all sizes in all industries are included in this dataset. The data of trading partners at the firm level is valuable, though no information on trading value or volume is available in the TSR dataset. The exact timing of collecting information on trading partners may slightly vary across firms, as TSR asks firms to reveal information when firms obtain credit reports of other firms. As we use the 2020 edition of TSR database, basically all the variables are recorded before the COVID-19 pandemic, mostly in 2019. We can match 6,530 firms with TSR database among 6,722 firms covered by the RIETI survey.

TSR database lists all suppliers (up to 24) and customers (up to 24) of each firm without any cutoff in sales or employment. If the firm trades with more than 24 firms, TSR dataset does not necessarily cover all transaction partners. To alleviate possible problems due to this truncation, we combine the lists of transaction partners of firms in the TSR sample. Consider an example of two firms *A* and *B*. We include Firm *B* as a transaction partner of Firm *A* if *A* reports *B* as a transaction partner (self-reported partners) or if Firm *B* reports *A* as a transaction partner (partners reported by others) even when *B* is not included within the 24-firm list of transaction partners of *A*.[17] As another important point, this TSR database distinguishes each firm's upstream suppliers

[16] This TSR inter-firm transaction network data has been used by previous studies, such as Bernard et al. (2019). Although this TSR database is valuable in tracing transaction relations, there are other datasets on transaction relations. For example, to analyze the shock of COVID-19, Calvalho et al. (2021) use transaction data of credit- and debit-cards of a bank in Spain.

[17] Bernard et al. (2019) also include other-reported partners and confirm no discontinuity around the 24-firm threshold in the TSR dataset.

and downstream customers among transaction partners. While this TSR database has such rare strengths, international trade relations are not included in this TSR database. As we focus on inter-firm trade within a country, we do not need to consider institutional differences between firms; all firms in our sample are under the same regulations, including the COVID-19 state of emergency and other public health regulations.

As shown in the summary statistics in Table 1, the average firm in our matched sample has 48 customers (selling to 48 firms) and 32 suppliers (buying from 32 firms). While 1.49% of the firms have no buyer or seller recorded in the TSR database and will be dropped from our regressions, the maximum number of customers is as many as 3,488 and the firm with maximal number has 11,437 suppliers in our sample. To check the robustness of our results, we will also estimate the same model by omitting outliers.

TSR database contains not only inter-firm transaction relationship data but also basic firm attributes, such as firm size and firm's age. We will also draw valuable data on personal characteristics of CEO, such as gender, age, and educational attainment, from TSR database. As shown in the table, 98% of the firm have male CEOs and 85% of CEOs are college-educated.

3. Estimation results

3.1. Variables in regressions

To examine the relation between transaction networks and remote work adoption, we estimate the following.

$$RW_{isr} = \beta_1 ln\#Suppliers_i + \beta_2 ln\#Customers_i + Z_i\gamma + \kappa_s + \lambda_r + \varepsilon_{isr} \qquad (1)$$

The firm, sector, and region are indexed by *i*, *s*, and *r*, respectively. We estimate (1) in a cross-section format for each period in our survey (December 2019, April/May 2020, September/October 2020, and January 2021) to allow every coefficient to vary across periods.

The dependent variable *RW* is a binary dummy taking the value of one if the firm introduces remote work to basically all or a wide range of employees and zero if the firm introduces remote work only to limited employees or asks basically all employees to commute.[18] As the main variable on the right-hand side of the regression, we include the firm's transaction partner variable, which we will define below. We control for a vector of firm characteristics *Z*, which will be explained later. *Z* represents firms' characteristics before the pandemic (December 2019).[19] It was almost completely impossible for firms to predict the timing of the COVID-19 pandemic. Firms were unable to fully prepare for the pandemic by introducing remote work arrangement. Bai et al. (2021) defend this type of identification assumption in analyzing the impact of pre-pandemic work-from-home feasibility on firm performance during the pandemic. In our case, we can assume away the possibility of reverse causality from remote work to transaction or ownership relationships, although we should be cautious in claiming the strict causality based on a one-shot survey. We estimate (1) by a linear probability model to include industry- as well as region-fixed effects, κ and λ (30 sectors and 47 prefectures). We will check the robustness of our results from the linear probability model by logit estimation in Section 4. The error term is denoted by ε.

Our main variable is the number of the firm's transaction partners (*#Suppliers* and *#Customers*) in logarithm.[20] The introduction of remote work by a firm may be relatively easy if

[18] Firms choosing the "others" option in the question of remote work are dropped from the regression. As a robustness check, we will alternatively define *RW* to take the value of one if a firm introduces remote work at least partially and zero if basically all employees are required to commute. We will also examine the extent of remote work introduction by estimating an ordered logit model. See Section 4 for these additional results.

[19] As explained in Section 2.2, the timing when TSR collects transaction information slightly varies across firms. However, as we draw our data from the 2020 edition of TSR database, we can safely assume that our right-hand side variables included in (1) represent pre-pandemic characteristics, mostly in 2019.

