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Assessing the Economic Impact of Climate Change on Japanese Agriculture: A Ricardian Analysis

Atomu NITTA*, Daisuke SAWAUCHI, Yongfu CHEN***, Hirokazu AKAHORI**** and Yasutaka YAMAMOTO****

*Graduate School of Agriculture, Hokkaido University, **Research Faculty of Agriculture, Hokkaido University, ***College of Economics and Management, China Agricultural University, ****Faculty of Bioresource Sciences, Akita Prefectural University

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Abstract

The purpose of this study is to determine whether climate change will increase or decrease agricultural net revenue in Japan as a whole. This study conducts the first Ricardian model analysis of this issue and finds that agricultural net revenue will decrease across Japan by the end of the twenty-first century. The impacts of climate change are quite different in different regions of the country; an increase in agricultural net revenue is predicted in the northern municipalities, whereas agricultural net revenue is predicted to decline in many other municipalities.

I. Introduction

Warming of the climate system is unequivocal and continued emissions of greenhouse gases will result in further global warming[1]. In the case of Japan, the Japan Meteorological Agency (JMA)[2–3] forecasts a rise in temperature and a change in precipitation patterns.

In terms of the value of net imports of agricultural products, Japan is the second largest in the world after China[4]. If Japan's agricultural production declines due to climate change, it can influence food supply and demand in Asia and the world by increasing imports from other countries, and potentially threaten food security in the world.

Agriculture is inherently sensitive to climate conditions, and there are many previous studies assessing the impact of climate change on Japanese agriculture. Seino[5] assessed the impacts of warming on rice, maize, and wheat production in

Japan using a crop model, and predicted that the increased temperature would slightly increase the yield of maize but decrease the yield of wheat. The predicted rice yield varied depending on the climate change scenario used. Tokunaga et al.[6] empirically identified the impact of climate change on Japanese agricultural production, and predicted that an increase of 1 ℃ in mean annual temperature would reduce rice yield by 5.8% in the short term and 3.9% in the long term, and reduce the yield of vegetables and potatoes by 5.0% and 8.6% in the short and long term, respectively.

From the above, it is evident that it is an empirical matter whether future climate change will have a positive or negative impact on Japanese agriculture overall. Whereas Seino[5] and Tokunaga et al.[6] predicted the impact of climate change on each crop, Kunimitsu[7] predicted the impact on the economy through changes in rice production using a computable general equilibrium (CGE) model. Kunimitsu[7] predicted that agricultural income in the whole of Japan would decrease, despite increased production in northern and eastern Japan. However, the CGE model has the disadvantage of quite drastic aggregation, whereas the Ricardian approach, in contrast, allows for calculation of the direct impact on each disaggregated region[8]. Ricardian analysis, originally developed by Mendelsohn et al.[9], is an empirical method that regresses land price or net revenue on climate and other control variables. The approach has been applied in a variety of countries and regions[8–23], including Asian countries[24–29].

However, despite its widespread use elsewhere, there are few studies that use the Ricardian model for East Asian countries and no previous study for Japan. Regarding the application of the Ricardian model to East Asian countries, Liu et al.[26] and Chen et al.[29] applied the model to China and revealed that climate change is expected to have a positive impact on China as a whole.

The purpose of this study is to determine whether climate change will increase or decrease Japanese agricultural net revenue. This study measures the impact of changes in precipitation and temperature on agricultural net revenue in Japan using the Ricardian model and municipality-level panel data. The paper proceeds as follows. Section 2 summarizes the method and data. Section 3 presents our empirical results and predicted impacts of climate change on agriculture, and Section 4 concludes.

II. Materials and Methods

A. Method

Ricardian analysis involves the use of cross-sectional data and the farmland price or agricultural net revenue is regressed on climate and other control variables. The basic hypothesis is that climate shifts the production function for crops. Farmers at particular sites take environmental variables, such as climate, as given and adjust their inputs and outputs accordingly. This approach accounts for the direct effects of climate on the yields of different crops as well as the indirect substitution of different inputs, the introduction of different activities, and other potential adaptations to different climate conditions[9].

Deschenes and Greenstone[30] argued that there is inherent bias in the cross-sectional estimates of the coefficients because of unobserved characteristics correlated with the climate variables; they suggested that a preferred specification would employ panel data models that include fixed effects. There are many determinants of farmland prices or agricultural net revenue, and not all can be included as explanatory variables. Therefore, using a fixed effects model, the fixed effects account for unobserved individual-specific time-invariant determinants of agricultural net revenue, for example, geographical characteristics, such as slope and altitude, distance from populated areas, and soil characteristics, can be considered, and the fixed effects method offers a possible solution to the omitted variables bias[30].

