WEATHER INDEX*

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Introduction

Weather is generally one of the most important factors influencing the yields and the production of crops. Many attempts to construct weather indexes which will be the measure of the impact of fluctuations in " weather " have been done by economists to improve economic analysis of agricultural outputs in the U. S. and Canada.[1] In Japan, no one has attempted to construct the weather index, although the need for such an index has often been expressed by many economists. In this paper an attempt is made to construct the weather index of rice production in Hokkaido that is considered to be greatly affected by the weather fluctuation. The usefulness of the weather index can be summarized as follows:

1) It will be a useful tool that enables us to analyze time-series data of agricultural production.

2) It will provide us with a probability distribution of " weather state in future ".

3) With the help of the weather index, we can analyze the interaction between the weather and technology. Since the weather is the most important enviromental variable which is beyond the control of economic organization, great efforts have been made to improve technology which will lighten the impact of weather. Cultivation of paddy

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rice has been expanded north-ward in Hokkaido by the development of varieties highly resistant to cold damage. The agricultural experimental stations established by the government have played an important role in the production of new varieties. The analysis of weather-technology interaction would enable us to estimate social benefit of such efforts.

1. Method

Agricultural meteorologists have studied the crop-weather relationship using multiple regression techniques. It was assumed that the year-to-year variation in yield data would give an indication of the influence of weather, after trend had been removed. Daigo[2)] estimated the following equations in many districts in Japan.

$$y_t = Y_t / \hat{Y}_t \qquad (1)$$

$$y_t = b_0 + b_1 T_{it} + b_2 S_{it} + b_3 P_{it} + b_4 R_{it} \qquad (2)$$

where

Y_t : real yield value per tan, (≒ 10 a)

$\hat{Y}_t$: estimated value per tan, (= the computed trend)

T : monthly average temperature,

S : Total sunshine hours per month,

P : Total rainfall per month,

R : Total days of rainfall per month,

and

i : suffix i means appropriate time period.

These results made clear what are the important meteorological variables in each district and enabled us to forecast the crop yield. They also gave a useful information to the farmer who adjusts the cultural practices to the weather fluctuations.

Our construction of the weather index in this paper is based on these studies. The method is (essentially) as follws:

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If time-series data of yields can be obtained from experiments where as many variables as possible are controlled, the computed y in equation (1) in each year is a measure of the influence of weather, the net effect of all the meteorological factors on yield[3]. We can define the weather index as follows:

$$WI = Y_t^* / \hat{Y}_t^*$$

where

WI = weather index,

Y_t^* = real yield value per tan from experiment plots,

and

$\hat{Y}_t^*$ = estimated yield value per tan using above data.

"Sakumotsu Hōkyō Kōshō Shiken",[4] an experiment on the effects of weather on crop yield, is available as the experimental data. The object of this experiment was to investigate the relationship between the fluctuation of weather and that of crop yield. These experiments were carried out under the following conditions:

(1) More than two varieties which were commonly cultivated in each district were used in the experiment. (2) The level of fertilizer application was held constant every year in each experimental plot.

(3) The same cultural practices, i.e., seeding, transporting, density of crops, which are most suitable for each district, were adopted every year.

(4) The adequate continuity of the experiment.

The procedure is summarized as follows:

1) Considering weather condition, we divided Hokkaido into 5 districts and selected 5 agricultural experimental stations which represent each district. Those experimental stations in Hokkaido and varieties selected in each period are illustrated in table 1.

