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Dynamic Panel Data Analysis of the Impacts of Climate Change on Agricultural Production in Japan

Suminori TOKUNAGA[1]*, Mitsuru OKIYAMA[2] and Maria IKEGAWA[3]

[1] Faculty of Economics and Business Administration, Reitaku University (Kashiwa, Chiba 277-8686, Japan) and Faculty of Life and Environmental Sciences, University of Tsukuba (Tsukuba, Ibaraki 305-8572, Japan)
[2] Reitaku Institute of Political Economics and Social Studies, Reitaku University (Kashiwa, Chiba 277-8686, Japan)
[3] Graduate School of Life and Environmental Sciences, University of Tsukuba (Tsukuba, Ibaraki 305-8572, Japan)

Abstract

This study empirically identifies the impact of global-warming-induced climate change on Japan's agricultural production using panel data. First, we constructed panel data; combining time-series data from 1995 to 2006 for a cross-section of eight regions in Japan. Next, we conducted a static panel data analysis, using a function for agricultural products incorporating labor and three weather variables (temperature, solar radiation, and precipitation.) From the estimation results of the production function, we selected the production function with the aforementioned labor and weather variables and found that the rising temperatures and precipitation and falling solar radiation caused by climate change have reduced the rice production, while rising temperatures and precipitation have reduced the vegetable and potato production in Japan. Second, we conducted dynamic panel data analysis, using a production function for agricultural products incorporating labor, a one-period lagged output, and the same three weather variables. Based on the estimation results of the dynamic panel data model, we selected the production function for agricultural products using only the labor and three weather variables and found the same results for both the rice production and vegetable and potato production in Japan. Based on the estimated results of the static and dynamic-panel data models for variable mean annual temperature, which serves as a proxy for climate change, we concluded that an increase of 1°C in mean annual temperature would reduce rice production by 5.8% in the short term and 3.9% in the long term, and vegetables and potatoes productions by 5.0% and 8.6% in the short term and long term, respectively.

Discipline: Agricultural economics
Additional key words: panel data analysis, precipitation, rice, solar radiation, vegetables and potatoes productions

Introduction

Scholars began debating the problem of global warming in the 1980s. In 1988, governments set up the "Intergovernmental Panel on Climate Change" as a forum to study global warming and as measures to reduce greenhouse-gas emissions, a major cause of global warming. While production in the manufacturing, electric power, and transportation sectors generate approximately 90% of greenhouse-gas emissions, the industries worst affected by global-warming-induced climate change are agriculture, forestry, and fisheries (Tokunaga et al. 2008). Considering changes in mean global temperatures over a century, we observe that the Earth has warmed by 0.7°C, since around 1900, while over the past 30 years, global temperatures have risen rapidly and continuously at a rate of approximately 0.2°C per decade, as shown in Figure 3 of Stern (2007). Consequently of these climatic and environmental changes, since the 1990s, extreme weather events, such as floods and droughts, have had a serious impact on global agricultural and food production. Most scholars attribute these unusual weather phenomena to global warming (Stern 2007).

The present study estimates the extent to which climate change is affecting Japan's agricultural production by introducing weather variables into the production function and

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*Corresponding author: e-mail tokunaga@reitaku-u.ac.jp
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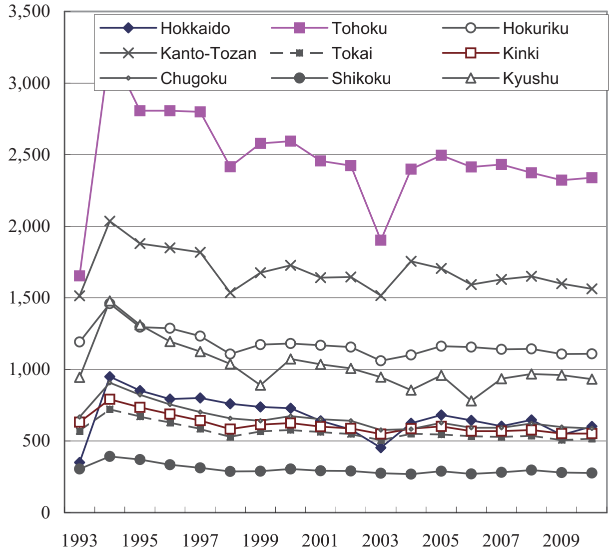
using these parameters to identify the effects of climate change on agricultural production, explaining which will require long-term data. However, this study mitigated the issue by constructing panel data comprising time-series data as well as data from eight regions in Japan having demonstrated regional differences in both agricultural production and climate. Using this panel data, we identify the effects of climate change on agricultural production through panel data analysis, a method of measurement that considers regional characteristics.

This paper proceeds as follows: Section 2 explains how we compiled the panel data and outlines the agricultural-production and climate-change trends. Based on these findings, Section 3 presents the panel data analysis and its estimated results. Finally, Section 4 concludes and discusses topics for future study.