Another issue is that the traditional Ricardian approach assumes the long-run equilibrium of factor markets. As the farmland markets of Japan and other countries are not complete, assuming a fully integrated market is a problem. For example, Ricardian studies in countries including India, Sri Lanka, and China[28,29,31,32] have used net revenue per unit of land as a proxy. The Ricardian theory is consistent when net revenue is used because land values are based on the discounted stream of future net revenues[28]. Consequently, we rely on agricultural net revenue per 0.1 hectares as the dependent variable instead of using farmland value.

Accordingly, this paper uses panel data and the fixed effects[*1] model proposed by Deschenes and Greenstone[30]. Equation (1) provides a standard formulation:

$$y_{m,t}=\alpha_m+\gamma_t+\sum_i(\beta_{1,i} * W_{i,m,t}+\beta_{2,i} * W^2_{i,m,t})+u_{m,t}, \tag{1}$$

where $y_{m,t}$ is agricultural net revenue per 0.1 hectares in municipality m and in year t and $W_{i,m,t}$ includes weather variables for municipality m in year t, where i denotes one of eight weather variables (including seasonal precipitation and seasonal mean temperature). We define the weather variables for each season as either total three-month precipitation or the average temperature. In this paper, we define the seasons as follows: spring as March through May, summer as June through August, fall as September through November, and winter as December through February. This paper also includes linear and quadratic terms for each weather variable to reflect the nonlinearities apparent in existing field studies.

Equation (1) also includes a full set of municipality fixed effects, α_m. The municipality fixed effects account for all unobserved municipality-specific, time-

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[*1] The results of the Hausman test and the F-test for the panel data of this study suggest that the use of the fixed effects model is appropriate.

Fig. 1. Area Classifications of Japan.

invariant determinants of the dependent variable.*2 The equation also includes year indicators, γ_t, that control for annual differences in the dependent variable common across all municipalities. We identify the weather parameters from municipality-specific deviations in weather from the municipality averages.

We predict the impact of climate change on agricultural net revenue, using the estimated parameters and forecasts of future climate variables. By dividing the forecasted change amount obtained by the predicted values of agricultural net revenue for the analysis period, we estimate the change rate in agricultural net revenue. The simulation is solely based on the impact of precipitation and temperature, without changes in the frequency of extreme weather events and carbon dioxide concentration.

B. Data

For the analysis, we construct and utilize a balanced panel of data with observations from 2,869 municipalities across nine regions (Fig. 1) over the period 1995–2002, providing a sample of 22,952 (= 2,869 * 8) municipality-years.

The dependent variable is agricultural net revenue per 0.1 hectares of land in farms. To construct it, the sources used were the Statistics of Agricultural

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*2 Fixed effects model treats α_m as an unobserved random variable that is potentially correlated with the observed regressors, while the other variant of the model, random effects model, assumes that the unobservable individual effects are random variables that are distributed independently of the regressors.[33]

Table 1. Municipality-level Summary Statistics.

	1995	1996	1997	1998	1999	2000	2001	2002
Agricultural net revenue per 0.1 hectares (thousand JPY)	96.14	93.85	83.06	84.14	77.85	73.66	69.86	69.96
Winter precipitation (mm)	197.22	227.79	331.97	201.20	232.37	280.61	277.40	281.63
Spring precipitation (mm)	500.09	339.01	410.34	527.66	417.41	394.79	288.60	378.25
Summer precipitation (mm)	643.73	580.78	694.04	691.27	793.48	513.29	587.40	551.52
Fall precipitation (mm)	349.51	366.47	482.65	580.50	510.08	587.49	536.52	415.30
Winter mean temperature (degrees Celsius)	2.40	3.25	3.84	3.56	3.21	2.84	3.64	2.97
Spring mean temperature (degrees Celsius)	11.18	10.12	11.80	13.12	11.80	11.21	11.74	12.63
Summer mean temperature (degrees Celsius)	23.11	23.03	23.10	23.17	23.43	23.83	23.65	23.50
Fall mean temperature (degrees Celsius)	14.94	15.08	15.30	16.58	16.57	16.16	15.23	14.63

Note: Averages are calculated for a balanced panel of 2,869 municipalities. All entries are simple averages over the 2,869 municipalities. "Agricultural net revenue per 0.1 hectares (thousand JPY)" is in 2000 constant yen.