TABLE 1 Experimental stations and rice varieties selected

Experimental station (address)	Selected varieties	(period)	Administrative [1] district
Honjo	Akage	1905–1914	Ishikari
(Sapporo)	Bōzu	1915–1926	Sorachi
	Bōzu–5	1927–1947	
	Chusei eiko	1948–1966	
	Eikō	1967–1969	
Oshima	Jimai	1912–1928	Oshima [2]
(Ōno)	Kinsei	1929–1943	Hiyama
	Tomoenishiki	1944–1951	Iburi
	Chusei eiko	1953–1961	Hidaka
Kamikawa	Bōzu	1911–1935	Kamikawa
(Nagayama)	Fukoku	1936–1947	Rumoi
	Chusei eikō	1948–1954	
	Eikō	1955–1967	
Tokachi	Akage	1909–1827	Tokachi [3]
(Obihiro)	Bōzu–5	1927–1948	
Kitami	Kitami Akage	1925–1929	Abashiri
(Kitami)	Bōzu–6	1930–1947	
	Nōrin–20	1948–1969	

1) Considering weather condition, administrative districts are devided into 5 groups. 2), 3) These districts are supposed to be included in "Honjo", "Kitami" respectively in the postwar period that is wanting of data.

Source: in prewar

Shigemitsu Fukuda: Data of "Hōkyō Kōshō Shiken" of Hokkaido for 1910–1948, unpublished.

in postwar

Suitō Kishō Kannō Shiken 1948–1959 , 1961
Suitō Inasaku Sakkyō Shiken 1960–1967 , 1969
Sakumotsu Tōkei, 1968 , 1969.
Suitō Hōkyo Kōshō Shiken 1902–1946 , 1950

2) Two methods are adopted in computing $\hat{Y}_t^*$ in equation (3). One is to regress yield per tan on time trend linearly, the other is to calculate seven years moving average value; actually five years average excluding maximum and minimum value were calculated in each seven years. The latter is the conventional way which many meteorologists have adopted. The preliminary calculations indicated that the regression coefficients of time trend are not statistically significant except

two cases, "Honjō" and "Oshima" in pre-war, therefore we adopted moving average method to compute $\hat{Y}t^*$.

3) Indexes for each series were computed as the ratio of the actual yield Y_t to the computed yield $\hat{Y}_t^*$.

4) Indexes at each district were synthesized into an index for Hokkaidō, using annual production for each district as weight.

The computed indexes are presented in table 2.

Table 2 Weather index of rice in Hokkaido

	Weather index	Accumulated temperature index 1936=100
1912	107.3	92 6
1913	24.2	86.6
1914	123.5	100.1
1915	103.9	97.3
1916	103.4	104.8
1917	91.9	98.1
1918	100.3	101.4
1919	100.4	98.6
1920	105.8	108.4
1921	98.1	98.8
1922	97.0	99.0
1923	96.4	97.8
1924	83.7	101.9
1925	112.5	102.5
1926	85.6	96.1
1027	104.9	100.6
1928	107.1	105.0
1929	107.1	97.2
1930	117.7	100.9
1931	81.0	91.9
1932	83.7	97.6
1933	115.2	104.9
1934	95.8	96.9
1935	94.1	95.6
1936	105.8	100.0
1937	112.5	100.2
1938	101.7	105.1
1939	108.3	100.6
1940	73.6	—

1941	70.7	
1942	96.9	
1943	110.1	
1944	115.1	
1945	80.2	
1946	97.5	
1947	93 1	
1948	88.3	
1949	101.8	
1950	111.0	
1951	97.9	
1952	106.1	
1953	92.3	
1954	78.5	—
1955	102.1	104.7
1956	68.1	100.2
1957	100.2	99.2
1958	107.0	102.3
1959	97.9	103.0
1960	112.2	103.6
1961	116.0	110.0
1962	98.1	103.9
1963	116.7	102.5
1964	93.7	99.1
1965	95.4	100.9
1966	79.6	98.7
1967	122.3	105.2
1968	117.4	102.6
1969	107.0	97.9

Notes

Accumulated temperature index are calculated in the period of supply analysis.

2. Evaluation

An indication of the reliability and usefulness of weather index was obtained by estimating supply function of rice production in Hokkaidō. We also calculated the accumulated temperature index[5] (presented in table 2), and compared the results.

