RIETI Discussion Paper Series 24-E-069

Aging Farmers and the Role of Community in Adaptation to Extreme Temperature Effects on Crop Yields

KO, Yi-Chun
Asian Growth Research Institute

UCHIDA, Shinsuke
Nagoya City University

HIBIKI, Akira
RIETI

RIETI
Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
https://www.rieti.go.jp/en/

RIETI Discussion Paper Series 24-E-069
September 2024

Aging Farmers and the Role of Community in Adaptation to Extreme Temperature Effects on Crop Yields[#]

Yi-Chun Ko
Asian Growth Research Institute
Shinsuke Uchida
Nagoya City University
Akira Hibiki
Tohoku University and Research Institute of Economy, Trade and Industry

Abstract

This study explores the mechanisms underlying farmers in adapting to climate change, with a focus on the effect of farmers' age on the relationship between temperatures and crop yields. Using municipality–level data on Japanese rice production between 2001–2018, we find a nonlinear (inverted U–shaped) age effect on the temperature–yield relationship. Farmers in their late 50s exhibit the highest resilience to extreme temperatures, experiencing minimal yield loss, while farmers above and below this age threshold suffer more from extreme temperatures. We also find that active participation of local communities can help retiring and inexperienced farmers mitigate the negative temperature effects.

Keywords: Age, Farmers' adaptation, Climate change, Crops yields, Extreme temperatures, Local community, Rice

JEL classification: Q10, Q51, Q54

[#] This study is conducted as a part of a research project undertaken at the Research Institute of Economy, Trade and Industry (RIETI). This study is also supported by the Environment Research and Technology Development Fund (JPMEERF20S11821) of the Environmental Restoration and Conservation Agency of Japan.
The author is grateful for helpful comments and suggestions by Discussion Paper seminar participants at RIETI.

1. Introduction

Population aging in mature societies shows no signs of stopping. The share of older cohorts in the population continues to increase in most OECD countries (Daniele, et al. 2020). Japan is one of the fastest aging societies around the world, with the aging population rate (proportion of people aged 65 and older) of nearly 30 percent as of 2021. Agricultural sector has led this trend to another level. The aging rate of rice farmers has reached over 70 percent according to the 2020 Agricultural Census.

Such abnormal aging of farmers can make them susceptible to extreme temperatures under the rapid progression of global warming in recent years. Heat–oriented reductions in crop yields and quality are reported worldwide (e.g., Schlenker and Roberts 2009; Burke and Emerick 2016; Chen et al. 2016; Kawasaki and Uchida 2016; Aragón et al. 2021). To mitigate the crop damage, active introduction of adaptive technologies has been encouraged by governments and local authorities, such as introduction of heat-resistant varieties, crop conversion, changes in planting seasons, and production environment management using ICT technologies. Whereas many adaptive technologies are available to farmers, their adoption in the field depends on their management skills and incentives.

Generally, as age increases, physical and cognitive abilities decline, making it difficult to adapt to new environmental changes (Barnes et al. 2019; Shang et al. 2021). Elderly farmers approaching retirement have little incentive to invest in costly new technologies. If there is no successor, this incentive further weakens. Consequently, the decline in physical and cognitive functions and the lack of investment incentives lead to a decrease in the ability to adapt to warming temperatures.[1] In contrast, aging of young farmers can initially have a positive impact on production, as farmers accumulate valuable experiences and knowledge through learning–by–doing.[2] This can enhance the ability to adapt to warming temperatures.

We incorporate this inverted U–shaped aging–production relationship to the context of crop response function to extreme temperatures.[3] Most crops such as corn, soybeans and rice have certain threshold of temperatures for growing, beyond which yields significantly decline, shaping the inverted U–shaped temperature–yield relationship (Schlenker and Roberts 2009; Burke and Emerick 2016; Kawasaki and Uchida 2016). We submit that the degree to which yields decline at extreme temperatures can be explained by farmer's age. That is, aging at an early stage can mitigate the negative temperature effects on crop yields, while aging at a later stage causes the opposite result.

Factors contributing to the decline in the adaptive capacity are not limited to the aging of individual farmers. Matured communities that sometimes fall into dysfunction also become vulnerable to external shocks. In healthy farm communities, active participation of local communities can facilitate farmers' access to valuable social support networks, information resources, learning opportunities, and market insights. These factors collectively serve as strong motivators, encouraging

---

[1] Negative aging effects are also highlighted in the economic literature on labor productivity (Maestas et al. 2016; Eggertson et al. 2019; Lee and Shin 2019) and total factor productivity (Park et al. 2021). Park et al. (2021) have shown that total factor productivity (based on an age category of 30–50 years old) declines as the percentage of workers in their 60s increases.

[2] Tamura et al. (2021) found the positive correlation between farmers' experience and knowledge of adaptation measures and their adaptive behavior.

[3] Such a concave relationship between age and crop productivity has been observed for decades (Tauer 1984; 2017).

farmers to adapt and modernize their farming practices as well as manage common properties such as waterway maintenance for irrigation. The findings of several studies indicate that this engagement significantly enhances farmers' adaptability (Uddin et al. 2014; Rondhi et al. 2019). This suggests active participation of local communities can buffer the negative effects of aging on crop yields.

In sum, this study explores to what degree farmers' age and local community engagement affect the negative impact of extreme temperatures on crop yields.[4] Revealing the mechanisms of adaptation to temperature–induced productivity changes becomes a critical consideration for policymakers, particularly in the aging society. We use Japanese rice paddy production for the empirical analysis. Rice is widely cultivated throughout Japan and also is highly susceptible to extreme temperatures. As mentioned earlier, the aging rate of Japanese rice farmers is markedly high overall, but it varies across Japan over time. Spatial and temporal heterogeneities of farmers' age as well as local community engagement and temperatures allow us to examine whether aging and local community engagement have a nonnegligible impact on crop production under extreme temperatures in recent years.

We employ a rich dataset at the municipality level, covering the years 2001 to 2018, which encompasses specific information on rice yields and farm characteristics across Japanese municipalities. This dataset is combined with daily records of average temperatures, precipitation, and global solar radiation for all Japanese municipalities over the same period. These precise and extensive weather data enable us to accurately estimate the nonlinear effects of the cumulative heat, precipitation, and radiation experienced by rice throughout its respective growing season.

We confirm that the farmers' age can partly explain the inverted U–shaped temperature–yield relationship. Farmers in their late 50s demonstrate the highest resilience to extreme temperatures, experiencing minimal yield loss, while those below/above this age threshold suffer more declines due to negative temperature effects. These findings hold across various specifications. They suggest that aging acts as a barrier to adaptation to extreme temperatures. In contrast, the active involvement of local communities can serve as effective strategies for elderly and inexperienced farmers to mitigate yield losses caused by extreme temperatures.

The remainder of this paper is organized as follows: Section 2 describes the background of Japanese rice production and the aging population; Section 3 discusses the empirical methodology and data; Section 4 represents estimation results; and Section 5 concludes.

2. Background: Rice Production in the Aging Community in Japan

Japan's aging population shows no signs of stopping. As of 2021, the aging population rate (proportion of people aged 65 and older) has risen to nearly 30 percent. This is one of the largest aging societies around the world. Agricultural sector has led this trend to another level. The aging rate of rice farmers

[4] Many studied the determinants of adaptation to climate change. Kgosikoma et al. (2018) found that farmers' gender, age, household size, poverty, and knowledge about climate change significantly influence their adaptation. Apart from the above, level of education, access to extension and credit, and membership to farmers' groups are also found to determine farmers' choices (Deressa et al. 2009; Shikuku et al 2017). However, it is unclear whether such determinants help farmers mitigate the negative impacts of climate change.

has reached over 70 percent according to the 2020 Agricultural Census.[5] This stems from the long–standing control policy of rice production by the Japanese government. The policy had prevented efficient large-scale firm farms from entry as well as subsidized inefficient rice farmers for long-term survival.[6]

Since the early 2000s, hot temperatures have been observed more frequently during the rice growing season in Japan, resulting in adverse effects on rice production (Kawatsu et al. 2007; Okada et al. 2011; Kawasaki and Uchida 2016). Figure 1 presents the change in temperature over the period 2001–2018. We denote the difference in average daily mean temperature during the growing season between the 2001–2005 and 2014–2018 periods. The temperature has increased in more than 75 percent of the municipalities over this 18–year span, with a maximum recorded increase of 1 ºC. Figure 2 displays the evolution of rice yields over the same timeframe. Rice yields also have exhibited an overall increase in most of the municipalities, with much heterogeneity from colder north to warmer south. Municipalities in southern Japan have experienced less improvement in rice yields.

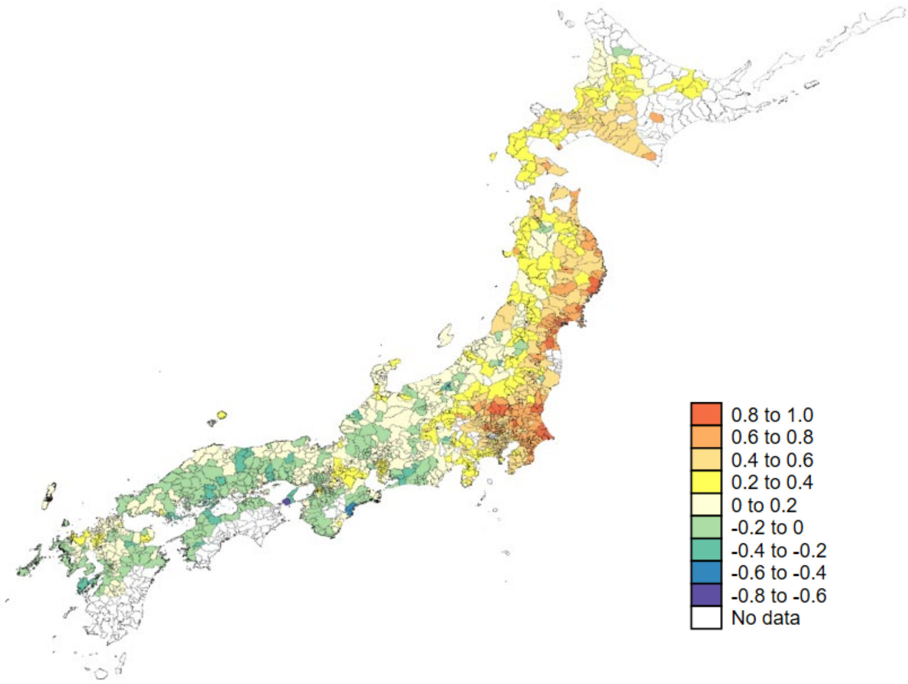


Figure 1: Change in temperature (°c) over 2001–2018

Notes: Temperature is measured over the rice–growing season in Japan (Apr. to Oct.) in each targeted municipality.

[5] Rice farmers exhibit the highest aging rate when compared to farmers of other crops. Figures A2–3 illustrate the age structure of core persons engaged primarily in farming for the years 2000 and 2015, respectively. In both census years, rice farming consistently stands out with the highest percentage of farmers aged 65 years and older. Particularly in 2015, this demographic represented a striking 77% of rice farmers (compared to 65% in 2000).

[6] As a result, the Japanese rice production sector stays at the significantly low rate of new entrants. Figure A4 presents the share of new–entry farmers across different farm types in recent years. To determine the barriers to entry in each sector, we calculate this share by dividing the number of new–entry farmers by the total number of households associated with each product. The findings reveal a substantial disparity. Approximately 0.8 out of every 1,000 rice farm households are new entrants to rice production. In contrast, the number of new vegetable farms is about 15 out of 1000. Much less dynamism in the rice farming sector helps deal with the issue of endogeneity regarding farmer’s age in empirical identification in the following section.

Information is not provided for white–colored municipalities, which are not targeted in our study because of no rice production or double cropping. See Figure 5 for more detailed information.