Trends in Climate Change and Agricultural Production

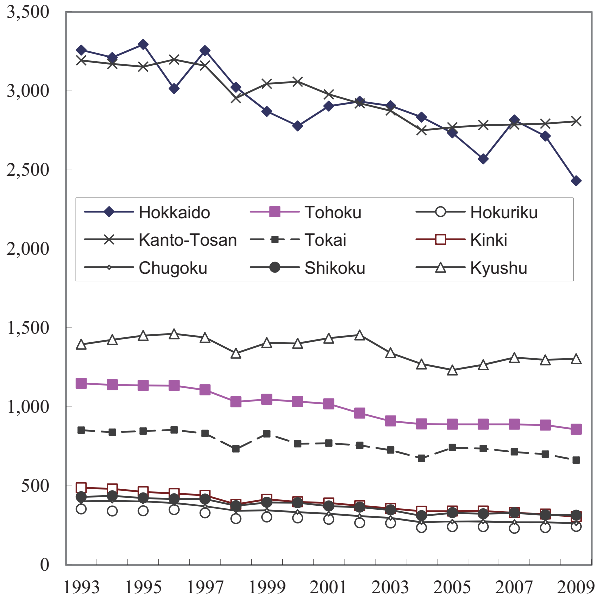
We first explain how the panel data was compiled. The regional divisions comprised nine regions used in various statistics by the Ministry of Agriculture, Forestry and Fisheries: Hokkaido, Tohoku, Hokuriku, Kanto-Tosan, Tokai, Kinki, Chugoku, Shikoku, and Kyushu (excluding Okinawa). The two agricultural product categories selected to investigate the extent to which climate change is affecting agricultural production in Japan were (1) rice and (2) vegetables and potatoes and crop yield data was compiled from 1995 to 2006 (Okiyama et al. 2013). We specifically aggregated and calculated the yield of nine varieties of vegetables and tuber/root crops, including white radishes, potatoes, carrots, Chinese cabbage, Japanese cabbage, green onions, cucumbers, eggplants, and tomatoes.

Figure 1a depicts the variation in total rice production; reflecting phenomena such as the national crop failure of 1993 and regional crop failures of 2003 and 2006, both of which appear attributable to abnormal weather patterns at national and regional levels. As shown in Figure 1b, variation in the total production of vegetables and potatoes included a temporary decline in certain years and in specific regions, although not to the same extent as that of rice crops. Next, the “Report of the Statistical Survey on Farm Management and Economy” and the “Census of Agriculture and Forestry” were used as sources for data on labor as an explanatory variable. From the former source, we collected data on man hours expended per single farming household[1], whereas the latter source determined the number of these households, as required to calculate the total man hours.



Notes: Unit is 1000t.
Source: the Ministry of Agriculture, Forestry and Fisheries

Fig. 1a. Rice production by region



Notes: Unit is 1000t.
Source: the Ministry of Agriculture, Forestry and Fisheries

Fig. 1b. Vegetable and potato productions by region (1000 t)

Finally, we explain the weather variables. For meteorological data, figures from 1990 to 2006 were provided by AMeDAS[2]. The data was cross-sectioned by municipality and monthly figures for temperature, solar radiation, and precipitation, and arranged in two series: annual averages and fixed interval averages. Figure 2 depicts the variation

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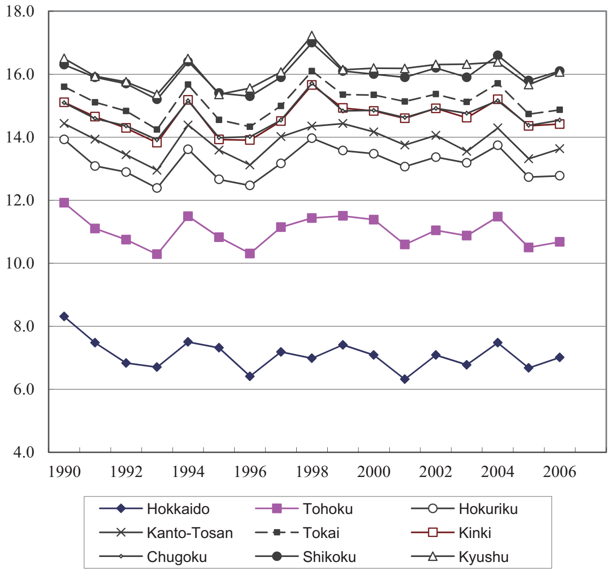
[1] A single farming household earns money from major farm products, which accounts for more than 80% of its sum total of cash receipts.

[2] We were using prefectural data processed by Dr. Nishimori, who belongs to the National Institute for Agro-Environment Sciences, according to specific observatory data of AMeDAS. We are grateful to him for his cooperation.



Notes: The unit is °C. These data are provided by the AMeDAS.

