CHARACTERISTICS OF AGRICULTURE IN JAPANESE REGIONS AND CONVERGENCE: AN EMPIRICAL ANALYSIS USING PANEL UNIT ROOT TEST*

By TOMOKO KINUGASA† and YUKIO FUKUMOTO‡

This research investigates whether several characteristics of agriculture in Japanese regions were converging empirically. Four kinds of panel unit root tests imply that agricultural income per farm tended to converge among Japanese prefectures from 1965 to 1995. However, other characteristics of agriculture did not necessarily converge. The dependent ratio of agriculture in Hokkaido is so large that it would be difficult for other prefectures to match its level. We could not find strong evidence that agricultural research stock per farm was converging. Therefore, it is possible that agriculture had not been operating in a similar way throughout Japan.

1. Introduction

Japanese agriculture is facing a critical situation. The food self-sufficiency ratio has decreased year by year, and many farms abandoned agricultural pursuits or devoted more effort to businesses other than agriculture. Japan is a small country, and the limited amount of arable land is a serious problem. In such a situation, Japanese farms with relatively high productivity have expanded their agricultural land by absorbing smaller farm holdings in an attempt to strengthen their international competitiveness.

The purpose of this research is to investigate the convergence of characteristics of agriculture in Japanese regions by using the panel unit root test. The basic tenets of convergence theory are that an economy with low productivity tends to grow faster than one with higher productivity, and that a poor economy tends to catch up with a rich economy over the long run.1) Many previous studies tried to analyze this convergence by using not only income data from the whole economy but also agricultural data. Sasaki et al. (2005) found that the agricultural productivity of Japanese prefectures tended to converge after the policy of reducing rice acreage was enforced.2) Yamaguchi and Chen (1999) and Kinugasa (2000; 2004) find conditional convergence of agricultural productivity; after controlling for several variables that can affect growth in agricultural productivity, they found that agricultural productivity tends to converge among prefectures in Japan. No study thus far has analyzed the convergence of aspects other than productivity, although many have tried to analyze the convergence of Japanese agricultural productivity. Japan is a small country with a long, narrow shape. Weather and geographi-
cal conditions vary widely among the different regions. Whether several characteristics in each Japanese region other than agricultural productivity are moving towards sameness or diversity poses an interesting research question somewhat related to ours. We analyze agricultural income per farm, the degree of agricultural dependence, and agricultural research stock per farm.

Yamaguchi and Chen (1999) and Kinugasa (2000; 2004) tested the convergence hypothesis using the mean of the data from several years for each cross-section, but this does not adequately capture the annual change in the variables. This research uses the panel data of the agricultural variables with 47 cross-sections and 30 time periods. We analyze convergence based on all the variables that are available from the data for every year from 1965 to 1995. There are several studies that analyze the convergence of agricultural productivity by using a panel unit root test (see, for example, Suhariyanto and Thirtle (2001) and Kondo et al. (2005)). However, these studies use only the method devised by Levin et al. (2002). The value of using various empirical methods is to increase the robustness of the results. We analyze the convergence of each variable by using four modern variations of the panel unit root test.

Our empirical results show that agricultural income per farm tended to converge from 1965 to 1995. However, other characteristics of agriculture in Japanese prefectures, such as the dependent ratio of agriculture and agricultural research stock per farm, did not necessarily converge. Therefore, it is possible that agriculture was not managed in a similar fashion throughout Japan.

The rest of this paper is organized as follows. Section 2 presents the methods of the panel unit root test used in our empirical analyses. Section 3 explains the data used in the empirical analyses. We discuss the empirical results using the panel unit root test in section 4, before outlining the conclusions of this research in section 5.

2. Panel Unit Root Methodology

Let $A_{i,t}$ represent an agricultural variable in prefecture $i$, $i = 1, 2, \ldots, n$ at time $t$. The agricultural variable in prefecture $i$ at time $t$ is expressed in the following equation.

$$\ln A_{i,t} = \gamma_i + \lambda \frac{A_{f,t-1}}{A_{i,t-1}} + \ln A_{i,t-1} + \epsilon_{i,t},$$

where $\gamma_i$ is the asymptotic rate of growth of prefecture $i$, and $\epsilon_{i,t}$ is the error term. $A_{f,t-1}$ is the agricultural variable of prefecture $f$ at time $t-1$, and $f$ is the prefecture of the benchmark level. The parameter $\lambda$ represents the speed of convergence.