Income Produced and Crop Surveys. We specify "Agricultural Income Produced" from the Statistics of Agricultural Income Produced as agricultural net revenue, and "Cultivated Land Area" from the Crop Survey as the land in farms. Agricultural net revenue per 0.1 hectares is equal to the total net revenue of the municipality divided by the area of farmland per 0.1 hectares of the municipality. All dependent variables are converted to constant 2000 JPY using Quarterly Estimates of GDP (reference year = 2000).

We construct a municipality-level weather dataset including total seasonal precipitation and mean seasonal temperature to capture seasonal effects of each variable. Throughout Japan, the JMA monitors about 1,300 rain gauges and more than 800 thermometers. Using the daily data of the weather stations, we calculate the precipitation and average temperature values in each season of each year, and we estimate the variables for all the regions in which no weather station is present by interpolating using a kriging technique in Geographic Information System software. Finally, we extract values of the weather variables at representative points of each municipality to construct the municipality-level dataset.

Table 1 reports municipality-level summary statistics. Over the period, the agricultural net revenue per 0.1 hectares varied between 70,000 and 96,000 yen, with a downward trend. The precipitation was greatest in the summer, except for 2000, and the temperature was highest in the summer over the whole period.

In terms of the forecast variables, to develop our estimates of climate change effects on Japanese agricultural net revenue, we use the two sets of mean seasonally adjusted changes in precipitation and temperature for the baseline period 1980–1999 and the future 2076–2095[2,3]. The two sets of predictions from the JMA[2,3] rely on the A1B scenarios of the Intergovernmental Panel on Climate

Table 2. Climate Change Scenarios.

	Seasonal precipitation in 1995–2002 (mm/3 months)	Precipitation change in 2076–2095 (mm/3 months)		Daily mean temperature in 1995–2002 (Degrees Celsius)	Temperature change in 2076–2095 (Degrees Celsius)	
		JMA 2013	JMA 2017		JMA 2013	JMA 2017
Winter	254	+41.6	−14.9	3.2	+3.36	+5.0
Spring	407	+56.8	−9.7	11.7	+2.88	+4.0
Summer	632	+38.6	−23.6	23.4	+2.74	+4.2
Fall	479	−27.9	+16.3	15.6	+3.08	+4.6

Source: JMA[2,3].

Change's *Special Report on Emissions Scenarios* and the 8.5 emission scenario of the Representative Concentration Pathway, respectively.

Table 2 shows the predicted change in precipitation and temperature from the two scenarios (hereafter, the JMA 2013 scenario and the JMA 2017 scenario) for the end of this century. As the table shows, both models forecast increased temperature levels for all seasons, whereas forecasted changes in precipitation differ between the two scenarios. The JMA 2013 scenario is milder, with warming of around 3 ℃, and the JMA 2017 scenario is harsher, with warming of close to 5 ℃.

III. Results and Discussion

A. Empirically estimated results

Table 3 presents the results of the fixed effects regressions. In this paper, two separate models, both linear regressions with fixed effects, are estimated. Model A includes unrestricted year dummy variables, which, in Model B, are replaced with interaction terms by prefecture and year.

The first column of Table 3 reports the results from Model A. It includes weather variables for the four seasons and is specified as a quadratic equation. This model also includes year dummy variables. As for the 16 coefficients for weather variables, 14 of them are significant at the 5% level.

The coefficients of quadratic terms for summer precipitation, spring temperature, and summer temperature are negative.

The second column reports the results from Model B. In this case, compared with Model A, fewer variables (six rather than 14 of the 16) are statistically significant at the 5% level. The coefficients of quadratic terms for spring temperature and summer temperature are significant and negative. In both models, both the linear and quadratic terms for temperature in spring and summer are significant at the 1% level.

To present the impact of weather variables on agricultural net revenue more

Table 3. Parameter Estimates for the Fixed Effects Model.