[20] Firms are dropped from the regression if they record no customers or suppliers in the TSR database.

the firm has experiences in trading with many partners, as the remote work adoption costs may be low due to the firm's accumulated skills for coordinating across firm boundaries. Erikson and Norlander (2022) emphasize that remote work and outsourcing across firm boundaries share common factors in organizing work. In surveying related literature, Lakhani et al. (2013) report that employment relations of other firms have impacts through supply chains. One may alternatively argue that remote work may be difficult for firms trading with many partners because coordinating with many other firms may require face-to-face contact for non-codifiable contents and hence prevent the adoption of remote work. We will investigate which of these two opposing effects dominates in our case. While this paper considers the inter-firm variability in the costs of adoption, the needs for remote work are also likely to vary across firms. Bernard et al. (2022) formalize firms differing not only in their productivity levels but also in their relationship capabilities, defined as the (inverse of) fixed costs of supplier-customer matching, to explain empirical regularities observed in Belgium firm-level data. Firms trading with many other firms may gain more from saving travels to their business partners' offices.

In counting the number of transaction partners, we do not separate remote work adopters among transaction partners from the following reasons. First, merely a negligible number of firms had adopted remote work when TSR database collected inter-firm relation information before the COVID-19 pandemic. The motivation of these exceptional firms for introducing remote work may differ from those during the pandemic. This makes the distinction of adopters useless for our analysis. Second, during the pandemic, especially in the first wave of contagion in the spring of 2020, the introduction of remote work was made almost simultaneously by basically all firms. This indicates no possibility of learning or spillover across firms, making our research different from the literature on social learning in technology diffusion. Third, the coverage of our one-shot original RIETI survey is inevitably narrower than that of TSR database constructed by one of the

most established credit reporting agencies for many years. Although firms in the RIETI survey are almost always included in the TSR dataset, all transaction partners of RIETI-surveyed firms are not necessarily covered by the RIETI survey. This implies that, even if no transaction partners adopt remote work in our combined dataset, there could exist a firm adopting remote work among firms not covered by or not responding to the RIETI survey. This limitation prevents us from constructing pair-wise network variables for our analysis.

As firm attributes *Z*, we include the following variables drawn from TSR database: the number of employees, the firm's age, the operation of an establishment or a manufacturing plant separated from corporate headquarters (binary dummy and the number of establishments/plants in logarithm), the dummy for firms in deficits,[21] and the personal characteristics of the firm's CEO (age, gender, the dummy for college education). We expect larger firms, or firms operating multiple branches tend to introduce remote work more actively to facilitate within-firm communications.[22] Firms established recently or run by young or educated CEOs are likely to actively learn new technologies, as surveyed by Foster and Rosenzweig (2010) in the case of technology adoption in developing economies. Remote work may be difficult for firms operating manufacturing plants as they handle tangible goods. In the regressions, we also include the following unique firm-level variables captured by our RIETI survey: whether the firm regularly collects digital data from the firm's daily operations, whether the firm's decision-making is based on data, whether the firm uses cloud computing, and whether the firm uses English for oral communications inside the firm.

[21] Ding et al. (2021) find that pre-pandemic financial factors affect corporate performances in the COVID-19 pandemic.

[22] Firm size is an important factor in responses to the pandemic. Bloom et al. (2020) find that the least productive firms are especially affected by the COVID-19 pandemic based on a firm survey in UK.

3.2. Main results

The estimation results from our sample with inter-firm trade relations are reported in Table 2. As some variables derived from TSR database are missing or unobserved for some of the surveyed firms, the sample size shrinks in our regressions. The summary statistics for the limited sample used in our regressions are shown in Appendix Table A2. We will check the robustness of our results from this limited sample by estimating the same model with selected control variables over a larger sample of firms in Section 4.

As the most notable finding, firms sourcing their inputs from more suppliers are more likely to adopt remote work during the pandemic. The relation with this transaction relation is statistically significant at any conventional significance level, though the magnitude is not large; The probability of remote work adoption is 0.5 to 0.8 percentage points higher in firms buying from ten percent more suppliers (on average three additional suppliers). Such a relationship was not strongly observed before the pandemic. In overcoming the shock of the unprecedented pandemic by introducing remote work, firms appear to take advantage of their experiences of trading with many suppliers. Although relatively larger firms may have more opportunities to trade with many firms, our finding of this relation is after controlling for the firm's size.

We also find that firms selling to more customers appear to be less likely to introduce remote work during the pandemic, especially during the state of emergency, but not before the pandemic. This relationship with customers is less clear than that with suppliers, but both are in contrast. This asymmetry is possibly because, compared with the shipment of outputs to downstream customers,[23] firms may intensively coordinate with upstream suppliers for their inputs, which include differentiated components or materials often tailored to the firms' specific

[23] As a related piece of evidence, the average share of manufacturers is higher among suppliers than among customers in our dataset (35%>21%).

requirements in the production process, as often discussed in previous studies.[24] In addition, customer relation or customer service is one of the frequently cited reasons for not introducing telework during the COVID-19 pandemic, according to a survey in Japan.[25] This survey result suggests that Japanese sellers appear to hesitate to adopt remote work from fears of losing sales or reputations by cutting face-to-face contact with customers.