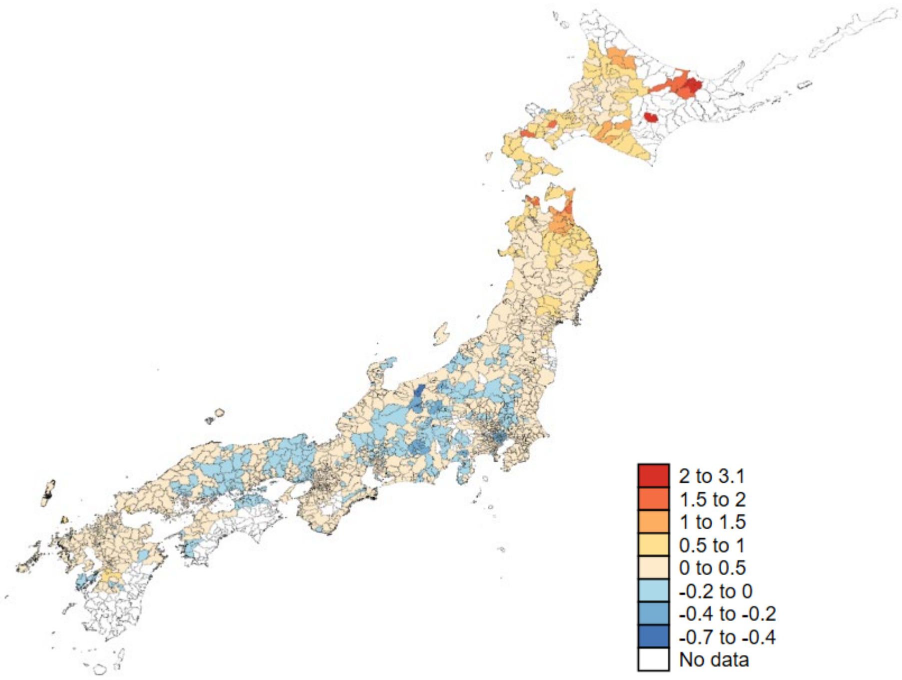


Figure 2: Change in rice yield (t/ha) over 2001–2018

Notes: Information is not provided for white–colored municipalities. See Figure 5 for more detailed information.

Rice yield heterogeneity across Japan seems also associated with aging in rice farmers. Figure 3 displays the distribution of average age of farmers in our sample municipalities.[7] We observe that farmers in southern Japan are older than farmers in northern Japan, positing negative association of age and rice yields. Figure 4 provides additional insights about the negative aging effect on rice yields and the role of local community. By plotting municipality average rice yields and farmers' age over the period, we observe the inverted U–shaped relationship between age and rice yields. This is consistent with the previous studies (e.g., Tauer 2017). We also see that such a relationship is clearer in the municipalities where local community participation is lower. In another words, more active participation of local communities seems to mitigate the negative aging effect. Combining with the other negative relationship between temperatures and yields may indicate a limit of capacity for older farmers to adapt to extreme temperatures, while the limit can be remediated by the power of local community engagement.

[7] We have the age data of all farmers, which can represent age of rice farmers because more than 70 percent of farmers produce rice all over Japan.

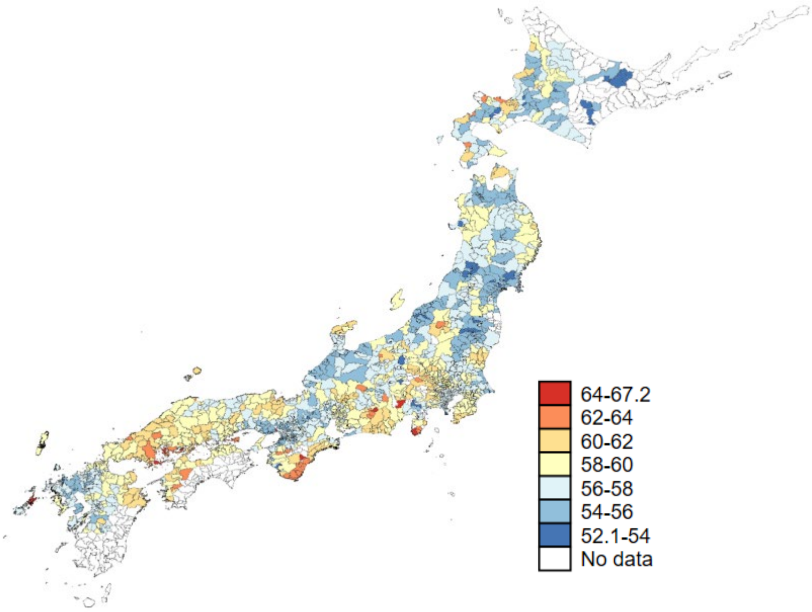


Figure 3: Municipality-average age (years old) over 2000–2015

Notes: Information is not provided for white–colored municipalities. See Figure 5 for more detailed information.

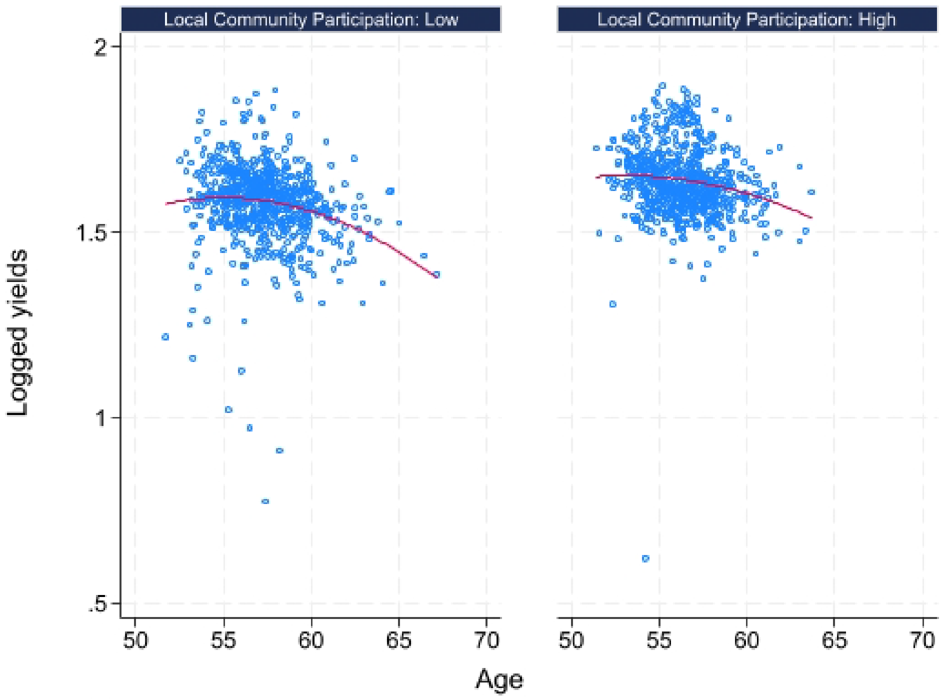


Figure 4: Municipality–average rice yields and age (years old) over 2000–2015

3. Methodology and Data

3.1 Methodology

To estimate the impact of farmers' age on the temperature–yield relationship, our baseline specification uses temperature bins as a measure of heat. We employ the following empirical model:

$$(1) \quad \ln(\mathrm{Y}_{it}) = \sum_{n=1}^{N} \alpha_n T_{nit} + \sum_{n=1}^{N} \beta_n (T_{nit} \times \mathrm{X}_{it}) + \delta \mathrm{X}_{it} + \mathbf{Z}_{it}\gamma + \mathrm{C}_i + \lambda_{pt} + \varepsilon_{it},$$

where Y_{it} is the rice yield in the municipality *i* in year *t*, T_{nit} denotes the number of days where the daily mean temperature is in the n^{th} of the N bins. X_{it} represents farmers' age to measure the adaptation capability, a vector $\mathbf{Z}_{it}$ includes the other characteristics of farmers such as farm size and the other weather variables such as the sum of daily precipitation and global solar radiation over the growing season, C_i represents the municipality fixed effects, λ_{pt} represents the prefecture-by-year fixed effects which controls for the technological change and policy interventions, and ε_{it} indicates the error term.

We further explore the extent to which active local community participation can effectively mitigate the negative effects of age on the temperature–yield relationship. We separate data to two subsets, high participation group and low participation group, using local community participation rate and estimate the same equations as equation (1) for each group.

3.2 Data

The agriculture data used in this study is obtained from Ministry of Agriculture, Forestry and Fisheries (MAFF).[8] We have the annual data of rice–planted area and rice production from 1993 to 2018 at the municipality (city) level.[9] Based on the rice–planted area and rice production data, we calculate the rice yield in each year for each municipality. Farmer characteristic data (farmer age, etc.) and participation of local community data are obtained from quinquennial Agricultural Censuses in years 2000 to 2015.[10] Combining these data allows us to analyze the panel data of 2001 to 2018 because the Census data collected as of the end of the year.

The weather data applied in this study is acquired from Agro–Meteorological Grid Square Data, NARO.[11] They provide 14 types of daily meteorological weather data by 1km square (third–order grid unit) covering the entirety of Japan. Among these variables, we focus on three key factors that significantly influence rice growth: daily mean temperature, daily precipitation, and daily global solar radiation. To align the grid–level data with municipality–level data, we utilize a list of mesh codes by

---

[8] See Ministry of Agriculture, Forestry and Fisheries for more detailed information: https://www.maff.go.jp/.

[9] See MAFF Statistics Sakumotu Tokei Sakkyou Kome for more detailed information of data: https://www.maff.go.jp/j/tokei/kouhyou/sakumotu/sakkyou_kome/index.html.

[10] See MAFF Agriculture and Forestry Census for more detailed information: https://www.maff.go.jp/j/tokei/census/afc/about/setumei.html.

[11] See Agro–Meteorological Grid Square Data, NARO for more detailed information: https://amu.rd.naro.go.jp/wiki_open/doku.php?id=start.

municipality provided by the Statistics Bureau of Japan, facilitating the integration of these datasets for our analysis.

We specifically focus on municipalities that engage in single cropping, continuously producing rice.[12] Figure 5 presents the rice growing status of each municipality in Japan, revealing that single cropping municipalities make up a substantial majority, accounting for 90.2% of all rice producing municipalities. The remaining 9.8% engage in double cropping. Among the single cropping municipalities, an overwhelming 92% consistently grow rice. Only 5.4% of municipalities never produce rice, with 1.4%/0.2% having initially produced/not produced rice but eventually discontinued/initiated rice cultivation. Additionally, 1% falls into other categories. This distribution suggests that selection bias is unlikely to significantly impact our analysis. We concentrate on the weather data during the rice growing season from April to October, as this period directly affects rice production.

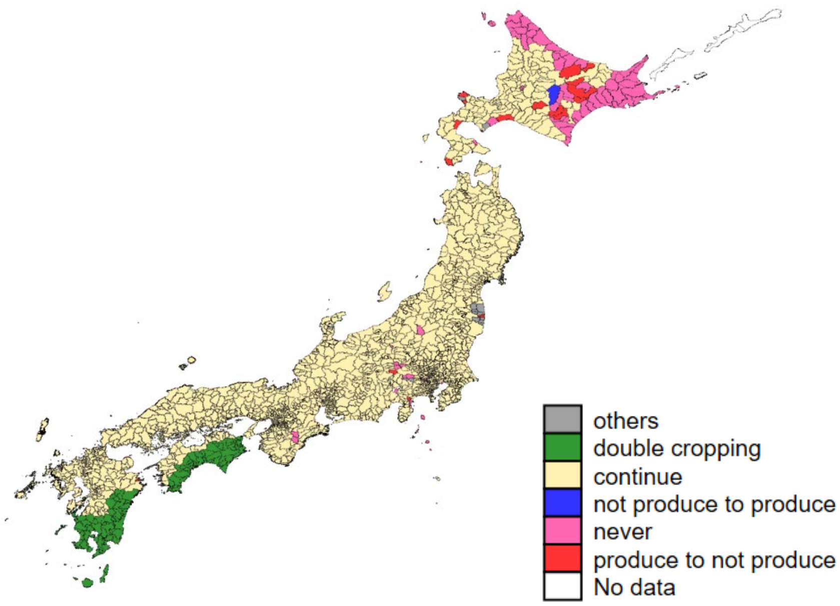


Figure 5: Rice growing status of each municipality in Japan over 2001–2018

Notes: Pink indicates the municipalities which never produce rice. Yellow presents the municipalities which continuously grow rice. Red (or Blue) color shows the municipalities which originally produced (or did not produce) rice but eventually quit (or start) growing rice. Green gives the double–cropping areas, which is excluded in our study.