	Model A			Model B		
Winter precipitation	−0.023	***	(0.003)	0.001		(0.005)
Spring precipitation	−0.009	**	(0.004)	0.007		(0.005)
Summer precipitation	0.001		(0.002)	−0.005	*	(0.003)
Fall precipitation	−0.011	***	(0.003)	−0.001		(0.005)
Winter temperature	0.114		(0.214)	1.313	**	(0.535)
Spring temperature	5.186	***	(0.424)	4.805	***	(0.740)
Summer temperature	14.210	***	(1.458)	14.290	***	(2.280)
Fall temperature	−8.765	***	(0.883)	−1.831		(1.258)
Winter precipitation squared	0.000	***	(0.000)	0.000		(0.000)
Spring precipitation squared	0.000	***	(0.000)	−0.000		(0.000)
Summer precipitation squared	−0.000	***	(0.000)	0.000	**	(0.000)
Fall precipitation squared	0.000	***	(0.000)	0.000		(0.000)
Winter temperature squared	0.058	***	(0.017)	0.017		(0.032)
Spring temperature squared	−0.271	***	(0.018)	−0.248	***	(0.039)
Summer temperature squared	−0.318	***	(0.035)	−0.348	***	(0.055)
Fall temperature squared	0.232	***	(0.028)	0.020		(0.045)
Constant	0.493		(17.210)	−73.300	***	(26.970)
Observations	22,952			22,952		
Adj R-squared	0.443			0.611		
Hausman test: chi 2 (degrees of freedom)	279.53 (19)			3228.11 (327)		
p-value	0.000			0.000		
F-value	87.39			94.49		
p-value	0.000			0.000		
Municipality FE	YES			YES		
Year dummy	YES			NO		
Prefecture* Year dummy	NO			YES		

Note: Robust standard errors in parentheses. The symbols*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

clearly, we estimate the marginal impacts and elasticities of agricultural net revenue with respect to weather variables (Table 4).

In both models, temperature has stronger (negative) effects on net revenue than does precipitation. In Model A, the elasticity of precipitation ranges from −0.05 to 0.02, whereas the elasticity of temperature ranges from −0.29 to 0.02. In Model B, the elasticity of precipitation ranges from −0.01 to 0.02, whereas the elasticity of temperature ranges from −0.54 to 0.05. Warming in spring, summer, and fall is harmful for agricultural net revenue per 0.1 hectares, whereas changes in precipitation have only a small impact on agricultural net revenue per 0.1 hectares. These findings differ from those of Chen et al.[29] which are based on data from China. The effect of precipitation change on net crop revenue per area is smaller in Japan than in China. In Japan, farmers have better irrigation equipment than in other areas of East Asia[5]. The main Japanese agricultural product is paddy rice, and it is grown all around the country. Paddy fields account for about 54% of the cultivated land area[34] in

Table 4. Marginal Impacts and Elasticities.

Model A	Marginal impact		Elasticity	
Precipitation	(Thousand yen/0.1 ha/mm)			
Winter	−0.02	***	−0.05	***
Spring	0.00	***	0.02	***
Summer	−0.00	***	−0.02	***
Fall	−0.00	***	−0.02	***
Temperature	(Thousand yen/0.1 ha/degrees Celsius)			
Winter	0.49	**	0.02	**
Spring	−1.15	***	−0.17	***
Summer	−0.64	**	−0.18	**
Fall	−1.54	***	−0.29	***
Model B	**Marginal impact**		**Elasticity**	
Precipitation	(Thousand yen/0.1 ha/mm)			
Winter	0.00		0.00	
Spring	0.00		0.02	
Summer	−0.00		−0.01	
Fall	0.00		0.01	
Temperature	(Thousand yen/0.1 ha/degrees Celsius)			
Winter	1.42	**	0.05	**
Spring	−1.01	*	−0.14	*
Summer	−1.94	***	−0.54	***
Fall	−1.21	**	−0.22	**

The symbols*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Japan and they are supplied with sufficient irrigation equipment[5]. Irrigated land as a percentage of cultivated land is 81% in Japan, whereas it is 35% in East Asia[35]. Thus, a change in precipitation might not affect Japan's agricultural production[36].

B. Simulated results of the impact of climate change

Using the coefficient estimates, we predict the impact of climate change until the end of the twenty-first century based on two climate scenarios, the JMA 2013 scenario and the JMA 2017 scenario. By dividing the forecasted change amount thus obtained by agricultural net revenue predictions for the analysis period, we calculate a change rate in agricultural net revenue.

Table 5 describes the national-level impact for the two climate change scenarios. In both models, the total effect of precipitation change and temperature change would decrease the agricultural net revenue over the whole of Japan. Under the JMA 2013 scenario, the total effect would decrease the total agricultural net revenue in Japan by 8% to 10% by the end of the twenty-first century, compared with the average total agricultural net revenue in 1995–2002, whereas it decreases by 14% under the JMA 2017 scenario. Because the Ricardian model takes the technology of each farmer as given and does not consider changes in

Table 5. Simulated National-level Impacts of Climate Change on Agricultural Net Revenue.