We also find that remote work is less likely to be introduced if the firm operates manufacturing plants. In contrast, firms having establishments tend to introduce remote work actively. While the relationship with the firm's operation of establishments is significant after the start of the pandemic, the relationship with manufacturing plants is observed even before the COVID-19 pandemic. Establishments include non-production offices, while plants specialize in the production of tangible products. The contrast between firms with versus without plants/establishments, possibly reflecting the difference in amenability for telecommunications, is clear. The magnitudes of the relationship with the probability of introducing remote work are sizable: 8 to 12 percentage points lower in firms operating manufacturing plants and 3 to 8 percentage points higher in firms operating establishments. The negative relation with remote work tends to get strong with the number of plants, but the positive effect appears to be slightly attenuated with the number of establishments when the state of emergency was lifted. We also find that firms active in data-related activities (digital data collection, data-based decision-making, and the use of cloud computing) are likely to introduce remote work during the pandemic based on their ICT investment. Firms in deficit appear to be forced to abandon or postpone the

[24] The relationship with upstream firms is often more intense than that with downstream firms. For instance, López and Südekum (2009) detect productivity spillovers from upstream firms, not from downstream firms, in Chilian plants. In the case of adoption of electronic data interchange (EDI), Hart and Saunders (1997) argue that the buyer's power to influence the suppliers' EDI adoption increases with the size of the supplier pool.

[25] See the survey of telework population by the Ministry of Land, Infrastructure, Transport and Tourism in 2021 (https://www.mlit.go.jp/toshi/daisei/content/001471975.pdf).

introduction of remote work only in the first wave of the pandemic, though our deficit dummy may not work as an appropriate proxy for liquidity constraints.

The results shown in Table 2 also contain informative findings on the personal characteristics of CEO. The firm's age and the CEO's age are included in our regression after dividing by 100.[26] Firms run by younger CEOs or younger firms (firms established more recently) are more likely to introduce remote work. The age effect is significantly observed during the pandemic, not before the pandemic, but small in magnitude. Firms run by male CEOs appear to be active in remote work adoption, but this observed gender gap may reflect numerous unobservable factors in our limited data. Firms run by college-educated CEOs are also on average active in remote work, but this relation is observed only in a later period and is statistically weak.

Several attributes of firms remain related with remote work adoption irrespective of the historic pandemic.[27] Large-sized firms tend to introduce remote work significantly frequently before and during the pandemic. Firms using English language for intra-firm communications tend to introduce remote work significantly actively possibly due to their skills for distant communications or globally standardized work style.

4. Robustness checks

This section reports results from several robustness checks. First, by limiting the control variables, we expand the coverage of firms used for estimation. Second, we consider non-linearity by

[26] One firm is omitted from our sample due to its obvious error in CEO's age.

[27] We estimate the regressions by dropping survey-based variables (use of English, data collection and data-based decision), dropping survey-based variables plus operations of plants/establishments, or controlling only for firm size, as these variables may be endogenous. We keep sector dummies and region dummies. In all three cases, we confirm the significantly positive coefficient on the number of suppliers with similar magnitude as in our baseline regressions. The results from the regressions gradually dropping firm-level controls are available upon request.

estimating the model by logit and adjust differing sampling frequencies by estimating weighted regressions. We also concentrate purely on manufacturers by excluding wholesalers. Third, we add control variables, such as the locations of plants/establishments. We also distinguish inter-firm transactions within the same industry versus between different industries. Second-tier transaction partners are also included into our regressions. Fourth, we consider an alternative remote work dummy variable by relaxing the definition. We also disaggregate firms in their extent of remote work adoption by using detailed ordered data from our survey. Finally, we trim the sample by omitting outlier firms trading with an extremely large number of firms.

4.1. Estimation results from a larger sample

As some of the variables included as controls are missing or unobserved in TSR database for some of the surveyed firms, the sample size used for our baseline regressions is considerably smaller than the total number of surveyed firms. To expand the sample size as large as possible, this sub-section includes, as the firm-specific control variable, only the number of employees, for which the data are available for many firms. We keep sector- and prefecture-dummies as in the baseline case.

Table 3 reports the regression results from a larger sample. The number of firms covered by the regressions increases from around 3.7 thousand in our baseline to more than 5.8 thousand. Even in this large sample covering most of the surveyed firms, we confirm significantly positive coefficients on the number of suppliers and negative coefficients on the number of customers. Significantly positive relation with firm size is also confirmed robust in this larger sample.

4.2. Other estimation methods

This sub-section reports robustness check results from alternative estimation methods: logit and

weighted regression. We also investigate how our main results are affected by focusing on manufacturing among surveyed firms.