Table 1 presents the of the main variables in our study. The average rice yields among the study municipalities from 2001 to 2018 is 5 t/ha. In fact, municipalities with rice yields below 1 t/ha are concentrated in Hokkaido and Tohoku regions (northern and relatively colder regions of Japan) in 2003 (severe cool summer damage years). The average number of days during the rice growing season (214 days) experiencing daily mean temperature below 15°C totals 56 days, ranging between 24 and

[12] In Japan, 42 out of 47 prefectures conduct single cropping and the rest of 5 prefectures (Tokushima, Kochi, Miyazaki, Kagoshima, and Okinawa) perform double cropping for paddy rice. Those 5 prefectures are excluded in this research.

27°C is 29 days, and above 27°C amounts to 15 days. Figure 6 illustrates the average distribution of daily mean temperature over six temperature bins (<15, 15–18, 18–21, 21–24, 24–27, >27°C). The average sum of daily precipitation and daily global solar radiation during the growing season are 1217 mm and 3315 MJ/m2, respectively. The average age of farmers is 57 years old, as shown in Figure 3, which displays the distribution of average age among the study municipalities and reveals regional differences in farmer demographics.

Table 1—Summary statistics ($N = 24606$)

	Mean	SD	Min	Max
Rice yield (t/ha)	5.07	0.57	0.17	7.00
<15 °C (days)	56.43	33.85	3	192
15–18 °C (days)	36.31	8.11	11	69
18–21 °C (days)	41.04	8.83	1	74
21–24 °C (days)	36.66	12.46	0	79
24–27 °C (days)	28.96	17.40	0	79
>27 °C (days)	14.61	16.95	0	70
Precipitation (mm)	1216.76	396.83	373.72	4216.56
Global Solar Radiation (MJ/m^2)	3314.80	229.15	2505.86	4785.79
Age (years old)	57.39	2.95	48.10	68.70

Notes: Only Apr. to Oct. data is used for weather variables.

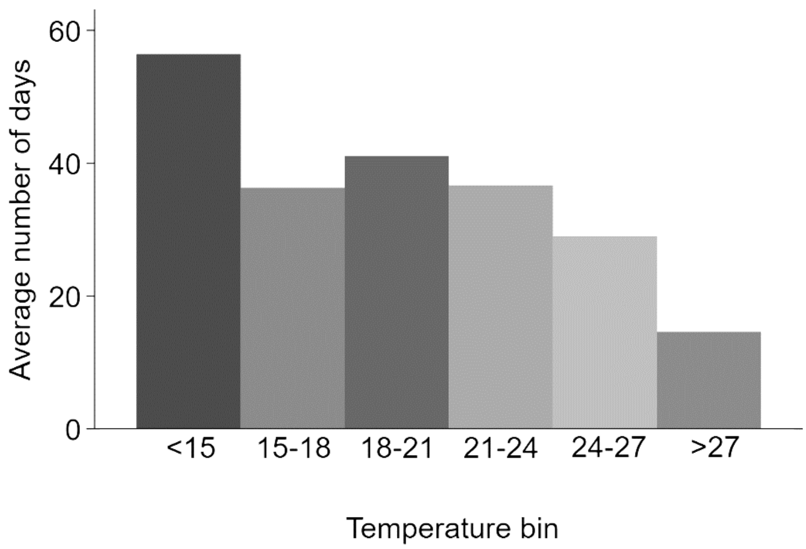


Figure 6: Distribution of daily mean temperature over 2001–2018

Notes: The figure represents the average number of days per year during the rice growing season in each temperature bin (<15, 15–18, 18–21, 21–24, 24–27, >27°C).

4. Empirical Results

4.1 Yield–Temperature Response Function

Before presenting our regression results of the age effect on the temperature–yield relationship, we first examine the nonlinear temperature effects on rice yields with no cross terms. The estimation results are presented in Table 2. Columns 2–3 include additional control variables, as detailed in the data section. In Column 3, municipalities with a low percentage (below 5th percentile) of rice–farm households among all households at the census years. We choose the 21-24℃ bin as reference.[13]

All specifications deliver similar results for estimations with and without the inclusion of the other control variables. We find the negative response of rice yields to the temperature below and above the reference bin. Our preferred specification in Column (2) shows that exposure to an additional day below 15°C decreases rice yields by 0.20 percent, and an extra day above 27°C reduces rice yields by 0.08 percent.[14]

Figure 7 displays the yield–temperature response function in Column (2) with the 95 percent confidence intervals. The results indicate that rice productivity in Japan is particularly susceptible to cold temperatures, consistent with the finding of Kawasaki and Uchida (2016) at the prefecture-level analysis.[15]

Table 2—Results of the nonlinear temperature effects on rice yields

	(1)	(2)	(3)
<15°C	-0.0021**	-0.0020**	-0.0021**
	(0.0008)	(0.0008)	(0.0008)
15–18°C	-0.0003	-0.0002	-0.0002
	(0.0003)	(0.0003)	(0.0003)
18–21°C	0.0001	0.0001	0.0001
	(0.0002)	(0.0002)	(0.0002)
24–27°C	-0.0004	-0.0004*	-0.0004
	(0.0002)	(0.0002)	(0.0002)
>27°C	-0.0008**	-0.0008**	-0.0008**
	(0.0003)	(0.0003)	(0.0003)

[13] We follow the agronomy literature in choosing the 21-24℃ bin as reference. Morita (2005) finds that the rate of occurrence of white immature grains begins to rise when the average daily mean temperature for 20 days after heading exceeds 23°C to 24°C. The maximum grain weight was observed at 24°C in Wakamatsu et al. (2007) and 19°C to 25°C in Yoshida and Hara (1977).

[14] We also performed robustness check at different clustering (Appendix Figure A5) and with different temperature functions (Figure A6). Results are robust among them.

[15] Precipitation appears to have no significant impact on rice yields because the irrigation system is widely practiced for paddy rice production in Japan. Solar radiation shows weak evidence of its inverted U–shaped relationship with rice yields.

Precipitation (1000mm)	0.0284	0.0269	0.0269
	(0.0435)	(0.0423)	(0.0423)
Precipitation squared	-0.0066	-0.0061	-0.0060
	(0.0113)	(0.0109)	(0.0110)
Solar radiation (100 MJ/m^2)	0.0771*	0.0765*	0.0769*
	(0.0437)	(0.0431)	(0.0438)
Solar radiation squared	-0.0011*	-0.0011*	-0.0011
	(0.0006)	(0.0006)	(0.0006)
Municipality fixed effects	YES	YES	YES
Prefecture-by-year fixed effects	YES	YES	YES
Control variables	NO	YES	YES
Observation	24,606	24,606	23,366
Adj. R^2	0.767	0.767	0.769

Notes: Our sample consists of single cropping municipalities which continuously produce rice in 2001–2018. Standard errors clustered at the prefecture level are reported in parentheses. Regressions are weighted by the average rice planted area for the years 2001–2018. Column (3) excludes municipalities with a low percentage (below 5th percentile) of rice–farm households. ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively.

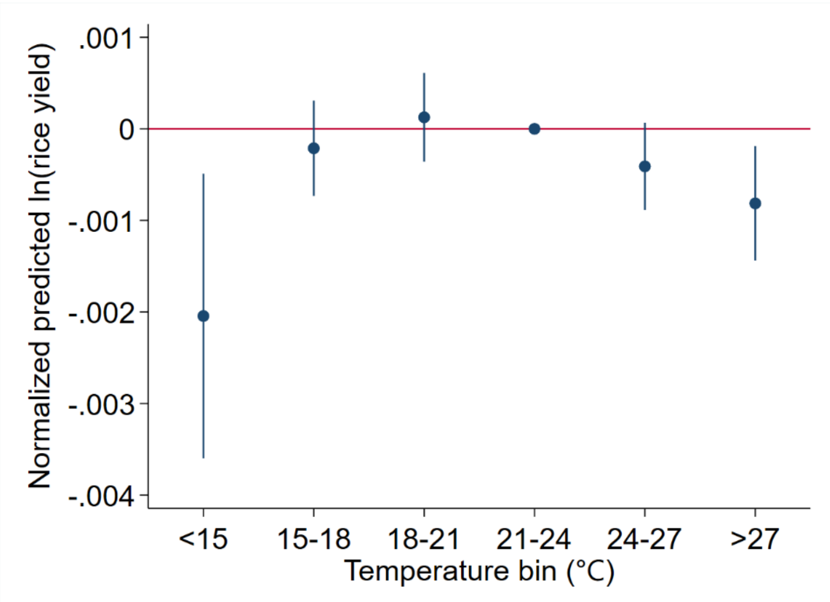


Figure 7: Relationship between temperature and rice yields

Notes: We plot point estimates in Column (2) of Table 2 where the vertical lines represent 95 percent confidence intervals.

4.2 Farmer Age and the Yield–Temperature Relationship

To mitigate the negative temperature effects on rice yields, farmers' adaptation is crucial. Aging farmers may face challenges in coping with abnormal temperature events due to reduced cognitive performance and physical ability, or a lack of incentives for investment in adaptation measures.

However, we assume that older farmers can partially offset the negative temperature impacts on yields due to their greater experience and beyond a certain threshold age is less of a factor in mitigating yield loss.[16] To capture this potential inverted U–shaped relationship between age and the impact of temperature on rice yields, our analysis includes cross–terms of bin variables with single and square terms of farmers' age.[17]

Our results in Table 3 indicate a significant inverted U–shaped relationship between farmers' age and the impact of extreme temperatures below 15°C and above 27°C. The threshold age, which minimizes the negative temperature impact, is found to be late 50s. Graphical illustration of estimation results in Table 3 for three age scenarios are presented in Figure 8. Farmers aged 60 demonstrate the highest resilience to extreme temperatures compared to those aged 50 and 70.

Below the threshold age, farmers' ability to adapt to extreme temperatures tends to improve with increasing age. Young farmers can accumulate valuable experiences and knowledge through learning–by–doing from daily production activities. This can enhance the ability to adapt to extreme temperatures.

Once farmers' age surpasses the threshold, their ability to adapt diminishes. This indicates that the positive aging effect of cumulative experiences and knowledge is overwhelmed by the negative aging effect. Generally, as age increases, physical and cognitive abilities decline, making it difficult to adapt to new environmental changes (Barnes et al. 2019; Shang et al. 2021). Also, old farmers are less aware of climate change (Tamura et al. 2021). Moreover, elderly farmers approaching retirement have little incentive to invest in costly new technologies. If there is no successor, this incentive further weakens. Consequently, the decline in physical and cognitive functions and the lack of investment incentives lead to a decrease in the ability to adapt to warming temperatures.

Table 3—Age effects on the rice yield response function to temperatures

	Single term	Cross term with age	Cross term with age squared
<15°C	-0.1524**	0.5066**	-0.4249**
	(0.0672)	(0.2273)	(0.1927)
15–18°C	-0.0780**	0.2727**	-0.2388**
	(0.0355)	(0.1203)	(0.1021)
18–21°C	-0.0525	0.1852	-0.1628
	(0.0411)	(0.1396)	(0.1185)
24–27°C	-0.1452*	0.4913*	-0.4147*

[16] Tauer (2017) finds that farmer productivity has a concave relationship with their age.