Fig. 2. Mean annual temperature by region

in mean annual temperature by region. Even when examining variations in average regional temperatures over a decade, no clear upward trend could be determined. However, temperature variations from 1993 to 1994 and in 1998 and 2004 significantly exceeded normal values by roughly 1°C, thus constituting abnormal weather. Even allowing for variations in average annual solar radiation from April to October, solar radiation in the years 1993, 1998, 2003, and 2006 decreased by 0.5–1.0 MJ/m^2 compared with the annual average. Further, regional precipitation data reveals above-average precipitation in the years in question.

Panel Data Analysis

1. Static Panel Data Model

First, before we specify the production function of this paper, we will review previous studies. The purpose of measuring the production function of rice in Japan was to clarify how the structure, efficiency, and productivity of Japanese agriculture have changed. Accordingly, the production function has mainly been used to estimate the rice-production function. Previous studies include Egaitsu and Shigeno (1983), Fukuchi and Tokunaga (1983), Nakashima (1989), Kondo (1991), and Takahashi (1991). In addition, there are studies on the measurement of the profit function (Kuroda 1979, Kako 1984, Godo 1991) and the cost function (Kusakari 1985, Kuroda 1988) as the dual production-function problem. Further, to quantitatively investigate the effect of programs set aside and the recent transfer of agricultural land to deal with the structural problem of agriculture in Japan, Sakamoto and Kusakari (2009) and Saito and Ohashi (2008) tried to estimate the rice-production function.

The estimated equations for the production functions presented in these studies have a common pattern: the rice yield is determined mainly by the three factors of land, labor, and capital. According to Egaitsu and Shigeno (1983), rice-production technology can be classified into mechanical (M) technology and biochemical (BC) technology; both of which complement each other. They have also pointed out that the BC function comprising BC technology with constant returns to scale to substitute completely for the land and fertilizer, and M functions comprising M technology with an increasing return to substitute completely for capital and labor. The BC function has also assumed homogeneous of degree one. For example, Takahashi (1991) used the Cobb–Douglas production function and cross-sectional data of each prefecture by scale in the Hokuriku region (the same method as Egaitsu and Shigeno (1983)) to estimate the M function comprising M technology, and the BC functions comprising BC technology, respectively. According to the estimation results, the parameter of land in the BC function is 0.999, i.e. approximately 1.0. Conversely, the capital and labor parameters in the M function are 0.9063 and 0.2666, respectively. In addition, Saito and Ohashi (2008) estimated the Cobb–Douglas, Stone–Geary type, CES type, and translog production functions, using panel data of the prefecture. According to the results of each function form, the land parameters (acreage) are measured within the range 0.79–0.99. In particular, the land parameter by the Cobb–Douglas function is 0.995. According to Sakamoto and Kusakari (2009), the land parameter (acreage), as estimated by the set aside rate and management land area, is also 0.7074 and significant when using the translog production function.

In this paper, we tried to estimate the Cobb–Douglas production function (1) for rice production with explanatory variables of three production factors, using panel data of 120 samples from eight regions, except Hokkaido, from 1995 to 2009.[3]

$$Ln(Q_{it}) = \alpha + \beta_i Ln(S_{it}) + \gamma_i Ln(K_{it}) + \delta_i Ln(L_{it}) + \varepsilon_{it} \qquad (1)$$

where Q_{it} represents the production of region i in year t and S_{it}, K_{it}, and L_{it} represent the land, capital, and labor expended in region i in year t, respectively.

The estimated results are shown in Table 1 and we found multicollinearity between the three explanatory variables such as land, labor and private capital. Consequently, we cannot adopt these variables simultaneously and must adopt one variable only. The two variables of capital and labor are insignificant in specification A-1; only the variable land is significant. The land parameter obtained by the fixed-effects model, which is selected by the Hausman test,

Table 1. Estimated results of the Cobb−Douglas production function of rice

	Fixed Effects Model				Random Effects Model			
Number of sample is 120	A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4
Ln(S)	0.8713***	0.9489***			1.0191***	1.0468***		
	(8.93)	(16.47)			(32.82)	(56.03)		
Ln(K)	0.0039		-0.0455		0.0238		-0.0259	
	(0.17)		(-1.54)		(1.24)		(-0.82)	
Ln(L)	0.3247		0.2642***	0.2598***	0.0121		0.2805***	0.2792***
	(1.01)		(10.54)	(10.37)	(0.55)		(10.41)	(10.39)
Constant term	2.7834***	2.2337***	11.4600***	10.9560***	0.9739***	1.0548***	11.0530***	10.7535***
	(2.72)	(3.22)	(27.46)	(41.97)	(4.36)	(4.68)	(24.28)	(36.16)
F-Test (vaule of F)	90.18	271.27	55.65	107.57				
Prob>F	(0.000)	(0.000)	(0.000)	(0.000)				
Hausman Test (value of χ^2)	6.19	3.22	-7.61	-3.99	6.19	3.22	-7.61	-3.99
Prob>χ^2	(0.1027)	(0.0727)			(0.1027)	(0.0727)		
Breusch and Pagan Test (value of χ^2)					13.42	41.07	399.69	360.94
Prob>χ^2					(0.000)	(0.000)	(0.000)	(0.000)
Adjustment-R^2	0.993	0.993	0.768	0.810	0.993	0.993	0.791	0.810

note:***<.001,**<0.05,*<0.1,t-statistics in parentheses.

is 0.9489 in specification A-2. On the other hand, when the Cobb–Douglas production function was estimated with capital and labor variables, except land, the variable of capital is insignificant in specification A-3 and the variable of labor is significant in specification A-4.[4] When adding the weather variables to the production function with land, the results are insignificant. Accordingly, we would like to adopt the production function with the labor and weather variables to measure the impact of climate change in equation (2).