Climate scenarios	Model A		Model B	
	JMA 2013 scenario	JMA 2017 scenario	JMA 2013 scenario	JMA 2017 scenario
Total effects (%) (precipitation + temperature)	−9.63	−13.88	−7.83	−14.29
Precipitation effects (%)	−0.57	0.23	0.16	0.02
Temperature effects (%)	−9.06	−14.11	−7.99	−14.31

technology, these results suggest that it is necessary to develop adaptation technologies in response to climate change to maintain current levels of agricultural net revenue.

In both scenarios, the impacts of precipitation change are small, ranging from −0.57% to 0.23% of the current agricultural net revenue. In both models, the impacts of temperature change are predicted to be harmful to the nation, with the loss ranging from −7.99% to −14.31% of the current agricultural net revenue.

The analysis also describes how the impacts vary across regions. Japan consists of nine regions (Fig. 1). Table 6 shows how net revenue in each region will be affected by the change in weather. Although the overall effect of climate change is negative in Japan, the effects are quite different in different regions of the country. The southern and western parts of Japan would have relatively large negative impacts compared with the northern part of Japan. Under the JMA 2013 scenario, the largest rate of decline in agricultural net revenue at the regional level is shown in the Kyushu region (−24%), the southernmost part of Japan. Under the same scenario, in Model B, the largest rate of increase in agricultural net revenue at the regional level is shown in the northernmost part of Japan, Hokkaido (15%). Although the net revenue in Hokkaido would decrease by 1% in Model A, the rate of decline in Hokkaido is the smallest in Japan.

The estimated municipality-level change rates in agricultural net revenue are shown in Fig. 2, in which different colors identify the different bands of percentage change in agricultural net revenue for the municipalities. The municipality-level results show that climate change will tend to be beneficial to the northern regions, whereas it will be harmful to the southern and western parts of Japan.

The regional trend in predicted impacts is similar to that reported by Kunimitsu[7] and Chen et al.[29] for Japan and China, respectively. Both authors predicted that the northern regions of each country would experience positive effects as a result of climate change, but that negative effects would occur in southern regions where agricultural damage would be caused by climate change. However, Chen et al.[29] emphasized that climate change was beneficial to agriculture in wide regions of China, and that there would be an increase in agricultural

Table 6. Simulated Regional Impacts of Climate Change on Agricultural Net Revenue.

	Model A					
	JMA 2013			JMA 2017		
Region	Total effect (%)	Precipitation effect (%)	Temperature effect (%)	Total effect (%)	Precipitation effect (%)	Temperature effect (%)
Hokkaido	−1.18	−0.80	−0.38	−0.33	0.26	−0.59
Tohoku	−7.99	−0.56	−7.43	−11.52	0.24	−11.76
Hokuriku	−12.45	−0.03	−12.42	−18.66	0.14	−18.79
Kanto/Tosan	−12.81	−0.64	−12.17	−18.77	0.25	−19.02
Tokai	−15.51	−0.35	−15.15	−24.26	0.15	−24.41
Kinki	−15.31	−0.47	−14.83	−22.90	0.14	−23.04
Chugoku	−14.73	−0.44	−14.29	−22.42	0.18	−22.61
Shikoku	−16.60	−0.60	−16.00	−24.67	0.23	−24.90
Kyushu	−17.46	−0.43	−17.04	−25.59	0.30	−25.89

	Model B					
	JMA 2013			JMA 2017		
Region	Total effect (%)	Precipitation effect (%)	Temperature effect (%)	Total effect (%)	Precipitation effect (%)	Temperature effect (%)
Hokkaido	14.94	0.26	14.69	16.60	0.06	16.54
Tohoku	−3.92	0.16	−4.08	−8.57	0.01	−8.58
Hokuriku	−14.08	0.09	−14.17	−22.11	0.00	−22.11
Kanto/Tosan	−13.49	0.14	−13.62	−22.22	0.03	−22.24
Tokai	−19.43	0.03	−19.46	−30.92	0.06	−30.97
Kinki	−17.54	0.11	−17.65	−27.09	0.03	−27.12
Chugoku	−16.88	0.13	−17.00	−26.17	0.00	−26.17
Shikoku	−21.40	0.12	−21.52	−33.38	0.02	−33.40
Kyushu	−24.34	0.20	−24.54	−37.10	−0.04	−37.06

net revenue for China as a whole as a result of climate change.