While we estimate a linear probability model to include sector- and prefecture-specific fixed effects in our baseline case, this sub-section reports non-linear estimation results, namely the logit estimation results, to handle the remote work dummy as the dependent variable. The choice of logit also facilitates the comparison with ordered logit results in Section 4.4. As shown in the panel (a) of Table 4, we confirm our main results unchanged even in the logit case.

Although the response rate of nearly 30% is relatively high as an academic survey, the variations of response rates across firm size classes and industries might affect our estimates. To mitigate this possible bias, we estimate the same model with weights according to the Economic Census. The census covers all firms in all industries in Japan and is conducted by the government with legal reporting obligations.

The weighted regression results are shown in the panel (b) of Table 4. Weights are based on 330 groups (30 industries times 11 firm size categories) to match the number of firms in Economic Census at 2016, the most recent census available at the time of our starting this research. Even after sampling frequencies are adjusted by census weights, our principal findings, especially for suppliers, remain basically robust.

While our survey covers both manufacturing and wholesale industries, we additionally estimate the same model only for manufacturing firms as a robustness check in the panel (c) of Table 4. We confirm our findings on the number of suppliers, while we find the number of customers turns to be insignificant in this limited sample. Our finding from the sample of manufacturers on the significant relation with the number of suppliers is in line with our daily observation that manufacturing firms tend to coordinate intensively with suppliers for securing procurement of inputs, particularly differentiated specially-designed input parts and components

or materials. The insignificant relation with customers in this case suggests that the significantly negative estimate in the baseline regressions is driven by non-manufacturers (wholesalers in our sample). Firms selling to many customers may hesitate to switch to remote work, but the impact of customer relation concerns appears to be more serious for wholesalers compared to manufacturers. However, we should be cautious before concluding this contrast between wholesalers and manufacturers as the sample size substantially decreases after eliminating wholesalers and as the boundary between manufacturers and wholesalers has become blurred.

4.3. Robustness checks with additional controls

This sub-section reports three robustness checks by adding control variables to our regressions. First, we additionally control for the locations of plants or establishments owned by multi-plant/establishment firms. Second, we distinguish inter-industry from intra-industry transactions. Finally, we additionally consider the relationships with second-tier transaction partners.

First, although we include region-specific fixed effects into our regressions, the locations of firms are identified by their corporate headquarters in our firm-level dataset. This sub-section adds a dummy variable taking the value of one if the firm owns a plant/establishment in the prefectures under the state of emergency in January 2021. While the first state of emergency was declared for all 47 prefectures, the second state of emergency was selectively issued to only eleven prefectures. As shown in the panel (a) of Table 5, we confirm our principal results even after controlling for the locations of plants/establishments.

Second, firms trade with other firms not only in different industries but also in the same industries. The intensity of inter-firm coordination may differ between differentiated intermediate components traded within the same machinery industry versus raw materials purchased across industrial boundaries. This sub-section distinguishes these two types of inter-firm transactions.

The panel (b) of Table 5 reports the regression results with the additional dummy for the trade within the same industry. Our main findings are largely robust, as we find no significant difference between inter-industry and intra-industry transactions for customers or suppliers except only for customers in the last period.

Third, while we have analyzed the relationship with the number of direct transaction partners, the transaction partners have different numbers of their own transaction partners in complex supply chains. Trading with partners selling/buying to/from many other firms may have a different impact on each firm in transactions. To consider this possible difference, we add the number of suppliers of the firm's suppliers (second-tier suppliers) and the number of customers of the firm's customers (second-tier customers) into our regressions.

The panel (c) of Table 5 confirms significantly positive/negative coefficient on the number of direct suppliers/customers as in the baseline regressions. We additionally find that selling to customers with more second-tier customers attenuates the negative relation with the number of first-tier customers. This suggests that firms tend to face barriers to introduce remote work if they sell to many customers, especially if they sell to firms with few customers. In other words, selling to customers with rich experiences in selling to many customers may not seriously deter the introduction of remote work. The number of second-tier suppliers, on the other hand, turns out to be statistically insignificant in our sample.

4.4. Alternative definitions of the remote work variable

We define the remote work adoption dummy to take the value of one if the firm introduces remote work basically to all employees or widely and zero if the firm introduces remote work only selectively or asks basically all employees to commute. However, to check the robustness of the results from the above definition of the remote work dummy, this sub-section considers alternative

definitions as follows.

First, we include all firms introducing remote work at least to a part of their employees as remote work adopting firms. Remote work dummy is this time defined to be zero only if the firm asks basically all its employees to commute. The regression results with this more widely defined remote work dummy are shown in the panel (a) of Table 6. We confirm that our main previous findings remain qualitatively intact.

While we have depended on the dichotomous dummy in discussing the introduction of remote work, our survey collects more detailed information on the extent of remote work adoption. This subsection estimates the ordered logit model by distinguishing firms with varying degree of remote work adoption. The panel (b) of Table 6 reports the results of ordered logit estimations. The dependent variable in this case is the four-step ordering in the extent of remote work adoption (1. all employees required to commute, 2. remote work introduced but limited to selected employees, 3. introduced widely but with exceptions, and 4. introduced to all employees). We omit firms choosing the fifth option in the survey ("others") from ordered logit estimation. We confirm the robustness of our main findings even if we disaggregate remote work adopters by their degree of adoption.