If a prefecture is the benchmark prefecture, equation (1) can be expressed as

$$\ln A_{f,t} = \gamma_f + \ln A_{f,t-1} + \epsilon_{f,t}.$$  

From equations (1) and (2),

$$\ln X_{i,t} = (\gamma_i - \gamma_f) + \rho \ln X_{i,t-1} + u_{i,t},$$

$$i = 1, 2, \ldots, N, \ t = 1, 2, \ldots, T, \ i \neq f.$$  

$$X_{i,t} = A_{i,t} / A_{f,t}, \ \rho = 1 - \lambda.$$
If $\rho = 1$ ($\lambda = 0$), then the gap between the levels of the agricultural variable in prefecture i and f does not diminish as time passes. That is, the agricultural variable does not converge among prefectures. In terms of the time-series analysis, the variable $\ln X_{i,t}$ has a unit root. On the other hand, if $\rho < 1$ ($\lambda > 0$), the gap between the levels of the agricultural variable in prefecture i and f does tend to diminish. Then, we may conclude that the agricultural variable converges among prefectures. In this case, $\ln X_{i,t}$ is considered to be stationary in terms of time-series analysis. We apply unit root test for equation (3). We consider two benchmark levels: Hokkaido and the mean of all prefectures. We first set the benchmark level at that of Hokkaido, where all three variables tended to be the highest of all prefectures, and analyze whether the variables in each prefecture were catching up to that level. Second, we set the benchmark level as the mean of all prefectures in each year. In this case, we analyze whether the level of each variable is converging with the mean of all prefectures.

We then investigate whether the gaps between agricultural variables in prefecture i and f were stationary by considering the characteristics of panel data using four kinds of panel unit root tests: the Levin, Lin, and Chu (LLC) test;\(^3\) the Im, Pesaran, and Shin (IPS) test;\(^4\) the Fisher augmented Dickey-Fuller (Fisher-ADF) test; and the Fisher Philips-Perron (Fisher-PP) test.\(^5\)

The structure of the panel unit root test in equation (3) can be written in a generalized form as follows:

$$\Delta \ln X_{i,t} = \gamma_i + (\rho_i - 1) \ln X_{i,t-1} + \sum_{l=1}^{p_i} \theta_{i,l-1} \Delta \ln X_{i,l-1} + u_{i,t},$$

(4)

where $p_i$ is the lag length, and $\rho_i - 1$ is the individual convergence speed.

### 2.1 LLC Test with Common Unit Root Process

The LLC test assumes that there is a common unit root process, so that $\rho_i$ in equation (4) is identical across the cross-sections; it examines the null hypothesis ($H_0$) against the alternative hypothesis ($H_1$) as follows:

$$H_0 : \rho_i = \rho = 0, \quad H_1 : \rho_1 = \rho < 1.$$  

(5)

The LLC test prescribes the use of the basic ADF test to each individual time period as the starting point of their testing procedure for unit roots. Thus, the regressions (4) are estimated by regressing $\Delta \ln X_{i,t}$ and $\ln X_{i,t-1}$ with respect to $\gamma_i$ and $\Delta \ln X_{i,l-1}$ ($L = 1, \ldots, p_i$); we obtain the residuals $\hat{e}_{i,t}$ and $\hat{v}_{i,l-1}$, respectively. To control for heterogeneity across individuals, we further normalize $\hat{e}_{i,t}$ and $\hat{v}_{i,l-1}$ by the standard error in the regressions (4), and we get $\tilde{e}_{i,t}$ and $\tilde{v}_{i,l-1}$.

Then, the LLC test estimates the parameter $(\rho - 1)$ using $\tilde{e}_{i,t}$ and $\tilde{v}_{i,l-1}$, and tests the null hypothesis $H_0 : \rho = 1$ in the following equation.

---

3) Levin et al. (2002).

4) Im et al. (2003).