[17] Our results are robust when municipalities with a low percentage (below 5th percentile) of rice–farm households among all households at the census year are excluded (See Appendix Figure A7). Our results are also robust when we use the share of farmers in each age category instead of city-level average age (See Appendix Figure A8). Besides, we investigate whether age is endogenous because temperature-driven yield loss could cause the exit of inefficient old farmers from production and promotes the entry of efficient young farmers, so that the distribution of both age and yields changes simultaneously. In addition to the fact that continuers of rice production are relatively stable due to the long-standing control policy of rice production as delineated in Section 2, we find no relationship between extreme temperatures in past years and the present age (See Appendix Table A1).

	(0.0734)	(0.2515)	(0.2151)
>27°C	-0.1633**	0.5516**	-0.4655**
	(0.0737)	(0.2520)	(0.2148)

Notes: Estimation results from Equation (1). Our sample consists of single cropping municipalities which continuously produce rice in 2001–2018. The unit of age is 100 years old. Standard errors clustered at the prefecture level are reported in parentheses. Regressions are weighted by the 2001–2018 average rice planted area. ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively.

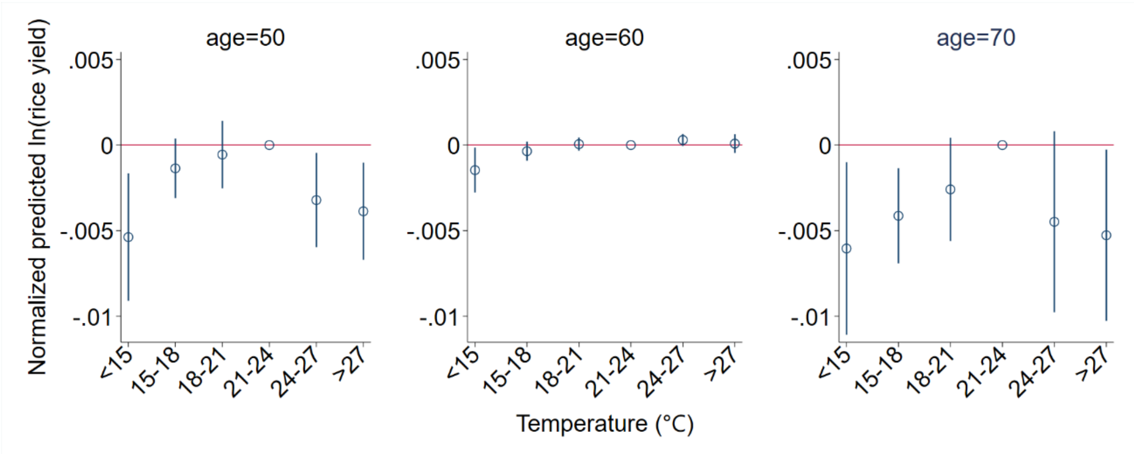


Figure 8: Relationship between age and temperature–rice yields

Notes: We plot the linear combination of point estimates of respective temperature bins in Table 3 with the vertical line of their 95 percent confidence intervals, when age is evaluated at 50, 60, and 70.

4.3 Effects of Local Community and Aging on the Temperature–Yield Relationship

To examine how active participation of local communities might moderate the negative age effect on the temperature–yield relationship, we categorize municipalities based on their average share of participation of local communities over the study period.[18] Specifically, we assign the municipalities into two groups: those with a higher share of involvement of local communities (above the 50th percentile) and those with a lower share of involvement of local communities (below the 50th percentile)[19]. We then analyze age effects using two separate sub datasets.

[18] The variable we use to represent participation of local communities is defined as participation in meetings regarding agricultural drainage channels, community common facilities, or agricultural production costs. All sets of results are very similar and are presented here with agricultural drainage channels in the main text and community common facilities and agricultural production in the Appendix Figures A9–A10.

[19] Higher temperatures may encourage the exit of farmers who do not prefer the participation of the local community, as these farmers don't receive the benefit of mitigating the yield loss due to high temperatures through the participation of the local community. Such exit may reduce the average yield loss in the community. If this is the case, the yield loss due to high temperature may be underestimated. To examine whether such a possibility occurs, we examine how temperature variables affect the assignment to two groups. As Table A2 in the appendix shows, we find no significant relationship between temperature variables and the participation variable. Therefore, the concern of biased estimates caused by such a

Figure 9 illustrates how the participation of local communities influences the age and temperature–yield relationship under the three age scenarios.[20] We rarely see the negative aging effects of farmers at age 60 who are resilient to extreme temperatures, regardless of local community involvement. In contrast, the negative age effects are magnified for farmers at ages 50 and 70, particularly at the lower level of local community involvement.

This indicates that active participation of local communities can serve as a compensating factor. By actively engaging with local communities, farmers gain access to innovative practices that enhance productivity, leading to increased yields and improved technical efficiency (Abdul-Rahaman and Abdulai 2018). This also emphasizes the crucial role of social capital through mutual assistance among farmers in the community by such as information sharing and co-management of common facilities, highlighting the significance of community support in fortifying agricultural resilience.[21]

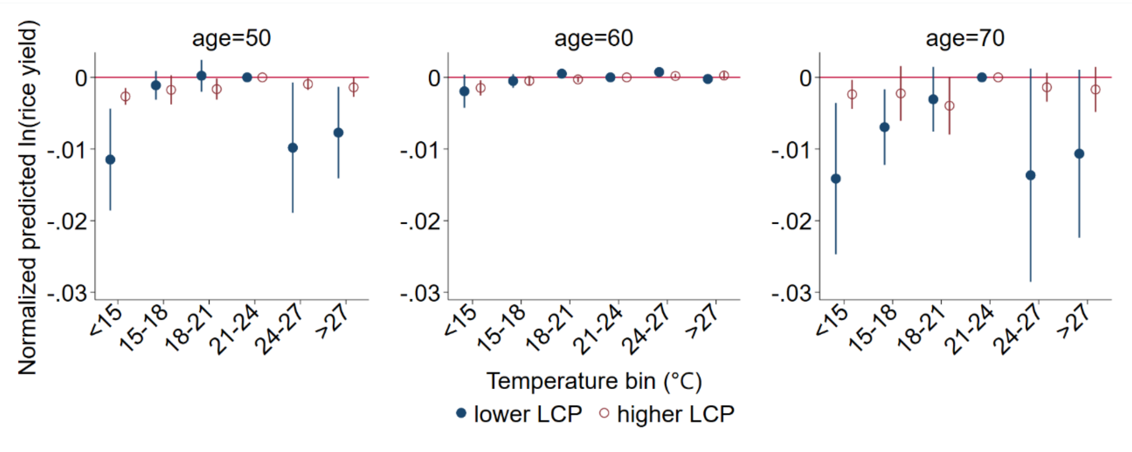


Figure 9: Relationship between age and temperature–rice yields
lower vs higher share of LCP municipalities

Notes: See Notes in Figure 8. LCP indicates local community participation.

5. Simulation of the Aging Effects

Figure 10 displays an additional box plot illustrating the trend in the average age of farmers within our sample municipalities. In the 2000 agricultural census, the average age stood at 54.8 years, but by 2015, it had notably risen to 60.2 years. This signifies an aging trend of approximately 6 years over

---

subgroup analysis is less likely to occur.

[20] Point estimate results are shown in the Appendix Table A3. The threshold age, which minimizes the negative temperature impact, consistently falls within the range of late 50s, aligning with our previous findings on age effects. We estimate the temperature effects at low and high participation of local communities and test the point estimates of the temperature effects, using the Bonferroni adjusted p-values, we cannot reject that the temperature effects in the two sub-datasets are the same. Results are available upon request.

[21] Our results are robust when we use the share of farmers in each age category instead of city-level average age (See Appendix Figures A11–A13).

the course of 15 years. If this trajectory persists, it is conceivable that the average age of farmers could approach nearly 70 years by 2035. Given this demographic shift, it becomes increasingly pertinent to explore how the aging of the agricultural sector may influence the relationship between temperature and crop yields.

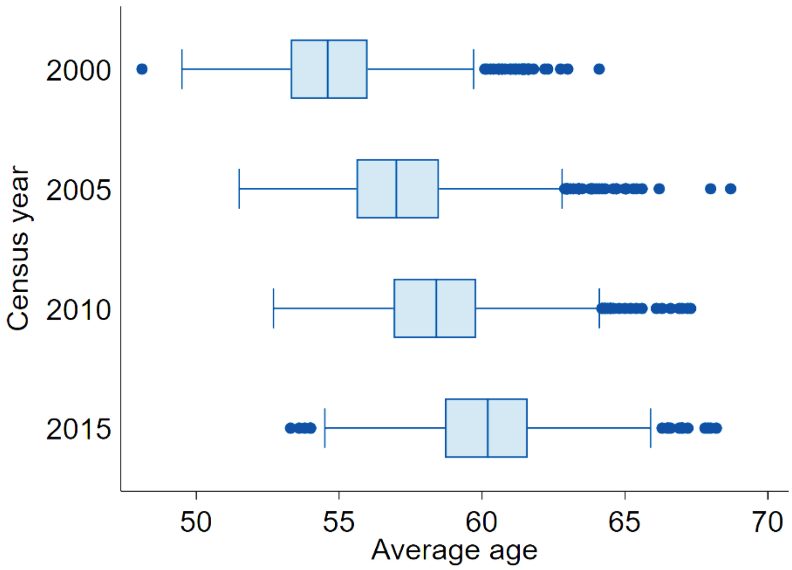


Figure 10: Box plot of average age trend of farmers

To evaluate the effect of aging in conjunction with temperature changes, we analyzed the following four scenarios:

(i) Percentage change in rice yields due to an increase in *colder* daily temperatures (<15, 15–18, 18–21°C) by 2°C under the current age.
(ii) Percentage change in rice yields due to an increase in *colder* daily temperatures by 2°C increase and an increase in farmers' age by 5 years.
(iii) Percentage change in rice yield due to an increase in *hot* daily temperatures (24–27, >27°C) by 2°C under the current age.
(iv) Percentage change in rice yield due to an increase in *hot* daily temperatures by 2°C and an increase in farmer's age by 5 years.

The average change in rice yields all over Japan in each scenario is summarized in Table 4. First, an increase in crop yields caused by colder temperature rise is higher under Scenario (ii) than (i) by 1.6% point (=5.76 – 4.14) on average, because the negative aging effects of extremely cold temperatures, which are larger in older farmers, are mitigated by warming. On the other hand, a decrease in crop yields caused by hotter temperature rise is higher under Scenario (iv) than (iii) by 0.1% point (= 0.96 – 0.87) on average, because the negative aging effects of extremely hot temperatures, which are larger in older farmers, are augmented by warming.

Table 4— Percentage change in rice yield for temperature rise and aging scenarios

Temperature bin	scenario: comparison with before temperature rise	Average yield change (%)
Colder bins	(i) Temperature rise under current farmer's age	4.14
below the reference	(ii) Temperature rise and 5-year age increase	5.76
Hotter bins	(iii) Temperature rise under current farmer's age	-0.87
above the reference	(iv) Temperature rise and 5-year age increase	-0.96

As shown in Table 4, the overall impact of temperature rise and aging appears to be positive on average for Japanese rice farming, since the negative impact of temperature rise in hotter temperatures is smaller than the positive impact of temperature rise in colder temperatures. However, the distributional effects of temperature rise and aging on yield changes is significant across regions.