4.5. Omitting firms with exceptionally many transaction partners

Firms buy inputs from and sell outputs to other firms, but a small number of firms trade with an extremely large number of firms. As shown in Table 1, a firm with the largest number of suppliers buys from 3,488 firms and a firm with the largest number of customers sells to 11,437 firms, while the average number of a firm's suppliers/customers is 32 and 48, respectively.

To check the robustness of our results from our whole sample, this sub-section omits the top 1% of the firms in terms of the number of suppliers/customers. After this 1% trimming, all

the firms trade with less than 1000 firms. The regression results from the trimmed sample are reported in the panel (c) of Table 6. Our main results shown in the previous tables remained unchanged. Thus, outlier firms with extremely many transaction partners do not affect our principal findings.

5. Concluding remarks

Remote work attracts attention not only as a new, efficient, and inclusive work style enabled by ICT, but also as a measure for the pandemic by reduced face-to-face contact. Despite these merits, only a limited fraction of firms introduced remote work even during the historic pandemic of COVID-19. Based on our dataset linking our unique survey with inter-firm transaction data, we find that firms sourcing from more firms tend to actively adopt remote work. Although larger-sized firms are likely to trade with a larger number of firms and tend to invest more in ICT necessary for remote work, our finding of positive relation with the number of transaction partners is robust even if we control for firm size. We also find that wholesalers selling to many customers appear to hesitate to introduce remote work. These results are in line with the interpretation that experiences in inter-firm coordination before the pandemic facilitates the adoption of remote work during the pandemic, though customer relations may deter the switch to remote work.

While we detect several informative regularities from our unique and matched dataset, there are issues remained for future research. Worker-level data, if collected from an additional survey, will be useful for improving the precision of our estimates by controlling for differing amenability of their tasks for remote work. Finding instrument variables will alleviate the possible self-selection problem associated with network formation between firms. The impact of newly introduced remote work on the formation of transaction networks will be another important research topic once inter-firm transaction data in the post-pandemic period will become available.

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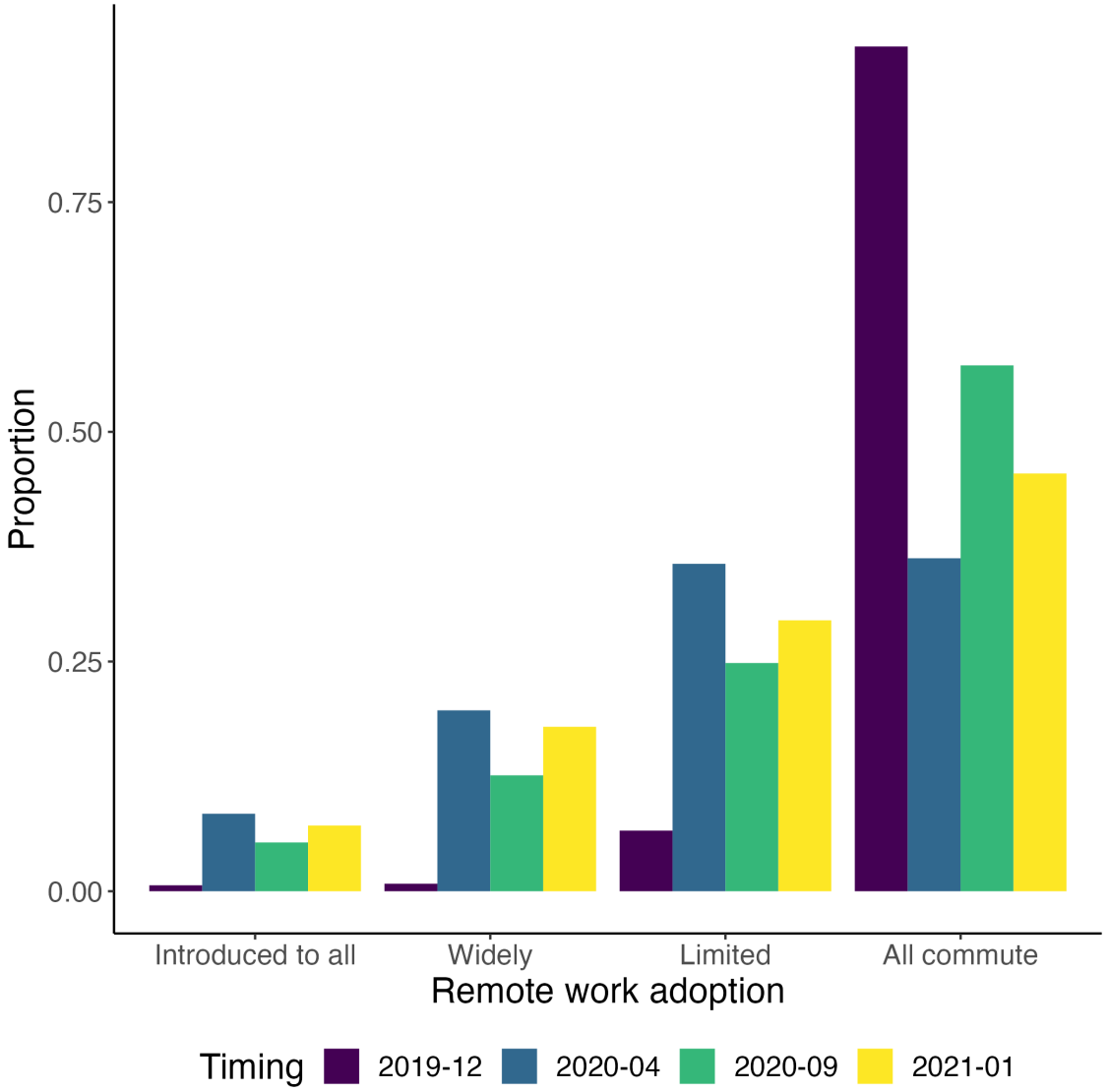
Figure 1 Transition of remote work adoption