The model used is the simple distributed lag model[6]. The estimated equation is:

$$\ln Y_t = b_0 + \gamma b_1 \ln P_{t-1} + (1-\gamma)\ln Y_{t-1} + b_2 \ln t + b_3 \ln WI_t + u_t$$

where

Y_t = Output of rice at time t,

P_{t-1} = Relative price of rice of the previous year,

Y_{t-1} = Output of rice in the previous year,

t = time trend,

WI_t = weather index at time t,

and

γ = the coefficient of adjustment.

The periods of 1912 - 1939 and 1955 - 1969 were chosed to avoid various complication caused by the war or acreage allotment policy in post war. The basic sources of data are indicated in the foot-notes of table 3 and table 4.

Table 3 Estimates of supply function of rice in Hokkaidō, 1912 - 1939

	P_{t-1}	WI	Y_{t-1}	t	AI	R^2	d
R1-1	.542*	2.243***	.218***	.323***		.952	1.976
	(.320)	(.161)	(.067)	(.094)			
R1-2	1.206***	2.516***	.369***			.932	2.011
	(.291)	(.161)	(.057)				
R1-3	.245		.094	.526**	9.436***	.712	2.557
	(.801)		(.163)	(.250)	(2.556)		
R1-4	-.886		-.116	1.052***		.560	2.359
			(.189)	(.255)			

Notes: Figures in the parentheses are the standard errors of the estimated coefficients. All R^2 are adjusted for degrees of freedom.
d is the Durbin-Watson test statistic.

Variable and Source: "Real" price - Index of wholesale price of rice in Otaru divided by the index of prices of current inputs paid by farmers.
Output - Index of rice production in Hokkaido.
Hokkaido Statistics Report.
L. T. E. S., vol. 9

Table 4　Estimates of supply function of rice in Hokkaidō, 1955 - 1969.

	P_{t-1}	WI	Y_{t-1}	t	AI	R^2	d
R2−1	.484	1.617***	−.053	.147		.904	2.458
	(.358)	(.214)	(.120)	(.094)			
R2−2	.871***	1.754***	.076			.891	2.438
	(.273)	(.207)	(.092)				
R2−3	.330		−.294	.413**	5.224**	.600	1.686
			(.241)	(.177)	(2.126)		
R2−4	−1.686		−.280	4.287**		.464	1.607
	(1.274)		(.272)	(1.777)			

Notes:　Same as to Table 3.
"Real price" - Index of price of rice received by farmers divided index of prices of commodities for agricultural use.

We illustrated the estimated results of supply analysis of rice production in Hokkaidō in table 3 and table 4. The following points can be particularly picked out from the results.

1) The estimated simple correlation between output and weather index is 0.82, and weather index is independent from the other explanatory variables.

2) In the comparison of equation R1−1 with R1−4, one finds that that the coefficient of determination R^2 in R1−1 has been considerably improved by including the variable of weather index, i. e. R^2 increased by about 0.40. The variable of weather index alone explains about 60.5 per cent of the whole explained variance in R1−1. All the coefficients appeared have the expected sign and are significantly different from zero at the level lower than 10 per cent. It should be emphasized that our statistical findings indicate fairly high positive price elasticity of supply. In the period of 1955-1969 the similar results are obtained, although all the coefficients are not significant at the conventional levels in equation R2−1 and R2−2. This may be due to the multicolinearity between trend and price, and that between trend

and lagged output.

These results show that the measure of the fluctuation of weather is inevitably needed to account for a substantial fraction of unexplained variance in economic analysis of rice procuction in Hokkaidō.

3) R1−3 presents the result of the estimation in which the weather index is substituted by the temperature index. It shows that the situation is not much improved. The coefficient of determination is much smaller than that in the case of R−1, although it increased by 0.15 by including the variable of the temperature index. The temperature index coefficient has the expected sign and is significantly different from zero at 1.0 per cent level. On the other hand the estimated coefficients of price and lagged output are not significantly different from zero. It is probably due to poor specification of the effect of weather. The similar results are obtained in the period of 1955–1969.

These results seem to indicate that the weather index constructed in this paper is superior to the temperature index in measuring weather effect.