Next, we will explain the weather variables added to the production function with labor. Previous studies have analyzed the impact of climate change on rice yield (Nishimori & Yokozawa 2001, Kawatsu et al. 2007, Shimono 2008, Yokozawa et al. 2009). Many of these studies have simulated the potential of rice growth, using data of the average daily minimum temperature during the rice-heading season, the minimum and maximum daily temperatures, and the total daily solar radiation to evaluate the impact of global warming on rice-yield fluctuations. We will adopt the mean annual temperature rather than the temperature measured over that period because a future temperature increase is predicted by year, and we deal with vegetable and potato produce, which is grown all year round, as well as rice.

A static panel data analysis, using time-series data from 1995 to 2006 and a cross-section of the eight regions, except Hokkaido, was conducted to determine the impact of climate change on agricultural production.[5] When estimating this production function with labor and weather as explanatory variables, we used the least squares dummy variable (LSDV) as the estimation method.[6] For weather variables, we adopted the variables of “mean solar radiation from April to October” and “average precipitation from August to October” as well as “mean annual temperature,” which directly indicates global-warming-induced climate change. Cross-sectional data on rice-harvest estimates were used from eight regions, excluding Hokkaido, and from seven regions, excluding Hokkaido and Hokuriku, to estimate vegetable and potato production.

In this subsection, we estimate the static panel data model for the production function, using the panel data of production and vegetable and potato production (as dependent variables), with the total man hours of farmers producing these products and the weather (as explanatory variables). Table 2 provides detailed descriptions of the explanatory variables used in the model.

We adopt the production function of equation (2).

$$ln(Q_{it}) = \alpha + \beta_1 ln(L_{it}) + \delta_1 ln(tema_{it}) + \delta_2 ln(suns_{it}) + \delta_3 ln(rains_{it}) + \varepsilon_{it} \qquad (2)$$

where Q_{it} represents the production of region i in year t, L_{it}

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[3] The main reason for excluding Hokkaido is that it differs from other regions in Japan in terms of productivity and the ratio of inputs on capital and labor.

[4] From Table 1, we cannot judge whether the fixed-effects or random-effects model is preferable because they fail to meet the asymptotic assumption of the Hausman test. However, it is pointed out that the fixed-effects model should be selected because it has at least maintained consistency.

[5] The years of abnormal weather in 1998 and 2004 are included in the time-series data.

[6] See Greene (2011).

Table 2. Detailed descriptions of explanatory variables used in the model

Variables	Definition	Unit	Mean	Std. Err.
ln L_rice	total labor time expended of all farm household of rice farming	(1000hours)	10.4937	0.0653
ln L_veget	total labor time expended of all farm household of veget able and potato farming	(1000hours)	10.9089	0.0811
ln Qt-1_rice	rice production of region in previous year	(1000t)	13.6884	0.0683
ln Qt-1_veget	vegetable and potato production of region in previous year	(1000t)	13.4654	0.0848
ln tema	mean annual temperature	(°C)	2.6448	0.0117
ln suna	mean annual solar radiation	(MJ /m^2)	2.4933	0.0063
ln suns	mean solar radiation from April to October	(MJ /m^2)	2.6636	0.0063
ln raina×100	mean annual precipitation	(100mm)	4.9658	0.0223
ln rains×100	mean precipitation from August to October	(100mm)	5.0948	0.033

represents the total labor expended in region *i* in year *t*, $tema_{it}$ represents the mean annual temperature of region *i* in year *t*, $suns_{it}$ represents the mean solar radiation from April to October in region *i* in year *t*, and $rains_{it}$ represents the mean precipitation from August to October in region *i* in year *t*. Accordingly, when equation (2) is estimated with significance, we can measure the impact of climate change on crop yields in that, if the mean annual temperature (*tema*) rises by 1%, the yield of the relevant agricultural products (Q_t) changes by only δ_1% (output elasticity with respect to temperature).