The adjusted $t$–statistic that the LLC suggests is

$$\hat{\xi}_{1,t} = (\rho - 1)\hat{\eta}_{1,t-1} + \hat{\kappa}_{1,t}. \quad (6)$$

The adjusted $t$–statistic that the LLC suggests is

$$t = \left[ t_p - \left( N\hat{T} \right) \hat{S}_N \hat{\sigma}^{-2}\text{STD}(\hat{\rho}) \hat{\mu}^{*}_{t} / \hat{\sigma}^{*}_{t} \right] \to \text{N}(0,1), \quad (7)$$

where $\hat{T} = T - (\sum_{i=1}^{N} p_i / N) - 1$; $t_p$ is the standard $t$–statistic for $H_0 : \rho = 1$; $\hat{S}_N$ is the mean of the ratio of long-run to short-run standard deviation for each individual; $\hat{\sigma}^2$ is the variance of the error term $\hat{\kappa}_{1,i}$; $\text{STD}(\hat{\rho})$ is the standard error of the estimated $(\rho - 1)$ in equation (6); and $\hat{\mu}^{*}_{t}$ and $\hat{\sigma}^{*}_{t}$ are adjusted terms for the mean and standard deviations.

### 2.2 IPS, Fisher–ADF and Fisher–PP Tests with Individual Unit Roots

The IPS, Fisher-ADF and Fisher-PP tests allow $\rho_i$ in equation (4) to vary freely across the cross-sections. The null hypothesis ($H_0$) and the alternative hypothesis ($H_1$) of these three tests are

$$H_0 : \rho_i = 1 \quad \text{for all } i,$$

$$H_1 : \rho_i = 1 \quad \text{for } i = 1, 2, \ldots, N_1 \quad \text{and } \rho_i < 1 \quad \text{for } i = N_1 + 1, N_1 + 2, \ldots, N. \quad (8)$$

The $i$ may be reordered as necessary. The alternative hypothesis means that $\ln X_{1,t}$ is stationary for at least one $i$.

The IPS test specifies a separate ADF regression for each cross-section as equation (4). The separate ADF regressions are estimated, and the average of the $t$–statistics for $(\rho_i - 1)$, $t_{1,i}(\rho_i)$, from the individual ADF regressions, are calculated as follows:

$$\bar{t}_{NT} = \left( \sum_{i=1}^{N} t_{1,i}(\rho_i) \right) / N. \quad (9)$$

$\bar{t}_{NT}$ is adjusted to have the desired test statistics.

The IPS shows that a properly standardized $\bar{t}_{NT}$ has an asymptotic normal distribution:

$$W_{\bar{t}_{NT}} = \sqrt{N} \left( \bar{t}_{NT} - N^{-1} \sum_{i=1}^{N} E(\bar{t}_{1,i}(\rho_i)) \right) \to \text{N}(0,1). \quad (10)$$

$W_{\bar{t}_{NT}}$ is the test statistic for the IPS test.

The Fisher–ADF and Fisher–PP tests use Fisher’s (1932) methods to derive tests that combine the p–values from individual unit root tests. Let $\pi_i$ be the p–value from any individual unit root test for cross–section $i$. Under the null hypothesis of unit root for $N$ cross–sections, the following asymptotic results are obtained:

$$-2 \sum_{i=1}^{N} \log(\pi_i) \to \chi^2_{2N}. \quad (11)$$
Choi (2001) demonstrates that

$$Z = \sum_{i=1}^{N} \Phi^{-1}(\pi_i) / \sqrt{N} \to N(0,1),$$  \hspace{1cm} (12)$$

where $$\Phi^{-1}$$ is the inverse of the standard normal cumulative distribution function. We obtain Z-statistic values in equation (12) by using the ADF and the Phillips–Perron individual unit root tests.

3. Description of the Data

Our data is comprised of the agricultural income per farm, the dependent ratio of agriculture, and the agricultural research stock per farm. The dependent ratio of agriculture is defined as the share of the farm/household income derived from agricultural sources. If the dependent ratio of agriculture is high, agriculture can be assumed to be operated intensely. Agricultural research stock per farm represents the amount of knowledge regarding agriculture that is accumulated. It is calculated from the data by using the agricultural research expenditure amount.

We analyze the convergence hypothesis of characteristics of Japanese prefectures’ agriculture by panel unit root tests for the entire sample period (from 1965 to 1995), in addition to the first (1965–1980) and the last half (1981–1995) of the sample period. Moreover, the hypothesis is investigated within eastern and western parts of Japan for the entire sample period.