Figure 11 depicts the difference in the impact of a 2°C increase in colder temperatures on rice yields between Scenarios (i) and (ii). Figure 12 depicts the difference in the impact of a 2°C increase in hotter temperatures on rice yields between Scenarios (iii) and (iv). In northern Japan, where the climate is relatively cooler and characterized by a higher frequency of low–temperature days, the positive impact of temperature rise in colder temperatures dominates the negative impact of temperature rise in hotter temperatures and thus the net effect of temperature rise is positive.

Conversely, in southern Japan, where the climate is relatively warmer and characterized by frequent high–temperature days, temperature rise is expected to result in a significant negative impact on yields, since the negative impact of an increase in hotter temperatures is larger. In addition, if aging occurs, the negative impact of an increase in hotter temperatures become larger, since farmers are old and thus less capable of adapting to extreme heat.

It is also noted in Figure 11 that the difference in the impact of a 2°C increase in colder temperatures on rice yields becomes negative in municipalities where farmers are relatively young as shown in Figure 3. Similarly, Figure 12 shows that the difference in the impact of a 2°C increase in hotter temperatures on rice yields becomes positive in relatively young municipalities. When the positive impact of aging on rice yields dominates the negative impact of a rise in hotter temperatures, aging can enhance the resilience to the temperature increase.

Policymakers should prioritize the consideration of regional and demographic heterogeneity when designing climate adaptation strategies. Tailoring support to address the specific impacts of temperature changes on different regions and age groups will be crucial for effectively managing the challenges faced by farmers.

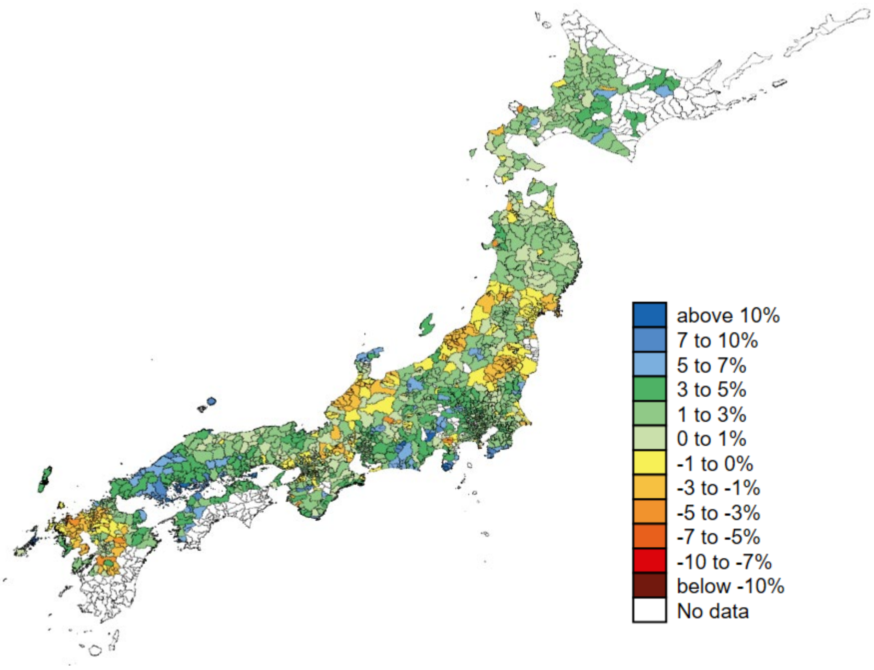


Figure 11: Difference in the percentage change in rice yields due to a 2°C increase in colder temperatures between Scenarios (i) and (ii)

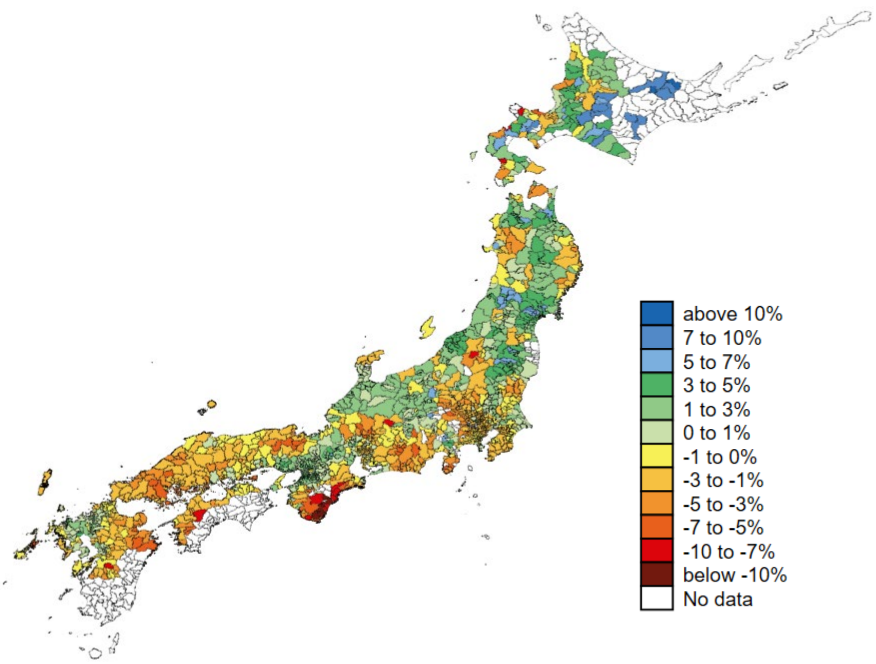


Figure 12: Difference in the percentage change in rice yields due to a 2°C increase in hotter temperatures between Scenarios (iii) and (iv)

6. Conclusion

Our study quantifies the nonlinear (inverted U–shaped) influence of farmer's age on the temperature–yield relationship. We also examine how the involvement of local communities can mitigate the negative age effect.

We find that age is a statistically significant factor to determine farmers' adaptation abilities. An estimated inverted U–shaped relationship between age and the temperature's impact on yields shows that farmers in their late 50s exhibiting the highest resilience to extreme temperatures. Below/Beyond this threshold age, farmers experience more significant yield losses due to negative temperature effects. We also find that the age effect is less pronounced in municipalities with a greater participation of local communities. This suggests that the active engagement of local communities can effectively mitigate yield losses for old and inexperienced farmers in the face of extreme temperatures.

These findings hold significant policy implications, especially in aging farming communities. Recent agricultural policies have emphasized structural transformations, such as attracting new entrants into farming and expanding large–scale agricultural enterprises. Despite these efforts, they have not yet succeeded in arresting the trend of farmer aging, indicating that substantial progress is still required. Concurrently, it is essential to implement support measures aimed at enhancing the adaptability of older farmers to the increasingly hot agricultural environment. Communication and knowledge spillover should emerge as key strategies to enhance adaptation capabilities. Providing both younger and older farmers with knowledge about weather and climate risks, as well as training in new agricultural technologies, can facilitate their adaptation. Extension services should play a prominent role in communicating with farmers but also in fostering and incentivizing active involvement of local communities. Engagement in the local community can promote knowledge sharing and collaboration among farmers, benefiting both older and inexperienced farmers. This community engagement can serve as a valuable platform for disseminating information on climate–resilient practices and enhancing the overall adaptive capacity of the farming population.

Aging of the farming population also occurs in other regions such as the United States and Europe. According to the US Census of Agriculture, the average age of all US farm principal operators in 2017 was 59.4 years, up 9.1 years from 1978. In the latest statistics in the EU only 11% of farmers were under the age of 40.[22] Similar to Japan, further aging in the farm society could reduce crop yields. Understanding and addressing the adaptation ability of farmers is an urgent agenda in these countries.

[22] See Statistics of "Farm indicators by agricultural area, type of farm, standard output, sex and age of the manager and NUTS 2 regions" by Eurostat for more detailed information: https://ec.europa.eu/eurostat/databrowser/view/ef_m_farmang/default/table?lang=en.

7. References

Abdul-Rahaman, Awal and Awudu Abdulai. 2018. Do farmer groups impact on farm yield and efficiency of smallholder farmers? Evidence from rice farmers in northern Ghana. *Food Policy* 81: 95–105.

Agro-Meteorological Grid Square Data, NARO. Daily mean temperature, daily precipitation, and daily global solar radiation, 1993–2018. https://amu.rd.naro.go.jp/wiki_open/doku.php?id=start (in Japanese)

Aragón, Fernando M., Francisco Oteiza, and Juan P. Rud. 2021. Climate change and agriculture: subsistence farmers' response to extreme heat. *American Economic Journal: Economic Policy* 13 (1): 1–35.

Barnes, Andrew P., Iria Soto, Vera Eory, Bert Beck, Athanasios Balafoutis, Berta Sánchez, Jürgen Vangeyte, Spyros Fountas, Tamme van der Wal, and Manuel Gómez-Barbero. 2019. Exploring the adoption of precision agricultural technologies: A cross regional study of EU Farmers. *Land Use Policy* 80: 163–174.

Burke, Marshall and Kyle Emerick. 2016. Adaptation to climate change: evidence from US agriculture. *American Economic Journal: Economic Policy* 8 (3): 106–140.

Chen, Shuai, Xiaoguang Chen, and Jintao Xu. 2016. Impacts of climate change on agriculture: evidence from China. *Journal of Environmental Economics and Management* 76: 105–124.

Cui, Xiaomeng and Wei Xie. 2021. Adapting agriculture to climate change through growing season adjustments: Evidence from corn in China. *American Journal of Agricultural Economics* 104: 249–272.

Czaja, Sara J., and Joseph Sharit. 1998. Age differences in attitudes toward computers. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* 53 (5): 329–340.

Daniele, Federica, Taku Honiden, and Alexander C. Lembcke. 2020. Ageing and productivity growth in OECD regions: Combatting the economic impact of ageing through productivity growth? In *Ageing and Fiscal Challenges Across Levels of Government*.

Deressa, Temesgen T., Rashid M. Hassan, Claudia Ringler, Tekie Alemu, and Mahmud Yesuf. 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change* 19 (2): 248–255.

Eggertsson, Gauti B., Manuel Lancastre, and Lawrence H. Summers. 2019. Aging, output per capita, and secular stagnation. *American Economic Review: Insights* 1 (3): 325–42.

Eurostat Statistics. Farm indicators by agricultural area, type of farm, standard output, sex and age of the manager and NUTS 2 regions, 2016. https://ec.europa.eu/eurostat/databrowser/view/ef_m_farmang/default/table?lang=en

Kawasaki, Kentaro, and Shinsuke Uchida. 2016. Quality matters more than quantity: Asymmetric temperature effects on crop yield and quality grade. *American Journal of Agricultural* Economics 98 (4): 1195–1209.