Table 3 reports the estimation results of the rice-production function. In specifications from S-A.1 to S-A.6, the coefficients of labor input are positive and statistically significant, while output elasticity with respect to labor is almost 0.29. In contrast, the coefficients of mean annual temperature (*tema*) are negative and statistically significant in specifications S-A.1, S-A.4, S-A.5, and S-A.6. Each output elasticity with respect to temperature is between −0.39 and −0.82. The higher magnitude of this elasticity in S-A.1 is −0.82, so when the average temperature rises by 1% in a year, the rice production decreases to approximately 0.82%. These measurement results are not necessarily consistent with those of previous studies, as described above[7]. For example Yokozawa et al. (2009) estimated that the average national rice yield was expected to increase slightly or remain constant until the temperature rose by 3°C, during the warm season from April to October, and if the rise were to exceed 3°C, the rice yield might decline in regions, except for Hokkaido and Tohoku (p. 204). The estimation results of their paper are derived from the relationship between rice production and temperature trend during the warm season in the past in each respective region, divided into the four regions of Japan. However, we used panel data from an area from Tohoku to Kyushu, where differences for two regions in mean annual temperature and in the warm season, namely April to October, reached 5.1 and 4.3°C, respectively. When viewed from this perspective, we estimated the equation with the panel data, including samples with a temperature difference exceeding 3°C as highlighted by Yokozawa et al. (2009). Therefore, our results match those of their paper.

The coefficients of solar radiation (from April to October, *suns*) are positive and statistically significant for S-A.2, S-A.4, and S-A.6 specifications, while each output elasticity with respect to solar radiation is between 0.56 and 0.64. The higher magnitude of this elasticity in S-A.2 is 0.64, so when the average solar radiation (from April to October) increases by 1% in a year, the rice production increases to approximately 0.64%. The coefficients of precipitation (from August to October, *rains*) are negative and statistically significant in specifications S-A.3, S-A.5, and S-A.6, while each output elasticity with respect to precipitation is between −0.05 and −0.08. The higher magnitude of this elasticity in S-A.3 is −0.08, so when the average precipitation rises by 1% from August to October, the rice production decreases to approximately 0.08%.

Table 4 reports that for vegetables and potatoes, only the labor parameter is statistically significant. In specifications from S-B.1 to S-B.6, the coefficients of labor input are positive and statistically significant and output elasticity with respect to labor is approximately 0.59. In contrast, the coefficients of mean annual temperature (*tema*) are negative and statistically significant for S-B.1, S-B.4, S-B.5, and S-B.6 specifications. Each output elasticity with respect to temperature is between −0.66 and −0.70. Since the higher magnitude of this elasticity in S-B.1 is −0.70, when the average temperature rises by 1% in a year, the production of vegetables and potatoes decreases to approximately 0.70%. The coefficients of mean annual solar radiation (*suna*) are not statistically significant in specifications S-B.2, S-B.4, and S-B.6, whereas those of mean annual precipitation

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[7] Shimono (2008) pointed out that the trend of the recent temperature increase in spring might increase the risk of cold damage to rice in the northern part of Japan. In addition, Kawatsu et al. (2007) estimated that a 1°C increase in the average daily minimum temperature between 10 and 30 days after the rice-heading period reduced the ratio of first-class rice by 3.57% and that a 1 Mj increase in the average daily solar radiation increased the ratio by 2.59%.

Table 3. Estimated results of the rice production function on the static panel data model

Number of sample is 94	S-A.1	S-A.2	S-A.3	S-A.4	S-A.5	S-A.6
ln (L)	0.2816***	0.3200***	0.2858***	0.2969***	0.2764***	0.2917***
	(9.57)	(11.67)	(9.70)	(11.23)	(9.53)	(11.28)
ln (tema):Annual Mean temperature (°C)	-0.8161***			-0.6589***	-0.5508**	-0.3948*
	(-4.08)			(-3.64)	(-2.35)	(-1.88)
ln (suns):Mean solar radiation during Apr.-Oct. (MJ/m^2)		0.6382***		0.5619***		0.5614***
		(5.21)		(4.82)		(4.94)
ln (rains×100):Mean precipitation during Aug.-Oct. 100mm			-0.0805***		-0.0496**	-0.0494**
			(-3.91)		(-2.07)	(-2.32)
Dummy_Tohoku	0.2912***	0.6236***	0.5901***	0.3871***	0.3921***	0.4876***
	(3.63)	(16.22)	(14.87)	(5.21)	(4.23)	(5.78)
Dummy_Hokuriku	-0.1205**	0.0431*	0.0435	-0.0822*	-0.0642	-0.0262
	(-2.60)	(1.68)	(1.60)	(-1.96)	(-1.21)	(-0.55)
Dummy_Kanto-Tosan	0.2796***	0.4221***	0.3926***	0.3275***	0.3164***	0.3641***
	(7.21)	(15.89)	(14.31)	(9.10)	(7.53)	(9.47)
Dummy_Tokai	-0.4419***	-0.3395***	-0.3851***	-0.4001***	-0.4274***	-0.3857***
	(-12.38)	(-11.16)	(-12.16)	(-12.14)	(-11.96)	(-11.78)
Dummy_Kinki	-0.4672***	-0.3424***	-0.4081***	-0.4187***	-0.4567***	-0.4084***
	(-13.45)	(-12.86)	(-14.43)	(-12.86)	(-13.25)	(-12.74)
Dummy_Chugoku	-0.5610***	-0.5079***	-0.4985***	-0.5632***	-0.5432***	-0.5454***
	(-18.26)	(-20.85)	(-19.48)	(-20.56)	(-17.32)	(-19.63)
Dummy_Shikoku	-1.0458***	-0.9509***	-0.9787***	-1.0313***	-1.0336***	-1.0192***
	(-24.24)	(-28.13)	(-26.66)	(-26.74)	(-24.17)	(-26.84)
Constant term	13.1421***	8.7546***	11.2470***	11.0337***	12.7168***	10.6120***
	(18.95)	(19.26)	(32.44)	(14.58)	(17.88)	(13.96)
Adjusted R-square	0.9912	0.9920	0.9910	0.9930	0.9915	0.9933