Figure 1 presents the graphs of the means for each variable for the prefectures of eastern and western Japan. Agricultural income per farm tended to be higher in eastern Japan than in western Japan. The mean agricultural income per farm for all prefectures and for eastern and western Japan decreased at the end of the 1970s and did not change significantly from 1980 to 1990. However, agricultural income per farm tended to increase in the 1990s (see Figure 1 [1]). The dependent ratio of agriculture tended to decrease rapidly from 1965 to 1980 and has remained low since, which may reflect a considerable increase in the percentage of part-time farming (Figure 1 [2]). Agricultural research stock per farm tended to increase throughout the sample period, thus possibly implying accumulated knowledge in agricultural research (Figure1 [3]).

4. Discussion of Empirical Results

Table 1 presents the results of panel unit root tests when Hokkaido is set as the benchmark prefecture. In Table 1 [1], the unit root hypothesis was rejected based on all four criteria in estimations using the entire sample and any sub-samples. The results show that agricultural income per farm tended to converge overall. The primary reason for this could be technological spillover; farms with lower productivity might apply new technology and thus increase their productivity enough to be considered as highly productive farms. It is also possible that

6) See Appendix 1 for sources and further descriptions about our data.
7) The data from 1965 to 1990 are obtained from Chen (1994). How to calculate the data after 1991 is described in Appendix 1.
8) See Appendix 2 for geographical explanations of Japan.
Figure 1 Changes in the means of the variables
owners of farms earning less income tend to quit farming, leaving only higher income farms to survive, thus explaining the convergence noted.

The null hypothesis that the dependent ratio of agriculture on the whole in Japan did not converge throughout the sample period is not rejected by IPS and Fisher–ADF tests (Table 1 [2]). When we test the unit root by using the first half of the sample period, all four tests support the convergence hypothesis at a significance level of 1 percent. In the latter half of the sample period, all but the LLC test reject the convergence hypothesis. All four tests prove that

<table>
<thead>
<tr>
<th>Table 1 The Results of Panel Unit Root Tests Regarding Matching the Levels of Hokkaido Prefecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
</tr>
<tr>
<td>[1] Agricultural income per farm</td>
</tr>
<tr>
<td>All prefectures 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1980</td>
</tr>
<tr>
<td>All prefectures 1981–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>LLC</td>
</tr>
<tr>
<td>IPS</td>
</tr>
<tr>
<td>F-ADF</td>
</tr>
<tr>
<td>F-PP</td>
</tr>
<tr>
<td>[2] Dependent ratio on agriculture</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1980 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1981–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>[3] Agricultural research stock per farm</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1980 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1981–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>[2] Dependent ratio on agriculture</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1980 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1981–1995 Eastern Japan 1965–1995</td>
</tr>
<tr>
<td>All prefectures 1965–1995 Eastern Japan 1965–1995</td>
</tr>
</tbody>
</table>

Note: The null hypothesis that variables in each prefecture tended to catch up to the prefecture with Hokkaido’s level is examined. Formal expressions about the null and alternative hypotheses are given in equations (5) and (8). “F-ADF” refers to the Fisher-ADF test. “F-PP” refers to the Fisher-PP test. The statistic for LLC is t in equation (7); for IPS, W_{t_i,n} in equation (10); and for F-ADF and F-PP, Z in equation (12). N is the number of observations.

CHARACTERISTICS OF AGRICULTURE IN JAPANESE REGIONS AND CONVERGENCE 31
the dependent ratio of agriculture in eastern Japan converged, but that of agriculture in western Japan did not. Possibly, the owners of farms with less agricultural income either quit farming entirely, or they decreased their agricultural production and replaced it with non-agricultural activities.

We know that agricultural divergence grew from 1980 to 1995. In eastern Japan, rice cropping is practiced within a relatively broad area, and the intensity of agriculture tended to converge. In western Japan, agriculture tends to be operated in mountainous terrain, and there are many small farms in the areas of Shikoku and Chugoku. The gap between the dependent ratios of agriculture in prefectures in western Japan and in Hokkaido, where larger tracts of arable land are available, seems to be expanding.