4) The weather index coefficients are always significant and surprisingly stable through all the equations. The estimates are about 2.4 in the 1912–1939, 1.6 in the 1955–1969. It indicates that a ten per cent of change in the weather index leads to a change of about 24 per cent and 16 per cent in the rice output respectively. It appears that the weather coefficient is smaller in the second sub-period.[7] F-test was applied to test the difference of the coefficients in two regressions. The results illustrated in table 5 indicate that the two parameters are quantitatively different each other at 5 per cent significance level. This is probably due to the improvements in practical cultural method, seeds, soil[8] and so forth.

Table 5 The results of covariance analysis

	Source	df	Sum of squares	Mean squares
(1)	1912 - 1939	23	.18309	
(2)	1955 - 1969	10	.02364	
(3)	(1) + (2)	33	.20673	.00626
(4)	1912 - 1939 1955 - 1969 pooling	34	.23472	
(5)	(4) − (3)	1	.02799	.02799
F	(5) / (3)			4.471

Notes
The ratio F (1, 33) is 4.14 at the 5 per cent level of significance.

Concluding remarks

The computation results indicate that the weather index constructed in this paper is a useful tool for supply analysis. We can take out the effect of weather and estimate the coefficient of economic variables without any bias due to weather flutation. The weather index also proves to be more appropriate as weather variable than the temperature index which has been often used.

The availability of experimental data is indispensable condition in constructing the weather index. Fortunately the experimental data for various kinds of crop are available from prewar to present in every district in Japan. Therefore we can construct the weather index of synthesized agricultural production as well as individual crops in a particular district, then these can be aggregated into an index of Japan without any difficulty.

We wish to take the opportunity to express our thanks to Professor Seiji Sakiura and other members of the Agricultural Development Symposium, Hokkaido University for their helpful comments, and Shigemitsu Fukuda who has permitted us to use the data of " Hōkyō

Kōshō Shiken" for 1912–1948 collected by him. Computer processing is executed on FACOM 230-60 at the Computing Center of Hokkaido University.

Notes

1) Stallings, J.L. "Weather indexes" "*J. Farm Econ.*, Feb. 1960. Shaw, L.H, "The effect of weather on agricultural output: A look at methodology", *J. Farm Econ.* 1964.
Doll John P., An Analytical Techniques for estimating Weather indexes for estimating from Meteorogical Measurements, J.F.E. 1967
Orlan Buller and Wuu-long Lin, Measureing the effects of weather crop production, Canadian Journal of Agricultural Economics, 1969

2) Daigo, Miho., "Suitō no Kishō seisanshisū no Sanshutsu to sono Ōyō, Hokkaido ni tsuite," *Nogyo oyobi Engei.*, vol. 19, 1944.
Nōsakumotsu no shūryō yosō ni kansuru Nōgyōkishōgaku teki Kenkyū," in *Sangyōkishō no Kenkyu*, 1964.

3) Daigo estimated equation (2) using the actual data of Hokkaidō and experimental data. He showed that the estimated equation from the experimental data was more powerful in forecasting than that from the actual data.

4) This experiment was conducted systematically at every agricultural experimental station in Japan from 1902 till 1950. In Hokkaido the experiments were carried out at 19 experimental stations from 1910 till 1950. "Kishō Kannō Shiken" can be linked with "Hōkyō Kōshō Shiken" in post war, although there was a change in the experimental system. The results of these experiments have been published as "Sakkyō Hōkoku" several times a year.

5) We accumulated the daily average temperature from May till September, and weighted together into a single index for Hokkaido using the same weights of constructing weather index. The simple correlation between this index and weather index is 0.662.

6) Nerlove, Marc, *The Dynamics of Supply:* Estimation of Farmers' Response to Price., Baltimore: Johns Hopkins Press, 1958.

7) The similar results are obtained also from the comparison of equation R1−3 with R2−3. The temperature index coefficient in 1912–1939 is

9.4, and higher than 5.2 in 1955-1969.

8) Osanami, F, "Tochikairyō Tōshi no Keizai Kōka", 1974. (unpublished)