***<.001, **<0.05, *<0.1, t-statistics in parentheses.

Table 4. Estimated results of the vegetable and potato production function on the static panel data model

Number of sample is 84	S-B.1	S-B.2	S-B.3	S-B.4	S-B.5	S-B.6
ln (L)	0.5926***	0.6220***	0.6158***	0.5931***	0.5932***	0.5934***
	(9.19)	(9.23)	(9.30)	(9.13)	(9.14)	(9.08)
ln (tema):Annual Mean temperature (°C)	-0.7017***			-0.6985***	-0.6645**	-0.6710**
	(-3.00)			(-2.96)	(-2.37)	(-2.34)
ln (suna):Annual Mean solar radiation (MJ/m^2)		0.0810		0.0438		0.0292
		(0.38)		(0.22)		(0.13)
ln (raina×100):Annual Mean precipitation 100mm			-0.0967*		-0.0155	-0.0119
			(-1.77)		(-0.24)	(-0.17)
Dummy_Tohoku	0.2103	0.5288***	0.4793***	0.2179	0.2205	0.2232
	(1.58)	(5.58)	(5.27)	(1.57)	(1.57)	(1.56)
Dummy_Kanto-Tosan	0.5150***	0.6097***	0.5710***	0.5162***	0.5140***	0.5150***
	(10.23)	(14.52)	(12.38)	(10.13)	(10.11)	(9.95)
Dummy_Tokai	-0.1892***	-0.1286***	-0.1478***	-0.1879***	-0.1889***	-0.1881***
	(-4.19)	(-2.97)	(-3.41)	(-4.1)	(-4.15)	(-4.07)
Dummy_Kinki	-0.3748***	-0.2603**	-0.3081***	-0.3705***	-0.3756***	-0.3726***
	(-3.8)	(-2.63)	(-3.14)	(-3.66)	(-3.78)	(-3.63)
Dummy_Chugoku	-0.3790***	-0.2620**	-0.2962**	-0.3779***	-0.3782***	-0.3777***
	(-3.14)	(-2.17)	(-2.47)	(-3.11)	(-3.11)	(-3.09)
Dummy_Shikoku	-0.8718***	-0.7880***	-0.8151***	-0.8712***	-0.8717***	-0.8713***
	(-15.8)	(-15.65)	(-15.78)	(-15.67)	(-15.7)	(-15.57)
Constant term	9.0092***	6.5102***	7.2881***	8.8837***	8.9784***	8.9020***
	(8.47)	(6.79)	(8.75)	(7.31)	(8.33)	(7.25)
Adjusted R-square	0.9920	0.9911	0.9914	0.9919	0.9919	0.9918

***<.001, **<0.05, *<0.1, t-statistics in parentheses.

Table 5. Estimated results of the rice production function on the dynamic panel data model

Number of sample is 88	D-A.1	D-A.2	D-A.3	D-A.4	D-A.5	D-A.6
ln (L)	0.1905***	0.1559***	0.1874***	0.1582***	0.1940***	0.1614***
	(4.70)	(5.10)	(4.67)	(5.02)	(4.80)	(5.15)
ln (Qt-1)	0.1981**	0.3644***	0.2124**	0.3536***	0.1818*	0.3391***
	(2.09)	(5.31)	(2.31)	(4.66)	(1.92)	(4.46)
ln (tema):Annual Mean temperature (°C)	-0.4420**			-0.0593	-0.2938	0.0568
	(-2.06)			(-0.34)	(-1.23)	(0.30)
ln (suns):Mean solar radiation during Apr.-Oct. (MJ/m^2)		0.7581***		0.7476***		0.7408***
		(7.86)		(7.35)		(7.33)
ln (rains×100):Mean precipitation during Aug.-Oct. 100mm			-0.0471**		-0.0334	-0.0270
			(-2.15)		(-1.36)	(-1.43)
Dummy_Tohoku	0.3692***	0.4948***	0.5238***	0.4780***	0.4319***	0.5276***
	(4.11)	(9.79)	(7.78)	(6.76)	(4.3)	(6.74)
Dummy_Hokuriku	-0.0222	0.0705***	0.0672**	0.0589	0.0091	0.0834*
	(-0.45)	(3.39)	(2.47)	(1.48)	(0.17)	(1.93)
Dummy_Kanto-Tosan	0.2849***	0.3226***	0.3427***	0.3173***	0.3112***	0.3383***
	(5.99)	(9.68)	(7.73)	(8.61)	(6.09)	(8.58)
Dummy_Tokai	-0.3531***	-0.2200***	-0.3148***	-0.2291***	-0.3485***	-0.2266***
	(-6.25)	(-5.78)	(-6.4)	(-4.92)	(-6.20)	(-4.89)
Dummy_Kinki	-0.3598***	-0.2111***	-0.3214***	-0.2220***	-0.3598***	-0.2233***
	(-6.28)	(-5.9)	(-6.73)	(-4.63)	(-6.31)	(-4.69)
Dummy_Chugoku	-0.4154***	-0.3142***	-0.3731***	-0.3247***	-0.4136***	-0.3241***
	(-6.66)	(-8.11)	(-7.08)	(-6.55)	(-6.67)	(-6.59)
Dummy_Shikoku	-0.8395***	-0.6446***	-0.7893***	-0.6611***	-0.8467***	-0.6685***
	(-7.69)	(-8.87)	(-8.01)	(-7.56)	(-7.79)	(-7.68)
Constant term	10.2980***	5.0882***	9.1458***	5.4065***	10.2466***	5.4093***
	(7.25)	(5.81)	(8.35)	(4.23)	(7.25)	(4.26)
Adjusted R-square	0.9921	0.9954	0.9921	0.9953	0.9922	0.9954