This study assumes that farmers' adaptation to climate change occurs through, for example, the indirect substitution of different inputs and the introduction of different activities[9]. This study shows that climate change will be beneficial only to the northern municipalities, whereas it will be less beneficial or even harmful to many other municipalities. This predicted trend is consistent with the agronomic literature. The benefits in the northern regions are expected to be associated with a reduction in cool-summer damage, whereas the harms in other regions are expected to be associated with an increase in heat stress and a reduction in biomass as a result of a shortening of the growth period[5,37].

IV. Conclusions

The purpose of this study was to determine whether climate change will increase or decrease Japanese agricultural net revenue. We conducted a Ricar-

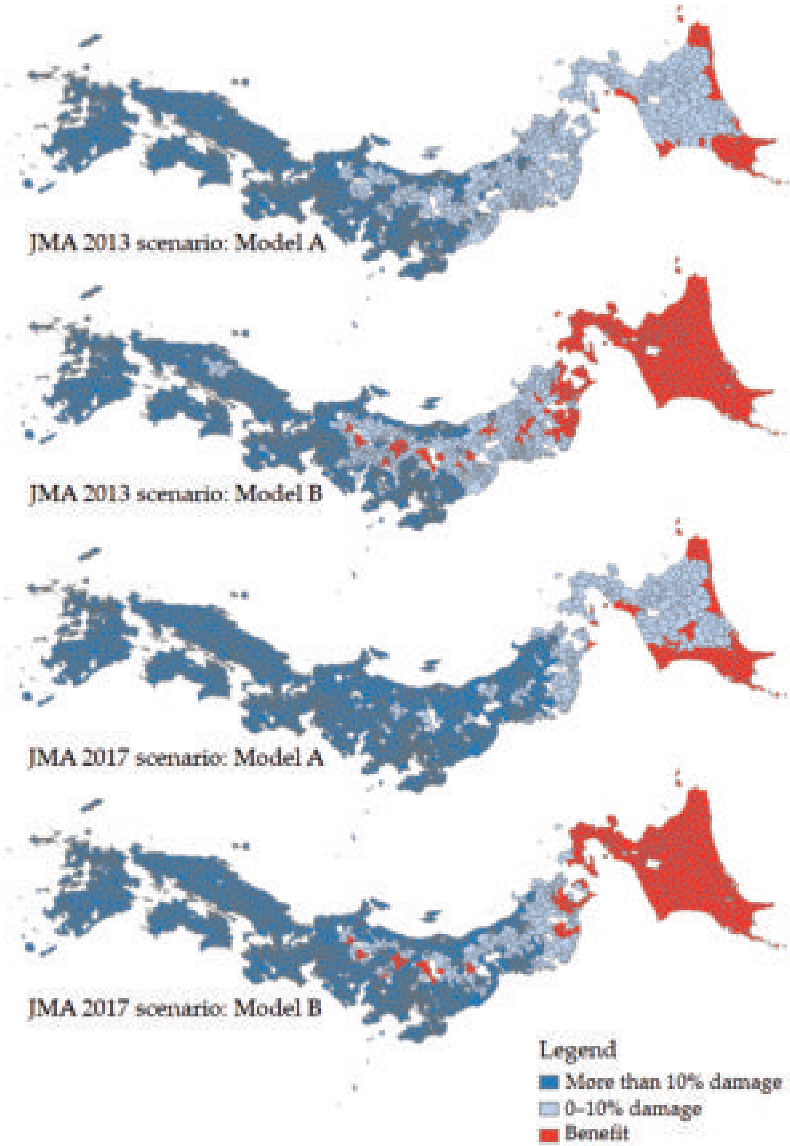

Fig. 2. Distribution of Simulated Climate Change Impacts on Agricultural Net Revenue.

dian analysis on a panel dataset on agricultural net revenue in Japan. Using a selected climate change scenario, we found that, by the end of the twenty-first century, agricultural net revenue would decrease across Japan. According to the values of the elasticities of agricultural net revenue with respect to weather variables, warming in spring, summer, and fall is harmful for agricultural net revenue. However, the impacts of climate change are quite different in different regions of the country; an increase in agricultural net revenue is predicted in the northern municipalities, whereas agricultural net revenue is predicted to decline in most other municipalities.

The results of this study suggest that policies to promote technological development, such as funding research on heat-tolerant crops[5,38,39], are relevant to mitigating the negative impacts of climate change. Moreover, the introduction of appropriate technologies in warmer countries, such as Southeast Asia and the southern part of China, may support adaptation to temperature rises.