Notes: The proportion is in terms of the number of firms at each point in time.

Table 1 Summary statistics

	Count	Mean	S.D.	Min	Max
Remote work (DUM, 2019-12, before the pandemic)	6026	0.01	0.11	0	1
Remote work (DUM, 2020-4, 1st state of emergency)	5837	0.26	0.44	0	1
Remote work (DUM, 2020-9, emergency lifted)	5914	0.16	0.37	0	1
Remote work (DUM, 2021-1, 2nd state of emergency)	5860	0.23	0.42	0	1
Remote work (DUM, wider definition, 2019-12)	6026	0.07	0.26	0	1
Remote work (DUM, wider definition, 2020-4)	5837	0.63	0.48	0	1
Remote work (DUM, wider definition, 2020-9)	5914	0.41	0.49	0	1
Remote work (DUM, wider definition, 2021-1)	5860	0.53	0.50	0	1
# Suppliers	6123	32.11	106.98	1	3488
# Customers	6123	48.33	199.37	1	11437
# Employees	6116	238.12	1134.46	3	40400
Using English (for intra-firm communication, DUM)	6020	0.10	0.30	0	1
Collecting data (through daily business, DUM)	6044	0.24	0.43	0	1
Decision based on data (DUM)	6078	0.44	0.50	0	1
Using cloud computing (DUM)	6063	0.05	0.21	0	1
Having an establishment (DUM)	6123	0.71	0.45	0	1
Having a plant (DUM)	6123	0.73	0.44	0	1
# Establishments	6088	5.54	16.14	0	584
# Plants	6089	1.56	1.97	0	48
Male CEO (DUM)	6063	0.98	0.15	0	1
College-educated CEO (DUM)	4776	0.85	0.35	0	1
Age of CEO	5186	61.32	9.71	29	97
Age of firm	6123	52.69	19.77	1	127
Firms in deficit (DUM)	5112	0.11	0.31	0	1

Notes: Variables labelled with DUM are dummy variables.

Table 2 Baseline regression results

	(1)	(2)	(3)	(4)
	2019-12	2020-4	2020-9	2021-1
ln (#Suppliers)	0.005*	0.072***	0.051***	0.078***
	(0.003)	(0.013)	(0.011)	(0.011)
ln (#Customers)	–0.001	–0.030***	–0.011	–0.017**
	(0.002)	(0.008)	(0.007)	(0.008)
ln (#Employees)	0.014***	0.061***	0.074***	0.062***
	(0.005)	(0.013)	(0.011)	(0.012)
Using English	0.027***	0.145***	0.136***	0.161***
	(0.009)	(0.025)	(0.024)	(0.012)
Collecting data	0.000	0.097***	0.056***	0.079***
	(0.004)	(0.017)	(0.015)	(0.016)
Data-based decision	0.003	0.032**	0.044***	0.040***
	(0.003)	(0.013)	(0.012)	(0.013)
Cloud computing	0.028*	0.091***	0.133***	0.074**
	(0.015)	(0.033)	(0.031)	(0.031)
Having an establishment	0.006	0.078***	0.030**	0.053***
	(0.004)	(0.015)	(0.013)	(0.014)
Having an Estab. × ln (#Estab.)	–0.003	0.001	–0.023***	–0.014
	(0.003)	(0.009)	(0.008)	(0.009)
Having a plant	–0.012**	–0.108***	–0.081***	–0.119***
	(0.006)	(0.025)	(0.020)	(0.023)
Having a plant × ln (#Plants)	0.000	–0.054***	–0.032***	–0.038***
	(0.005)	(0.013)	(0.010)	(0.012)
Male CEO	0.010***	0.129***	0.085***	0.091**
	(0.004)	(0.047)	(0.035)	(0.044)
College-educated CEO	0.004	0.005	0.018	0.028*
	(0.004)	(0.017)	(0.013)	(0.016)
Age of CEO	–0.017	–0.163**	–0.145***	–0.163***
	(0.015)	(0.064)	(0.051)	(0.059)
Age of firm	–0.005	–0.082**	–0.078**	–0.105***
	(0.012)	(0.038)	(0.035)	(0.036)
Deficit	–0.003	–0.037**	–0.018	–0.013
	(0.004)	(0.019)	(0.015)	(0.018)