***<.001, **<0.05, *<0.1, t-statistics in parentheses.

(*raina*) are statistically significant in specification S-B.3.

2. Dynamic Panel Data Model

Based on the results of our static panel data model, we conducted a dynamic panel data analysis to examine the impact of long-term climate change on agricultural production in Japan. In this subsection, we add the lagged output variable as an explanatory variable to estimate a dynamic production model of equation (3).

$$ln(Q_{it}) = \alpha + \beta_1 ln(L_{it}) + \beta_2 ln(Q_{it-1}) + \delta_1 ln(tema_{it}) + \delta_2 ln(suns_{it}) + \delta_3 ln(rains_{it}) + \varepsilon_{it}. \quad (3)$$

where Q_{it-1} represents the production of region i in year t–1.

When equation (3) is estimated with significance, we can measure the degree of impact of long-term climate change on agricultural product yields. Table 5 reports the estimation results of the rice production function. In specifications from D-A.1 to D-A.6, the coefficients of labor input and lagged output variables are both positive and statistically significant. However, the coefficients of mean annual temperature (*tema*) are negative and statistically significant only in specification D-A.1. The output elasticity with respect to temperature is −0.44, while the coefficients of solar radiation (from April to October, *suns*) are positive and statistically significant in specifications D-A.2, D-A.4, and D-A.6. The output elasticity with respect to solar radiation is between 0.74 and 0.76, while the coefficients of precipitation (from August to October, *rains*) are negative and statistically significant only in specification D-A.3. The output elasticity with respect to precipitation is −0.05.

Table 6 reports that for vegetables and potatoes, only the labor parameter had statistical significance. In specifications D-B.1 to D-B.6, the coefficients of labor input and the lagged output variable are positive and statistically significant, respectively. However, the coefficients of mean annual temperature (*tema*) are negative and statistically significant only in specifications D-B.1 and D-B.4. The output elasticity with respect to temperature is −0.49. The coefficients of mean annual solar radiation (*suna*) are not statistically significant in specifications D-B.2, D-B.4, and D-B.6, while the coefficients of mean annual precipitation (*raina*) are negative and statistically significant in specifications D-B.3, D-B.5, and D-B.6. Each output elasticity, with respect to precipitation, is between −0.07 and −0.11.

Next, to analyze the long-term production behavior, we can calculate long-term output elasticity with respect to mean annual temperature, using parameters for both the current annual temperature and one-lagged output variable in the dynamic panel data model. Table 7 shows that if we assume the economy remains steady state in the long run,

Table 6. Estimated results of the vegetable and potato production function on dynamic panel data model