Finally, a number of issues remain to be addressed in future work. First, the Ricardian model captures adaptation in its measure of impacts, but does not provide any insight into how farmers adapt[40]. An approach that explicitly models the underlying endogenous decisions by farmers, such as that taken by Seo and Mendelsohn[40], is needed to determine more concrete adaptation policies for climate change. Second, there is a need for new research on the impact of climate change on total factor productivity in Japan (e.g. Jacoby et al.[41]). Third, because this study used data for 1995–2002, more recent data are required to improve the accuracy of the analysis.

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References

1) Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2013: The physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press: Cambridge, UK, 2014.
2) Japan Meteorological Agency. *Global Warming Prediction Information Vol. 8*. 2013. (in Japanese).
3) Japan Meteorological Agency. *Global Warming Prediction Information Vol. 9*. 2017. (in Japanese).
4) Ministry of Agriculture, Forestry and Fisheries (MAFF). *Overseas Food Supply and Demand Report 2016*. 2016. (in Japanese).
5) Seino, H. "The Impacts of Climatic Warming on Cereal Crop Production in Japan." *Journal of Agricultural Meteorology*, 51, 131–138, 1995. (in Japanese).
6) Tokunaga, S., Okiyama, M., and Ikegawa, M. "Dynamic Panel Data Analysis of the Impacts of Climate Change on Agricultural Production in Japan." *Japan Agricultural Research Quarterly*, 49, 149–158, 2015.
7) Kunimitsu, Y. "Regional impacts of long-term climate change on rice production and agricultural income: evidence from computable general equilibrium analysis." *Japan Agricultural Research Quarterly*, 49, 173–185, 2015.
8) Schlenker, W., Hanemann, W. M., and Fisher, A. C. "The Impact of Global Warming on US Agriculture: An econometric analysis of optimal growing conditions." *Review of Economics and Statistics*, 88, 113–125, 2006.
9) Mendelsohn, R., Nordhaus, W. D., and Shaw, D. "The Impact of Global Warming on Agriculture: A Ricardian analysis." *American Economic Review*, 84, 753–771, 1994.
10) Maddison, D. "A Hedonic Analysis of Agricultural Land Prices in England and Wales."

European Review of Agricultural Economics, 27, 519–532, 2000.

11) Reinsborough, M. J. "A Ricardian Model of Climate Change in Canada." *Canadian Journal of Economics*, 36, 21–40, 2003.
12) Schlenker, W., Hanemann, W. M., and Fisher, A. C. "Will US Agriculture Really Benefit from Global Warming? Accounting for irrigation in the hedonic approach." *American Economic Review*, 95, 395–406, 2005.
13) Mano, R., and Nhemachena C. "Assessment of the economic impacts of climate change on agriculture in Zimbabwe: A Ricardian approach." *CEEPA Discussion Paper* No. 11, Centre for Environmental Economics and Policy in Africa, University of Pretoria, 2006.
14) Molua E. L., and Lambi CM. "The economic impact of climate change on agriculture in Cameroon." *CEEPA Discussion Paper* No. 17, Centre for Environmental Economics and Policy in Africa, University of Pretoria, 2006.
15) Timmins, C. "Endogenous Land Use and the Ricardian Valuation of Climate Change." *Environmental and Resource Economics*, 33, 119–142, 2006.
16) Deressa, T. T. "Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian approach." *World Bank Policy Research Working Paper*, 4342, 2007.
17) Eid, H. M., El-Marsafawy, S. M., and Ouda, S. A. "Assessing the Economic Impacts of Climate Change on Agriculture in Egypt: A Ricardian approach." *World Bank Policy Research Working Paper*, 4293, 2007.
18) Jain, S. "An Empirical Economic Assessment of Impacts of Climate Change on Agriculture in Zambia." *World Bank Policy Research Working Paper*, 4291, 2007.
19) Kabubo-Mariara, J., and Karanja, F. K. "The Economic Impact of Climate Change on Kenyan Crop Agriculture: A Ricardian approach." *Global and Planetary Change*, 57, 319–330, 2007.
20) Fleischer, A., Lichtman, I., and Mendelsohn, R. "Climate Change, Irrigation, and Israeli Agriculture: Will warming be harmful." *Ecological Economics*, 65, 508–515, 2008.
21) Seo, S. N., Mendelsohn, R., Dinar, A., Hassan, R., and Kurukulasuriya, P. "A Ricardian Analysis of the Distribution of Climate Change Impacts on Agriculture Across Agro-ecological Zones in Africa." *Environmental and Resource Economics*, 43, 313–332, 2009.
22) Mendelsohn, R., Arellano-Gonzalez, J., and Christensen, P. "A Ricardian Analysis of Mexican Farms.", *Environment and Development Economics*, 15, 153–171, 2010.
23) Nhemachena, C., Hassan, R., and Kurukulasuriya, P. "Measuring the Economic Impact of Climate Change on African Agricultural Production Systems." *Climate Change Economics*, 1, 33–55, 2010.
24) Kumar, K., and Parikh, J. "Climate Change Impacts on Indian Agriculture: The Ricardian approach." In *Measuring the Impact of Climate Change on Indian Agriculture;* Dinar, A., Mendelsohn, R., Evenson, R., Parikh, J., Sangi, A., Kumar, K., Mckinsey, J., Lonergan, S., Eds.; *World Bank Technical Paper, 402*, World Bank: Washington, DC, 1998.
25) Mendelsohn, R., Dinar, A., and Sanghi, A. "The Effect of Development on the Climate Sensitivity of Agriculture." *Environment and Development Economics*, 6, 85–101, 2001.
26) Liu, H., Li, X., Fischer, G. and Sun, L. "Study on the impacts of climate change on China's agriculture." *Climatic Change*, 65, 125–148, 2004.
27) Seo, S. N., Mendelsohn, R., and Munasinghe, M. "Climate Change and Agriculture in Sri Lanka: A Ricardian valuation." *Environment and Development Economics*, 10, 581–596, 2005.
28) Kurukulasuriya, P., and Ajwad, M. I. "Application of the Ricardian Technique to Estimate

the Impact of Climate Change on Smallholder Farming in Sri Lanka." *Climatic Change*, 81, 39–59, 2007.

29) Chen, Y., Wu, Z., Okamoto, K., Han, X., Ma, G., Chien, H., and Zhao, J. "The impacts of climate change on crops in China: A Ricardian analysis." *Global and Planetary Change*, *104*, 61–74, 2013.

30) Deschenes, O., and Greenstone, M. "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather." *American Economic Review*, 97, 354–385, 2007.

31) Mendelsohn, R., and Dinar, A. "Climate change, agriculture, and developing countries: does adaptation matter?" *The World Bank Research Observer*, 14, 277–293, 1999.

32) Wang, J., Mendelsohn, R., Dinar, A., Huang, J., Rozelle, S., and Zhang, L. "The impact of climate change on China's agriculture." *Agricultural Economics*, 40, 323–337, 2009.

33) Cameron, A. C., and Trivedi, P. K. *Microeconometrics: methods and applications*. Cambridge university press. 2005.

34) Ministry of Agriculture, Forestry and Fisheries (MAFF). *Area of Cultivated Land, and Expansion and Dilapidation of Cultivated Land*. 2016. (in Japanese).

35) Kawashima, H. *Food Production and Biomass Energy in the World: Perspectives in 2050*.; University of Tokyo Press: Tokyo, Japan, 2008. (in Japanese).

36) Tanaka, K., Managi, S., Kondo, K., Masuda, K., and Yamamoto, Y. "Potential climate effect on Japanese Rice productivity." *Climate Change Economics*, 2, 237–255, 2011.

37) Iizumi, T., Yokozawa, M., Hayashi, Y., and Kimura, F. "Climate change impact on rice insurance payouts in Japan." *Journal of Applied Meteorology and Climatology*, 47, 2265–2278, 2008.

38) Kawatsu, S., Homma, K., Horie, T., and Shiraiwa, T. (2007), "Change of Weather Condition and its Effect on Rice Production during the Past 40 Years in Japan.", *Japanese Journal of Crop Science*, 76, 423–432, 2007. (in Japanese).

39) Yokozawa, M., Iizumi, T., and Okada, M. "Large scale projection of climate change impacts on variability in rice yield in Japan." *Global Environmental Research*, 14, 199–206, 2009. (in Japanese).

40) Seo, S. N., and Mendelsohn, R. "Measuring Impacts and Adaptations to Climate Change: A structural Ricardian model of African livestock management." *Agricultural Economics*, 38, 151–165, 2008.

41) Jacoby, H. G., Rabassa, M., and Skoufias, E. "Distributional implications of climatechange in rural India: A general equilibrium approach." *American Journal of Agricultural Economics*, 97, 1135–1156, 2015.