Kawatsu, Syunsaku, Koki Homma, Takeshi Horie, and Tatsuhiko Shiraiwa. 2007. Change of weather condition and its effect on rice production during the past 40 years in Japan. *Japanese Journal of*

Crop Science 76 (3): 423–432 (in Japanese).
Kgosikoma, Keneilwe R., Phatsimo C. Lekota, and Olaotswe E. Kgosikoma. 2018. Agro-pastoralists' determinants of adaptation to climate change. *International Journal of Climate Change Strategies and Management* 10 (3): 488–500.
Lee, Hyun-Hoon, and Kwanho Shin. 2019. Nonlinear effects of population aging on economic growth. *Japan and the World Economy* 51: 100963.
Maestas, Nicole, Kathleen Mullen, and David Powell. 2016. The effect of population aging on economic growth, the labor force and productivity. *NBER Working Papers* No. 22452.
MAFF. Agriculture and Forestry Census, 1985, 2000, 2005, 2010, 2015. https://www.maff.go.jp/j/tokei/census/afc/about/setumei.html (in Japanese). Accessed 31 Oct. 2020.
MAFF. Statistics Sakumotu Tokei Sakkyou Kome, 1993-2018. https://www.maff.go.jp/j/tokei/kouhyou/sakumotu/sakkyou_kome/index.html (in Japanese).
MAFF. Survey on Movement of Agricultural Structure, 2018-2019.
https://www.maff.go.jp/j/tokei/kouhyou/noukou/index.html#r (in Japanese)
MAFF. Survey of New-Entry Farmers, 2018-2019.
https://www.maff.go.jp/j/tokei/kouhyou/sinki/index.html (in Japanese).
Morita, Satoshi. 2005. White immature kernels. Poor palatability, and grain weight decrease of rice due to high temperature during the grain-filling periods. *Agricultural Technology* 60: 442–446 (in Japanese).
Okada, Masashi, Toshichika Iizumi, Yousay Hayashi, and Masayuki Yokozawa. 2011. Projecting climate change impacts both on rice quality and yield in Japan. *Journal of Agricultural* Meteorology 67 (4): 285–295 (in Japanese).
Park, Cyn-Young, Kwanho Shin, and Aiko Kikkawa. 2021. Aging, automation, and productivity in Korea. *Journal of the Japanese and International Economies* 59: 101109.
Rondhi, Mohammad, Ahmad Fatikhul Khasan, Yasuhiro Mori, and Takumi Kondo. 2019. Assessing the role of the perceived impact of climate change on national adaptation policy: the case of rice farming in Indonesia. *Land* 8 (5): 81.
Schlenker, Wolfram, and Michael J. Roberts. 2009. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences* 106 (37): 15594–15598.
Shang, Linmei, Thomas Heckelei, Maria K. Gerullis, Jan Börner, and Sebastian Rasch. 2021. Adoption and diffusion of digital farming technologies – integrating farm-level evidence and system interaction. *Agricultural Systems* 190: 103074.
Shikuku, Kelvin M., Leigh Winowiecki, Jennifer Twyman, Anton Eitzinger, Juan G. Perez, Caroline Mwongera, and Peter Läderach. 2017. Smallholder farmers' attitudes and determinants of adaptation to climate risks in East Africa. *Climate Risk Management* 16: 234–245.
Statistics Bureau of Japan. List of Mesh Codes by City, 2015. https://www.stat.go.jp/data/mesh/m_itiran.html (in Japanese).
Tamura, Makoto, Haruo Uchiyama, Yoko Imai. 2021. Climate change impacts and adaptations in the

agricultural sector: 2020 survey of farmers' perceptions in 14 cities and towns, Ibaraki. *Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research)* 77 (5): 221–229 (in Japanese).

Tauer, Loren W. 1984. Productivity of farmers at various ages. *North Central Journal of Agricultural Economics* 6 (1): 81–87.

Tauer, Loren W. 2017. Farmer productivity by age over eight U.S. census years. *Working Paper* 2017-08, Cornell University.

Uddin, Mohammed N., Wolfgang Bokelmann, and Jason S. Entsminger. 2014. Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: a farm level study in Bangladesh. *Climate* 2 (4): 223–241.

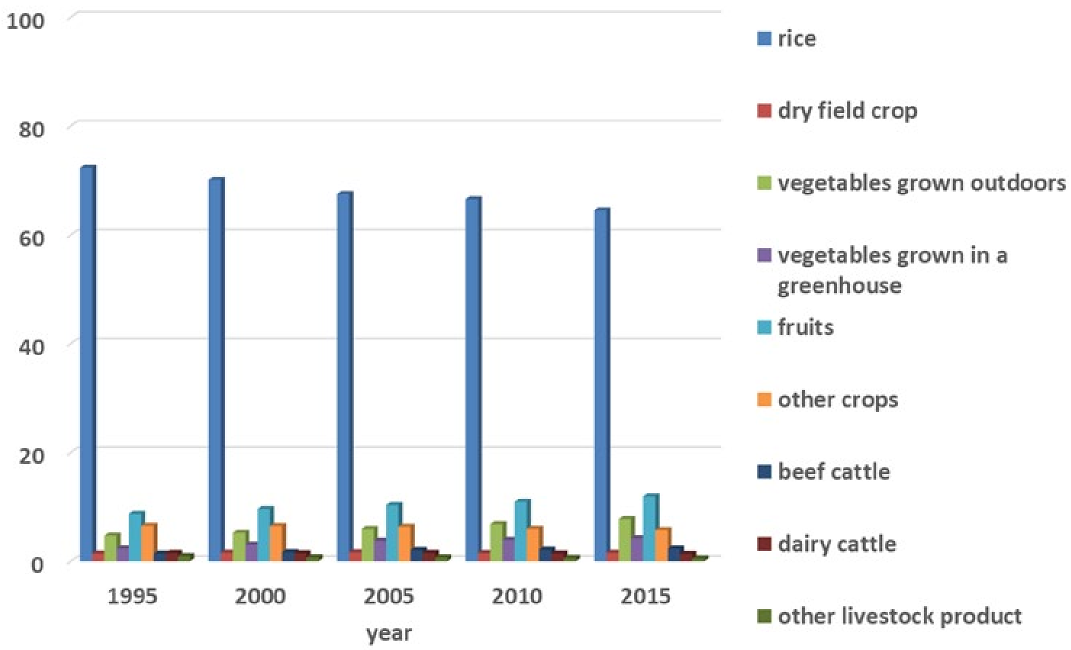
United States Department of Agriculture. Census of agriculture, 1978, 2017. https://www.nass.usda.gov/AgCensus/ Accessed 13 Jul. 2021.

Wakamatsu, Ken-ichi, Osamu Sasaki, Ichiro Uezono, and Akio Tanaka. 2007. Effects of high air temperature during the ripening period on the grain quality of rice in warm regions of Japan. *Japanese Journal of Crop Science* 76 (1): 71–78 (in Japanese).

Yoshida, Shouichi, and Tetsuo Hara. 1977. Effect of air temperature and light on grain filling of an Indica and Japonica Rice (Oryza sativa L.) under controlled environmental conditions. *Soil Science and Plant Nutrition* 23: 93–107.

8. Appendix

Figure A1: Percentage of farm households by crop and livestock (%) in Japan[23]

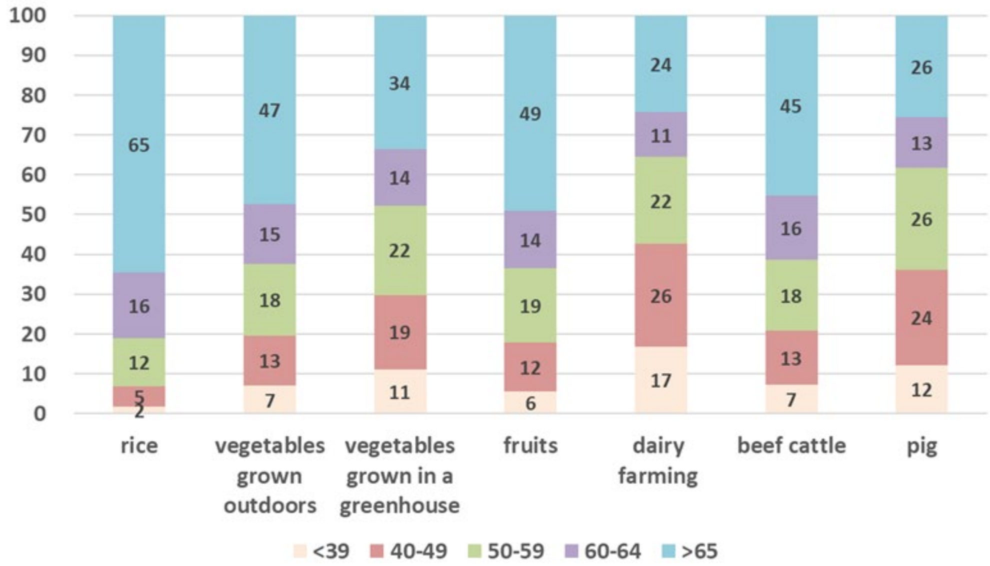


Notes: The number of each crop and livestock farm household data is attained from MAFF quinquennial agricultural censuses, 1995–2015. Only single enterprise farm data is used.[24]

[23] Rice stands as a staple food crop widely cultivated throughout Japan, with approximately 70% of farmers engaged in rice farming. The long–standing control of rice production by the Japanese government has played a pivotal role in maintaining a consistent presence of rice cultivation throughout the country. This government intervention effectively prevented rice farmers out of production. As a result, rice is cultivated extensively across Japan, in stark contrast to the production of other crops like wheat, vegetables, and fruits, which tend to vary considerably across regions and over time due to climate conditions and profitability factors.

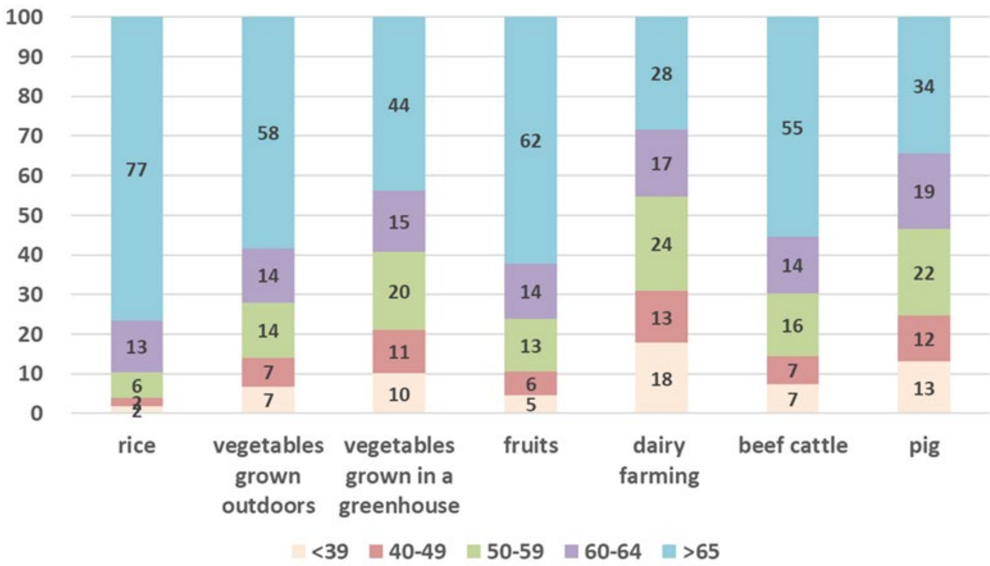
[24] Single enterprise farm definition: farm that sells 80% or more of the value of its agricultural product sales in the primary crop.

Figure A2: Age (years old) structure in 2000 (%) in Japan



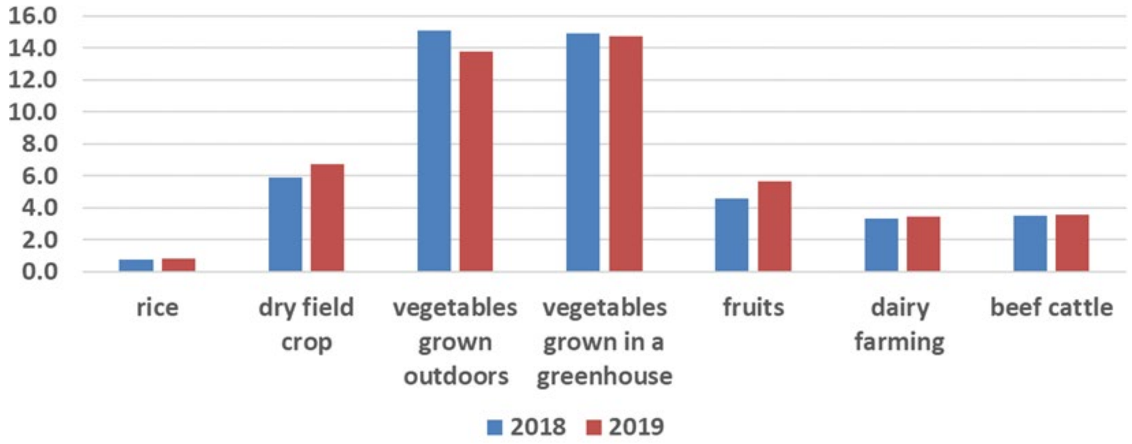
Notes: Age structure data is attained from MAFF quinquennial agricultural censuses, 2000. Only single enterprise farm data is used.