On the whole, agricultural research results per farm did not seem to converge (Table 1 [3]). The LLC and Fisher–PP tests demonstrate that agricultural research stock per farm did not tend to meet the Hokkaido results in the entire sample. Within the sub-samples from 1965 to 1980 and from 1981 to 1995, three tests did not reject the null hypotheses that the dependent ratio of agriculture did not converge. In eastern Japan, the LLC and Fisher–PP tests imply that agricultural research stock per farm did not tend to match Hokkaido’s level. This result is similar to that of the entire sample. In western Japan, none of the tests support the hypothesis that agricultural research per farm was converging to the level seen in Hokkaido. Therefore, the possibility that agricultural research results per farm tend to converge is low.

Agricultural research could be conducted intensely only in a limited area. Also, neighboring prefectures, as well as the prefecture where agricultural research is done, could benefit from agricultural research being carried out in a certain prefecture. Because the spillover effect of agricultural research is not considered, agricultural research stock did not seem to converge in the sample period.

Table 2 presents the results of panel unit root tests when we set the mean of all prefectures for each year as the benchmark level. Agricultural income per farm seems to converge to the mean of all prefectures from 1965 to 1995 in Table 2 [1]. All except the Fisher–PP test show that the dependent ratio of agriculture converges to the mean for any estimation in Table 2 [2]. This result is considerably different from that outlined in Table 1. The dependent ratio of agriculture did not tend to converge to the level of Hokkaido within sub-samples from 1981 to 1995 and within those of western Japan (Table 1); however, it did tend to converge to the mean of all prefectures, even within these sub-samples (Table 2). This might imply that the performance of the dependent ratio of agriculture in Hokkaido was unique. In Hokkaido, the dependent ratio of agriculture is much higher than in any other prefecture, and it would be difficult for other prefectures to match Hokkaido’s level.

We did not find strong evidence that agricultural research stock per farm was converging to the mean in the entire sample or in any sub-samples in Table 2 [3]. The LLC tests support the convergence hypotheses of agricultural research stock per farm in all prefectures for the entire

9) Shikoku area consists of Tokushima, Kagawa, Ehime, and Kochi prefectures. Chugoku area consists of Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi prefectures.

10) There is one exception. The Fisher–PP test does not reject the null hypothesis within the sub-sample from 1965 to 1980 for all prefectures.
sample, for the latter half of the sample periods, and in western Japan, but the convergence hypothesis is not supported in any other cases at the significance level of 5 percent. As mentioned above, agricultural research was not conducted evenly everywhere in Japan.

5. Conclusions

This research investigated the convergence of several characteristics of Japanese regional agriculture by using the panel unit root test. No previous research has analyzed the agricultural convergence of factors other than income or productivity. However, it would be important to

<table>
<thead>
<tr>
<th>Method</th>
<th>Statistic</th>
<th>P-value</th>
<th>Cross-sections N</th>
<th>Method</th>
<th>Statistic</th>
<th>P-value</th>
<th>Cross-sections N</th>
<th>Method</th>
<th>Statistic</th>
<th>P-value</th>
<th>Cross-sections N</th>
</tr>
</thead>
<tbody>
<tr>
<td>All prefectures 1965–1995</td>
<td>LLC</td>
<td>-10.78</td>
<td>0.000</td>
<td>All prefectures 1965–1980</td>
<td>LLC</td>
<td>-8.47</td>
<td>0.000</td>
<td>All prefectures 1965–1995</td>
<td>LLC</td>
<td>-1.66</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>IPS</td>
<td>-7.97</td>
<td>0.000</td>
<td></td>
<td>IPS</td>
<td>-7.37</td>
<td>0.000</td>
<td></td>
<td>IPS</td>
<td>-0.94</td>
<td>0.174</td>
</tr>
<tr>
<td></td>
<td>F-ADF</td>
<td>-5.40</td>
<td>0.000</td>
<td></td>
<td>F-ADF</td>
<td>-6.66</td>
<td>0.000</td>
<td></td>
<td>F-ADF</td>
<td>-0.21</td>
<td>0.418</td>
</tr>
<tr>
<td></td>
<td>F-PP</td>
<td>-8.73</td>
<td>0.000</td>
<td></td>
<td>F-PP</td>
<td>-6.09</td>
<td>0.000</td>
<td></td>
<td>F-PP</td>
<td>1.55</td>
<td>0.940</td>
</tr>
<tr>
<td></td>
<td>IPS</td>
<td>-9.59</td>
<td>0.000</td>
<td></td>
<td>IPS</td>
<td>-8.64</td>
<td>0.000</td>
<td></td>
<td>IPS</td>
<td>0.07</td>
<td>0.527</td>
</tr>
<tr>
<td></td>
<td>F-ADF</td>
<td>-8.53</td>
<td>0.000</td>
<td></td>
<td>F-ADF</td>
<td>-7.83</td>
<td>0.000</td>
<td></td>
<td>F-ADF</td>
<td>0.20</td>
<td>0.581</td>
</tr>
<tr>
<td></td>
<td>F-PP</td>
<td>-8.82</td>
<td>0.000</td>
<td></td>
<td>F-PP</td>
<td>-7.83</td>
<td>0.000</td>
<td></td>
<td>F-PP</td>
<td>2.10</td>
<td>0.982</td>
</tr>
</tbody>
</table>

Note: The null hypothesis that variables in each prefecture tended to converge to the mean of all prefectures is examined. See the note for Table 1.
analyze the convergence of several variables other than productivity in order to provide further insight into agricultural characteristics, because circumstances surrounding agriculture seem to vary a great deal between regions.

Empirical analysis using the panel unit root test shows that the convergence hypothesis holds for agricultural income per farm from 1965 to 1995. Japanese farms on the whole seem to have tried to increase their productivity, and regions with low productivity tend to eventually catch up to those with high productivity, possibly as a result of technological spillovers. Also, perhaps farms with low productivity either quit farming entirely, or reduced the percentage of agricultural activity they engaged in, while relatively large farms with high productivity survived.

Agriculture cannot be carried out the same way throughout Japan, owing to geographical factors. The dependent ratios of agriculture and agricultural research stock per farm did not necessarily converge during the sample period. Most panel unit root tests imply that the dependent ratio of agriculture tended to converge to the mean of all the prefectures. On the other hand, the dependent ratio of agriculture did not seem to catch up to the Hokkaido level from 1981 to 1995, nor did it do so within the sub-sample of western Japan. Hokkaido, the largest prefecture, could be much better suited to agricultural pursuits than any of the other prefectures, and it would be difficult for other prefectures to catch up with that area when measuring the dependent ratio of agriculture.

Our empirical analysis did not show strong evidence that agricultural research per farm was converging. It is possible that the spillover of agricultural research in each region is quite large. Research can benefit not only agriculture in the region where it is carried out but also other regions. In future research, it would be important to estimate the extent of the technological spillover effect.

Appendix 1. Data Sources and Descriptions

The data from various years regarding agricultural income per farm and the dependent ratio of agriculture were obtained from the Ministry of Agriculture, Forestry, and Fisheries, Statistics and Information Department of Japan, Noka Keizai Chosa Hokoku (Report on Farm Economics Search Report). Agricultural income per farm was deflated by the agricultural price index and the price level in 1985 was set to one. The agricultural price index for various years was sourced from the Ministry of Internal Affairs and Communications of Japan (Japan Statistical Yearbook). The dependent ratio of agriculture is defined as the share of agricultural income in farm household income. Agricultural research stock was obtained from Chen (1994). Research expenditure per farm (REF) is calculated as: (agricultural research expenditure of provincial research institute) / (number of farms) + (agricultural research expenditure of national research institute) / (number of farms). Agricultural research stock per farm (RST) from 1965 to 1991 was obtained from Chen (1994). RST is calculated from the following equation:

11) One reason why Hokkaido is well suited for agriculture could be because plenty of land is available in Hokkaido.
where RFE is research expenditure per farm. The research period is defined as the lag between research and development, and that lag is assumed to be six years; \( \delta \) is the depreciation rate, and the rate is assumed to be 10 percent. The RST after 1995 is also calculated based on equation (A.1): The agricultural research expenditure of the prefectural and national research institute over various years comes from Norin Suisan Kankei Shiken Kenkyu Yoran (Directory of Experiment and Research on Agriculture and Fishery). The number of farms for those same years is derived from the Japan Statistical Yearbook.

### Appendix 2. Geographical Outline of Japan’s Prefectures


### REFERENCES


### Acknowledgements

The authors would like to thank Professor Mitoshi Yamaguchi for helpful comments. This research is supported by JSPS KAKENHI Grant Numbers 24310031.