Sector FEs	Yes	Yes	Yes	Yes
Prefecture FEs	Yes	Yes	Yes	Yes
# Obs.	3767	3661	3706	3668
R^2	0.049	0.305	0.262	0.327

Notes: The dependent variables are dummy variables that take the value of one if the firm adopted remote work. Robust standard errors are in parentheses. Statistical significance is denoted by asterisks (*** 1%, ** 5%, and * 10%). This note applies to all the following tables unless otherwise noticed.

Table 3 Regression results from a larger sample

	(1)	(2)	(3)	(4)
	2019-12	2020-4	2020-9	2021-1
ln (#Suppliers)	–0.001	0.040***	0.022***	0.044***
	(0.003)	(0.009)	(0.008)	(0.009)
ln (#Customers)	0.000	–0.013**	–0.012**	–0.014**
	(0.002)	(0.006)	(0.005)	(0.006)
ln (#Employees)	0.020***	0.084***	0.095***	0.088***
	(0.004)	(0.008)	(0.008)	(0.008)
Sector FEs	Yes	Yes	Yes	Yes
Prefecture FEs	Yes	Yes	Yes	Yes
# Obs.	6019	5830	5907	5853
R^2	0.034	0.254	0.215	0.274

Notes: The only firm-level control variable included in the regressions shown in this table is the number of employees.

Table 4 Robustness check results

(a) Logit estimation

	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.427	0.474***	0.410***	0.567***
	(0.288)	(0.089)	(0.105)	(0.094)
ln (#Customers)	–0.195	–0.201***	–0.118*	–0.129**
	(0.196)	(0.061)	(0.071)	(0.063)
# Obs.	2150	3626	3427	3527
Pseudo R^2	0.202	0.286	0.279	0.315

(b) Weighted regression

	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.000	0.053***	0.029**	0.064***
	(0.003)	(0.017)	(0.014)	(0.017)
ln (#Customers)	–0.003	–0.026**	–0.007	–0.013
	(0.002)	(0.013)	(0.011)	(0.013)
# Obs.	3765	3659	3704	3666
R^2	0.060	0.417	0.305	0.402

(c) Manufacturing firms

	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.006	0.064***	0.054***	0.062***
	(0.004)	(0.016)	(0.014)	(0.015)
ln (#Customers)	0.000	–0.000	–0.003	0.011
	(0.003)	(0.010)	(0.009)	(0.010)
# Obs.	2461	2375	2410	2381
R^2	0.068	0.322	0.276	0.331

Notes: The same set of firm-level control variables and sector- as well as prefecture-fixed effects as in the baseline regression are included in all cases. Wholesalers are excluded from the panel (c).

Table 5 Robustness checks with additional controls

(a) Locations of plants/establishments

	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.005*	0.072***	0.051***	0.077***
	(0.003)	(0.013)	(0.011)	(0.011)
ln (#Customers)	–0.001	–0.029***	–0.011	–0.017**
	(0.002)	(0.008)	(0.007)	(0.008)
# Obs.	3767	3661	3706	3668
R^2	0.049	0.305	0.262	0.327

(b) Intra-industry transactions

	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.006*	0.074***	0.050***	0.075***
	(0.003)	(0.013)	(0.011)	(0.012)
Supplier in the same sector	–0.003	–0.019	0.010	0.006
	(0.004)	(0.016)	(0.013)	(0.015)
ln (#Customers)	–0.000	–0.029***	–0.012*	–0.020***
	(0.002)	(0.009)	(0.007)	(0.008)
Customer in the same sector	–0.004	0.004	0.014	0.038***
	(0.004)	(0.015)	(0.013)	(0.014)
# Obs.	3767	3661	3706	3668
R^2	0.049	0.305	0.262	0.328

(c) Second-tier transaction partners

	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.006*	0.070***	0.047***	0.077***
	(0.004)	(0.014)	(0.012)	(0.013)
ln (#Suppliers' suppliers)	–0.002	–0.004	0.001	–0.004
	(0.002)	(0.006)	(0.005)	(0.006)
ln (#Customers)	–0.002	–0.039***	–0.018**	–0.026***
	(0.002)	(0.009)	(0.007)	(0.008)
ln (#Customers' customers)	0.003*	0.015***	0.012***	0.015***
	(0.001)	(0.005)	(0.004)	(0.005)
# Obs.	3762	3656	3701	3663
R^2	0.050	0.307	0.263	0.329

Notes: The same set of firm-level control variables and sector- as well as prefecture-fixed effects as in the baseline regression are included in all cases. The panel (a) adds the dummy variable taking value of one if the firm has a plant or establishment in prefectures under the state of emergency in January 2021.

Table 6 Other robustness check results

(a) Wider definition of remote work dummy

Dependent var. = Remote work DUM (wider definition)	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	–0.001	0.056***	0.049***	0.049***
	(0.008)	(0.012)	(0.013)	(0.013)
ln (#Customers)	–0.004	–0.019*	–0.025***	–0.017*
	(0.005)	(0.009)	(0.009)	(0.009)
# Obs.	3767	3661	3706	3668
R^2	0.101	0.292	0.241	0.286

(b) Ordered logit

Dependent var. = Extent of remote work adoption (4-step ordering)	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	–0.017	0.420***	0.336***	0.406***
	(0.115)	(0.064)	(0.069)	(0.065)
ln (#Customers)	–0.073	–0.137***	–0.123***	–0.105**
	(0.080)	(0.046)	(0.046)	(0.045)
# Obs.	3767	3661	3706	3668
Pseudo R^2	0.146	0.191	0.163	0.194

(c) Trimming top 1% firms

Dependent var. = Remote work DUM	(1) 2019-12	(2) 2020-4	(3) 2020-9	(4) 2021-1
ln (#Suppliers)	0.003	0.070***	0.047***	0.074***
	(0.003)	(0.013)	(0.011)	(0.012)
ln (#Customers)	–0.002	–0.026***	–0.010	–0.015**
	(0.002)	(0.009)	(0.007)	(0.008)
# Obs.	3695	3588	3634	3596
R^2	0.027	0.294	0.233	0.310

Notes: The same set of firm-level control variables and sector- as well as prefecture-fixed effects as in the baseline regression are included in all cases.

Appendix

Table A1 List of sectors

Manufacturing sectors	Wholesale sectors
Manufacture of food	Wholesale trade, general merchandise
Manufacture of beverage, tobacco and feed	Wholesale, textile and apparel
Manufacture of textile products	Wholesale, food and beverages
Manufacture of lumber and wood products, except furniture	Wholesale, building materials
Manufacture of furniture and fixtures	Wholesale, machinery and equipment
Manufacture of pulp, paper and paper products	Wholesale, other products
Printing and allied industries	
Manufacture of chemical and allied products	
Manufacture of petroleum and coal products	
Manufacture of plastic products, except otherwise classified	
Manufacture of rubber products	
Manufacture of leather tanning, leather products and fur skins	
Manufacture of ceramic, stone and clay products	
Manufacture of iron and steel	
Manufacture of non-ferrous metals and products	
Manufacture of fabricated metal products	
Manufacture of general-purpose machinery	
Manufacture of production machinery	
Manufacture of business-oriented machinery	
Manufacture of electronic parts, devices and electronic circuits	
Manufacture of electronical machinery, equipment and supplies	
Manufacture of information and communication electronics equipment	
Manufacture of transportation equipment	
Miscellaneous manufacturing industries	

Table A2 Summary statistics for the regression sample

	Count	Mean	S.D.	Min	Max
Remote work (DUM, 2019-12, before the pandemic)	3606	0.01	0.11	0	1
Remote work (DUM, 2020-4, 1st state of emergency)	3606	0.27	0.44	0	1
Remote work (DUM, 2020-9, emergency lifted)	3606	0.16	0.36	0	1
Remote work (DUM, 2021-1, 2nd state of emergency)	3606	0.23	0.42	0	1
Remote work (DUM, wider definition, 2019-12)	3606	0.07	0.26	0	1
Remote work (DUM, wider definition, 2020-4)	3606	0.64	0.48	0	1
Remote work (DUM, wider definition, 2020-9)	3606	0.41	0.49	0	1
Remote work (DUM, wider definition, 2021-1)	3606	0.55	0.50	0	1
# Suppliers	3606	35.97	116.25	1	3488
# Customers	3606	52.47	109.09	1	2100
# Employees	3606	249.31	1195.73	3	35203
Using English (for intra-firm communication, DUM)	3606	0.10	0.30	0	1
Collecting Data (DUM)	3606	0.23	0.42	0	1
Decision based on data (DUM)	3606	0.43	0.49	0	1
Cloud computing (DUM)	3606	0.05	0.21	0	1
Having an establishment (DUM)	3606	0.76	0.43	0	1
Having a plant (DUM)	3606	0.72	0.45	0	1
# Establishments	3606	5.98	18.42	0	584
# Plants	3606	1.62	2.03	0	48
Male CEO (DUM)	3606	0.99	0.12	0	1
College-educated CEO (DUM)	3606	0.85	0.35	0	1
Age of CEO	3606	61.40	9.75	31	96
Age of firm	3606	55.49	18.97	2	127
Firms in deficit (DUM)	3606	0.11	0.31	0	1

Notes: This table summarizes basic statistics of the limited sample used for regressions.