Figure A3: Age (years old) structure in 2015 (%) in Japan



Notes: Age structure data is attained from MAFF quinquennial agricultural censuses, 2015. Only single enterprise farm data is used.

Figure A4: Barriers to entry by Japanese agricultural and livestock products (persons/ 1,000 households), 2018–2019



Notes: The number of new–entry farmers by product data is from MAFF Survey of New–Entry Farmers (https://www.maff.go.jp/j/tokei/kouhyou/sinki/index.html), with data available from 2018. The number of farm households by product data is from MAFF Survey on Movement of Agricultural Structure (https://www.maff.go.jp/j/tokei/kouhyou/noukou/index.html#r). Only single enterprise farm data is used.

Figure A5. Robustness check: Cluster standard error at the different level

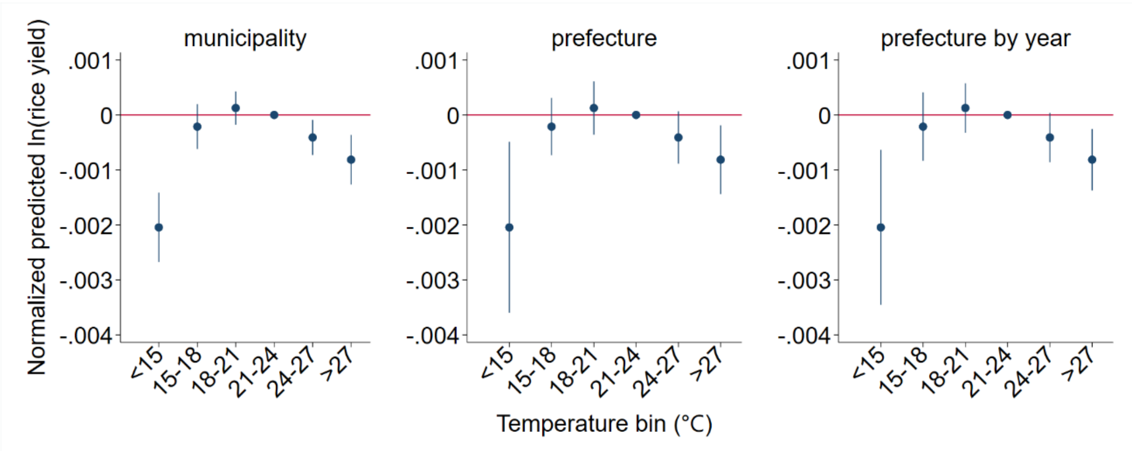
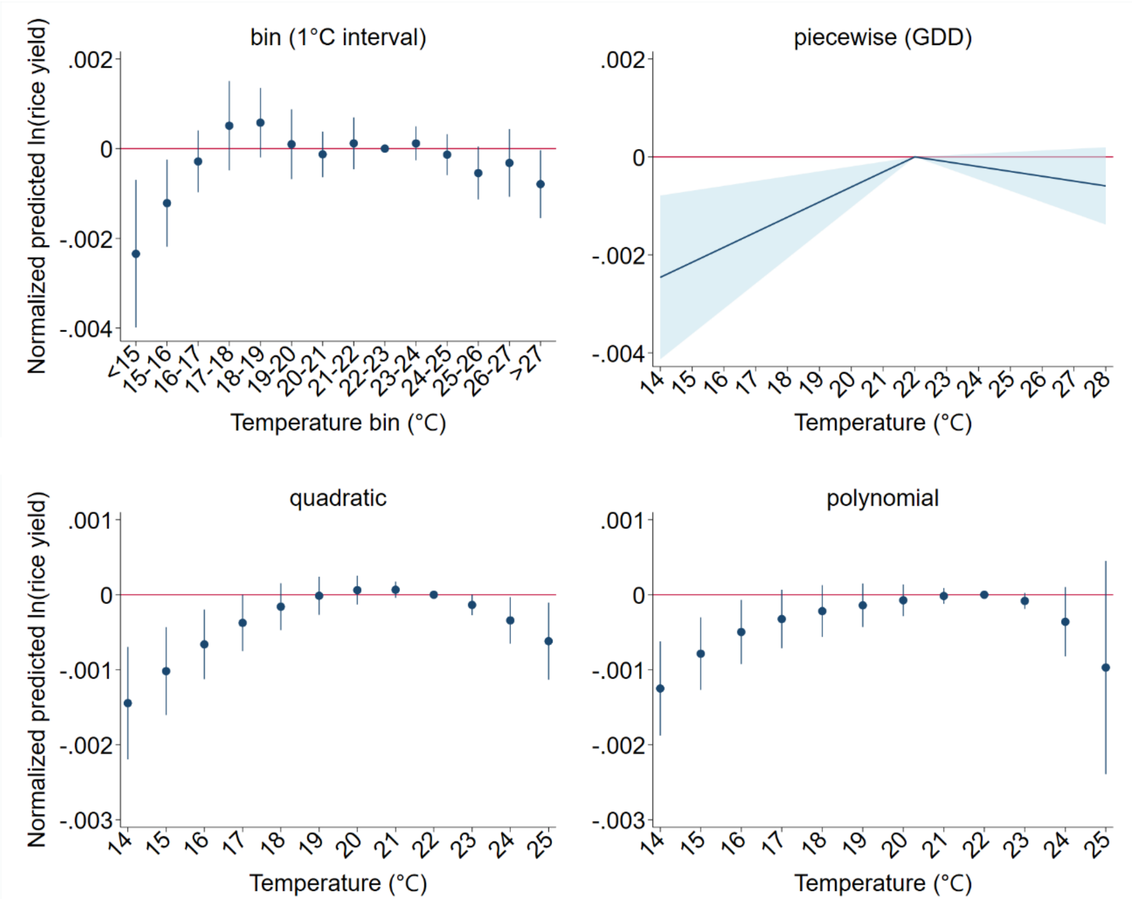
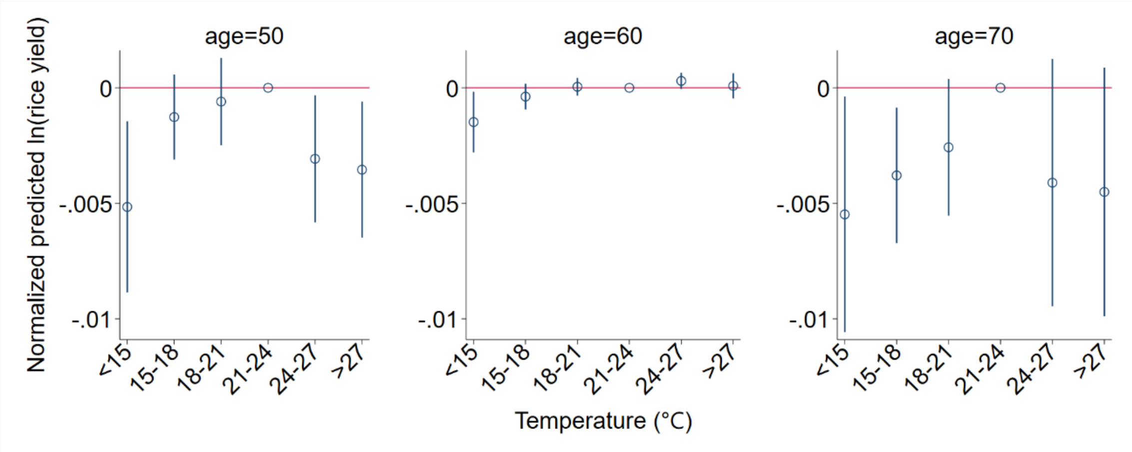


Figure A6. Robustness check: Model selections



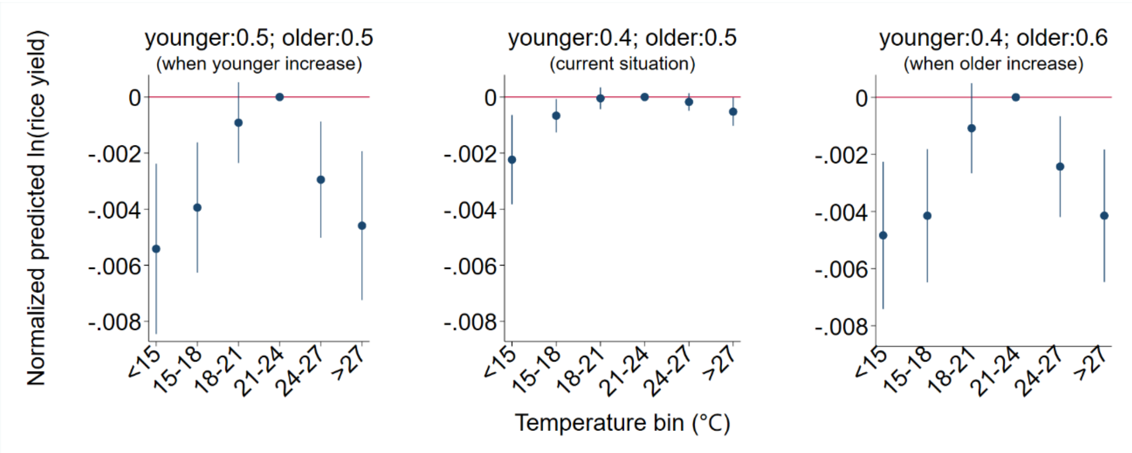
Note: Estimation results are extended from column 2 in Table 2. Temperatures above 25°C exhibit instability in polynomial form, possibly due to the maximum value of the average daily temperature over the growing season being only 24°C.

Figure A7. Relationship between age and temperature–rice yields: municipalities with a low percentage (below 5th percentile) of rice–farm households among all households at the census year are excluded



Note: Estimation results are extended from Table 3. Obs.=23,366.

Figure A8. Relationship between the share of farmers in each age category and temperature–rice yields: 15–54 years old (younger), 55–59 years old (base category), and above 60 years old (older) (unit: 0–1, 1 means 100%)



Note: Estimation results are extended from Table 3. Obs.=24,606.