Number of sample is 77	D-B.1	D-B.2	D-B.3	D-B.4	D-B.5	D-B.6
ln (L)	0.1898***	0.1907**	0.1723**	0.1890***	0.1774**	0.1774**
	(2.76)	(2.61)	(2.51)	(2.73)	(2.60)	(2.58)
ln (Qt-1)	0.5870***	0.5898***	0.6113***	0.5883***	0.6031***	0.6029***
	(7.74)	(7.32)	(8.06)	(7.69)	(8.00)	(7.94)
ln (tema):Annual Mean temperature (°C)	-0.4973***			-0.4940***	-0.3021	-0.2887
	(-2.92)			(-2.88)	(-1.49)	(-1.39)
ln (suna):Annual Mean solar radiation (MJ/m^2)		0.0673		0.0415		-0.0558
		(0.46)		(0.30)		(-0.38)
ln (raina×100):Annual Mean precipitation 100mm			-0.1103***		-0.0741*	-0.0809*
			(-3.05)		(-1.71)	(-1.72)
Dummy_Tohoku	-0.0658	0.1376	0.0751	-0.0600	-0.0259	-0.0300
	(-0.64)	(1.64)	(0.95)	(-0.57)	(-0.25)	(-0.29)
Dummy_Kanto-Tosan	0.2092***	0.2841***	0.2270***	0.2097***	0.2002***	0.1987***
	(3.49)	(4.95)	(3.98)	(3.47)	(3.37)	(3.32)
Dummy_Tokai	-0.1366***	-0.1012***	-0.1190***	-0.1354***	-0.1342***	-0.1357***
	(-3.99)	(-2.95)	(-3.66)	(-3.9)	(-3.97)	(-3.97)
Dummy_Kinki	-0.2553***	-0.1984**	-0.2435***	-0.2518***	-0.2618***	-0.2672***
	(-3.37)	(-2.51)	(-3.27)	(-3.26)	(-3.5)	(-3.48)
Dummy_Chugoku	-0.2806***	-0.2290**	-0.2591***	-0.2802***	-0.2805***	-0.2811***
	(-3.04)	(-2.38)	(-2.86)	(-3.02)	(-3.08)	(-3.07)
Dummy_Shikoku	-0.4163***	-0.3662***	-0.3789***	-0.4152***	-0.4048***	-0.4053***
	(-5.9)	(-5.04)	(-5.55)	(-5.84)	(-5.79)	(-5.76)
Constant term	4.9249***	3.3203***	3.9759***	4.8021***	4.6842***	4.8272***
	(5.47)	(3.71)	(5.17)	(4.83)	(5.22)	(4.92)
Adjusted R-square	0.9964	0.9959	0.9964	0.9963	0.9965	0.9964

***<.001, **<0.05, *<0.1, t-statistics in parentheses.

Table 7. Short- and long-term output elasticity with respect to mean annual temperature

	Elasticity of short-term climate change	Elasticity of long-term climate change
Rice	-0.816	-0.551
Vegetables and Potatoes	-0.702	-1.204

the long-term output elasticity with respect to mean annual temperature of rice yields is −0.55, so when the average temperature rises by 1%, the rice production decreases to approximately 0.55% in the long run.[8] This impact is less than the result of the static panel data model. Conversely, the long-term output elasticity of the vegetable and potato yield is −1.20. Accordingly, when the average temperature rises by 1%, the vegetable and potato production decreases to approximately 1.20% in the long run, with an impact exceeding the result of the static panel data model. Therefore, we conclude that farmers tend to refrain from cultivating certain types of vegetables and potatoes in the long run.

Based on the estimated results of the static and dynamic panel data models, for the variable of mean annual temperature, which serves as a proxy for climate change, we found that an increase of one degree reduces the rice yield by 5.8 and 3.9% and the vegetable and potato yield by 5.0 and 8.6% in the short- and long term, respectively.

Conclusions and Challenges for the Future

This study empirically demonstrated the negative impacts of global-warming-induced climate change on Japan's agricultural production. First, a static panel data analysis was conducted for the production function of agricultural products using panel data comprising time-series data from 1995 to 2006 and a cross-section of eight regions in Japan, with weather variables of temperature, solar radiation, and precipitation. Based on the estimation results of the static panel data model of the production function, we selected a production function with only the labor variable and aforementioned weather variables, and found that the rising temperatures and precipitation and decreasing solar radiation caused by climate change had reduced the rice production in Japan. We also found that rising temperatures and precipitation had reduced the vegetable and potato production in Japan. Second, a dynamic panel data analysis was conducted, using a production function for agricultural products, incorporating labor, a one-period lagged output,

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[8] As the economy reaches a steady state in the long run, its output remains constant over time, namely $Q_{it} = Q_{it-1} = Q_{i*}$. Accordingly, we calculate that the long-term output elasticity with respect to the mean annual temperature of the rice is −0.55 [=−0.44/(1 − 0.1981)].

and the three weather variables. The estimation result of the dynamic panel data model of the production function demonstrated equivalent results for both rice- and vegetable and potato productions in Japan as the static panel data model. Based on the estimated results of the static and dynamic panel data models, for the variable of mean annual temperature, which serves as a proxy for climate change, it was concluded that an increase of one degree in mean annual temperature reduces the rice production by 5.8 and 3.9% and the vegetable and potato production by 5.0 and 8.6% in the short- and long term, respectively.

Finally, we consider topics for future study. The present study found regional differences in the effect of climate change on agricultural production. Apart from Hokkaido, a mean annual temperature increase of 1°C reduced Japan's regional rice production by 3.9–5.8% and that of vegetables and potatoes by 5.0–8.6%, respectively. In future, we intend to construct a dynamic, regional general equilibrium model for nine regions, including Hokkaido. Such a model would identify the impact of global-warming-induced climate change on Japan's agricultural production and regional economy as well as the economic impact of any proposed countermeasures to this problem.

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