Figure A9. Relationship between age and temperature–rice yields: lower vs higher share of LCP municipalities—community common facilities

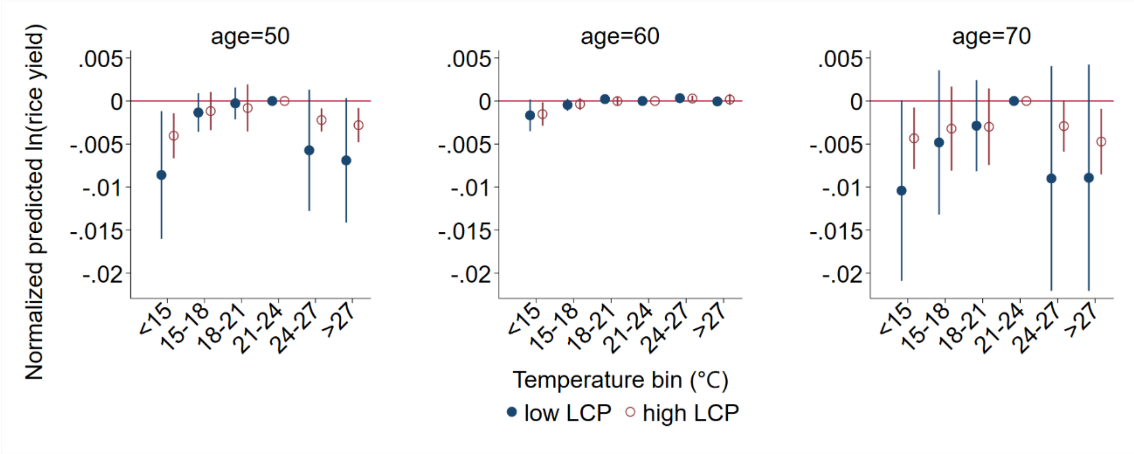


Figure A10. Relationship between age and temperature–rice yields: lower vs higher share of LCP municipalities—agricultural production

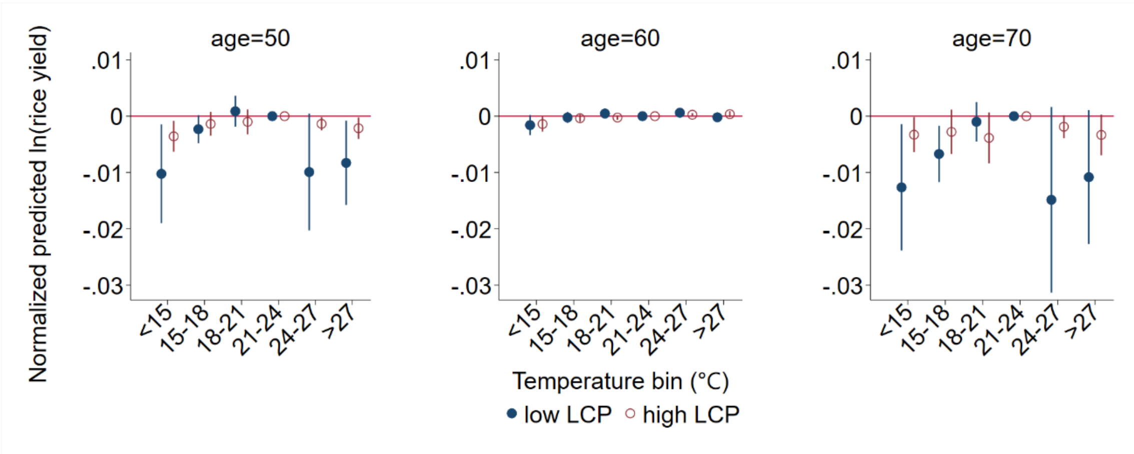


Figure A11. Relationship between the share of farmers in each age category and temperature–rice yields: lower vs higher share of LCP municipalities—agricultural drainage channels (15–54 years old (younger), 55–59 years old (base category), and above 60 years old (older) (unit: 0–1, 1 means 100%))

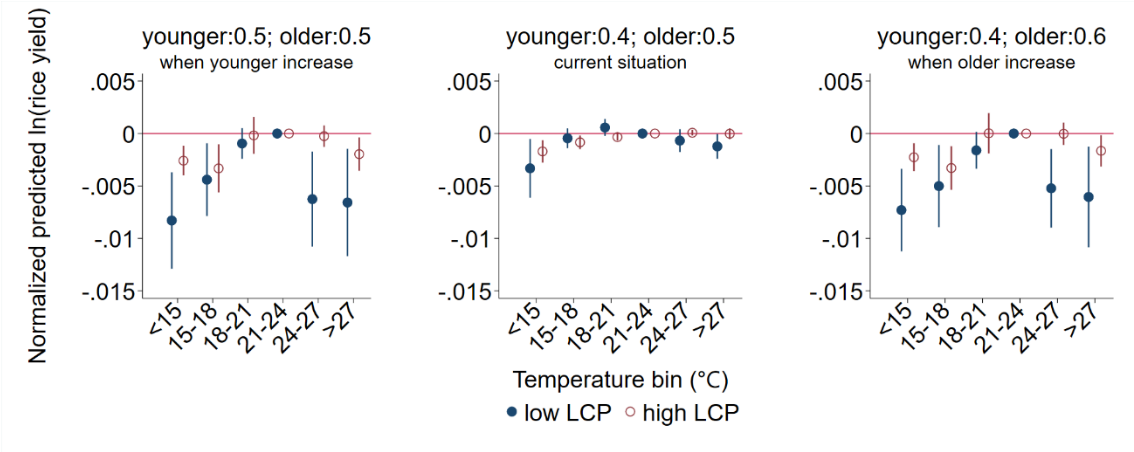


Figure A12. Relationship between the share of farmers in each age category and temperature–rice yields: lower vs higher share of LCP municipalities—community common facilities (15–54 years old (younger), 55–59 years old (base category), and above 60 years old (older) (unit: 0–1, 1 means 100%))

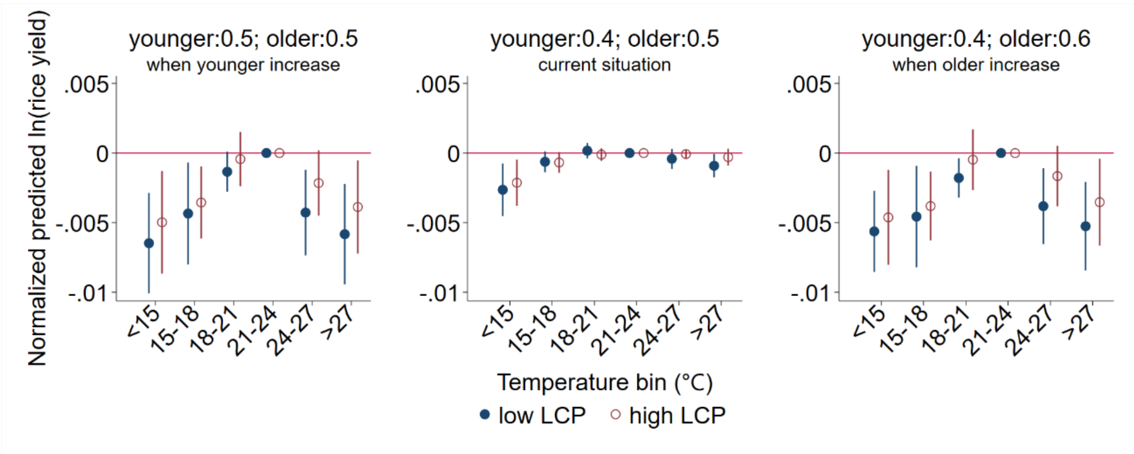


Figure A13. Relationship between the share of farmers in each age category and temperature–rice yields: lower vs higher share of LCP municipalities—agricultural production (15–54 years old (younger), 55–59 years old (base category), and above 60 years old (older) (unit: 0–1, 1 means 100%))

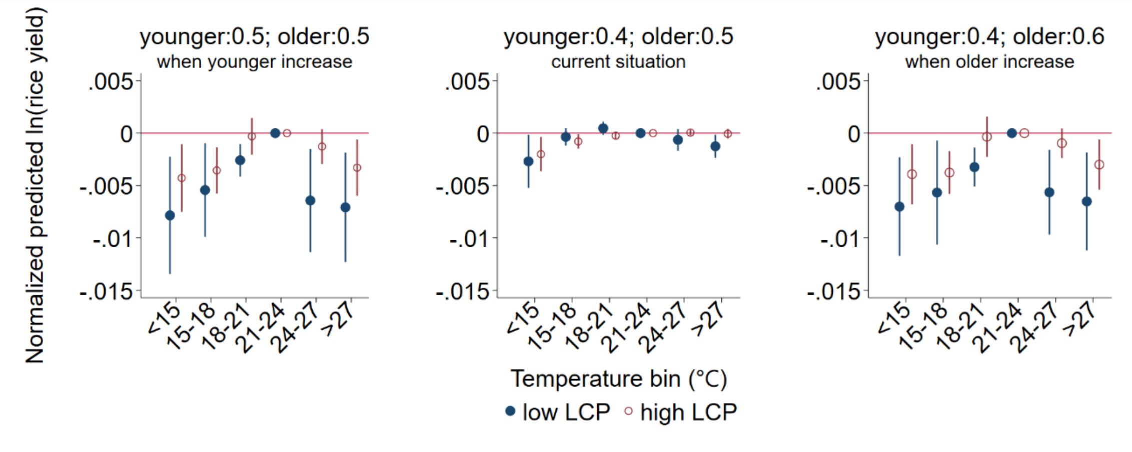

Normalized predicted ln(rice yield)
younger:0.5; older:0.5
when younger increase
younger:0.4; older:0.5
current situation
younger:0.4; older:0.6
when older increase
.005
0
-.005
-.01
-.015
<15
15-18
18-21
21-24
24-27
>27
Temperature bin (°C)
low LCP
high LCP

Table A1. Endogeneity of age: past 3–year vs past 5–year moving averages for weather variables as explanatory variables

Outcome: age	(1) past 3–year	(2) past 5–year
<15°C	-0.00004	0.00004
	(0.0001)	(0.0002)
15–18°C	-0.00003	0.0001
	(0.0001)	(0.0001)
18–21°C	-0.0001	-0.0001
	(0.0001)	(0.0001)
24–27°C	0.0001	0.0001
	(0.0001)	(0.0001)
>27°C	0.0002	0.0002
	(0.0001)	(0.0002)
Obs.	3,959	3,951
Adj. R^2	0.9337	0.9345

Notes: ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively. All specifications are estimated with municipality fixed effects and prefecture-by-year fixed effects. Past precipitation and global solar radiation are included in the regression. Only the years 2001, 2006, 2011, and 2016 are used for estimation. Standard errors clustered at the prefecture level are reported in parentheses.

Table A2. Endogeneity of participation: past 3–year vs past 5–year moving averages for weather variables as explanatory variables

Outcome: local com. par.	(1) past 3–year	(2) past 5–year
<15°C	0.0020 (0.0024)	0.0030 (0.0036)
15–18°C	0.0017 (0.0018)	0.0023 (0.0031)
18–21°C	0.0006 (0.0012)	0.0001 (0.0017)
24–27°C	-0.0027 (0.0023)	0.0005 (0.0025)
>27°C	-0.0018 (0.0028)	0.0025 (0.0040)
Obs.	2,630	2,628
Adj. R^2	0.8572	0.8572

Notes: ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively. All specifications are estimated with municipality-fixed effects and prefecture-by-year fixed effects. Past precipitation and global solar radiation are included in the regression. Only the years 2001, 2006, 2011, and 2016 are used for estimation. Standard errors clustered at the prefecture level are reported in parentheses.

Table A3. Age effects on the rice yield response function to temperatures: lower vs higher share of local community participation (LCP) municipalities

	Single term	Cross term with age	Cross term with age squared
Low LCP			
<15°C	-0.3847**	1.2890**	-1.0853**
	(0.1417)	(0.4808)	(0.4084)
15–18°C	-0.1102**	0.3949**	-0.3534**
	(0.0521)	(0.1815)	(0.1581)
18–21°C	-0.0590	0.2149	-0.1927
	(0.0483)	(0.1676)	(0.1455)
24–27°C	-0.4371**	1.4788*	-1.2483*
	(0.2152)	(0.7328)	(0.6232)
>27°C	-0.3139*	1.0604*	-0.8960*
	(0.1579)	(0.5404)	(0.4619)
High LCP			
<15°C	-0.0398	0.1264	-0.1041
	(0.0238)	(0.0836)	(0.0727)
15–18°C	-0.0530	0.1774	-0.1499
	(0.0482)	(0.1653)	(0.1416)
18–21°C	-0.0837*	0.2897*	-0.2511*
	(0.0435)	(0.1511)	(0.1312)
24–27°C	-0.0474**	0.1607*	-0.1358*
	(0.0230)	(0.0797)	(0.0689)
>27°C	-0.0637*	0.2146*	-0.1800
	(0.0355)	(0.1234)	(0.1070)

Notes: Estimation results from Equation (1) with the two-split sample by the level of local community involvement. Our sample consists of single cropping municipalities which continuously produce rice in 2001–2018. The unit of age is 100 years old. Standard errors clustered at the prefecture level are reported in parentheses. Regressions are weighted by the 2001–2018 average rice planted area. ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively.