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Analysis of private consumption using weather data

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Private consumption is affected by temporary disturbance factors such as weather conditions, so it is difficult to assess business conditions. In this paper, we propose "Macro Weather Index" as a comprehensive indicator of Japan's weather conditions, and analyze the effect of weather factors on private consumption. We find that a rise in the amount of precipitation depresses consumer spending and a rise in temperature has a positive effect on private consumption in the summer and a negative influence in the winter. We also find that the effects of weather factors on consumption differ by type as well as by item.

Introduction

In judging economic conditions, it is important to understand the development of private consumption, which accounts for the largest proportion of Gross Domestic Product (GDP). However, since private consumption can be affected by many temporary disturbance factors, it is difficult to assess economic conditions in real time. The consumption activity index (CAI) – which is calculated by combining various sales and supply side-statistics has fluctuated on a monthly basis despite increasing on average (Chart 1)[1].

[Chart 1] Consumption Activity Index (real)

Note: Figures adjust travel balance. The data was released on December 7, 2018.

Source: Bank of Japan.

Among the many potential temporary disturbance factors that affect private consumption, such as bargain sales at department stores and unusual patterns of holiday seasons around early-May (the so-called Golden Week holidays), weather can be considered as the most important. In fact, many retail firms report that the weather affects private consumption. For example, according to "Economy Watchers survey" conducted by the Cabinet Office, weather conditions have significant effects on firms' sales and number of customers (Chart 2). Specifically, it is reported that unusual scorching heat in the summer positively affects sales of beverages as well as air conditioners and winters that are warmer than usual negatively affect sales of winter clothes. These anecdotes demonstrate that the effects of weather on private consumption differ by season. In other words,

[Chart 2] Comments from Economy Watchers Survey

October 2017 Northern Kanto (Department store)	It rains for days due to the bad weather and the number of customers declines.
October 2017 Southern Kanto (Taxi)	Due to the rainy weather this month, there are more taxis than I expected. Our work depends on the weather and it is a blessed rain.
July 2018 Southern Kanto (Convenience store)	Because the heat reached a record high this month, the number of customers from evening to night increased. I feel that there are many customers buying beverages.
August 2018 Tokai (Electric appliance retailer)	Although the sales volume of air conditioners is growing due to the scorching heat, it is temporary and the rebound will come once the summer is over.
September 2018 Kinki (Restaurant)	Since the typhoons struck twice and the weather was too bad in September, few people walk along the shopping street and visit the restaurant at night.
November 2018 Tohoku (Clothing shop)	Due to the warm winter, sales of winter clothes are sluggish and we are struggling. We manage to earn profits.

Note: The comments are reasons for the assessment of current economic conditions.

Source: Cabinet Office.

a rise in temperature would push up consumption in the summer, while it could exert downward pressure on consumption in the winter.

Weather is also considered as a major disturbance factor for economic assessments abroad. For example, regarding the influence of the extreme cold winter from the end of 2013 to the beginning of 2014 in the United States, then Federal Reserve Chair Janet Yellen stated as follows[2].

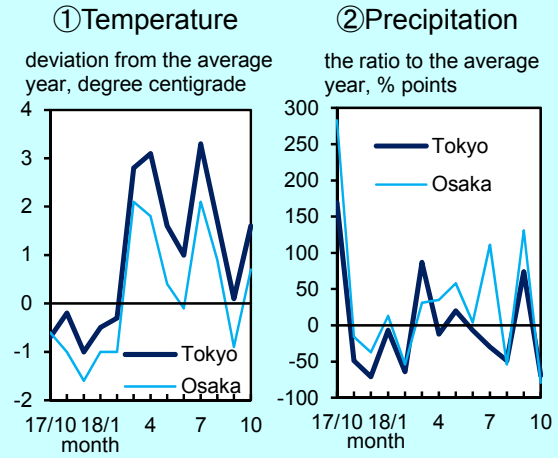
"In recent months, some indicators have been notably weak, requiring us to judge whether the data are signaling a material change in the outlook. The unusually harsh winter weather in much of the nation has complicated this judgment, but my FOMC colleagues and I generally believe that a significant part of the recent softness was weather related".

In response to the harsh winter experience, the analysis of the impact of weather on private consumption has been progressing further within the Federal Reserve Board (FRB)[3]. There are a few analyses by the Bank of Japan that examined the impact of changes in temperature and precipitation on consumption using consumption data by prefecture. They, however, only focused on the consumption of goods, and the effect of weather conditions on service consumption was beyond their scope[4]. Therefore, following the analyses by the FRB, this paper explores the effect of weather conditions on private consumption in Japan.

Construction of Macro Weather Index

Let us take a look at the developments of two weather data items, the deviation of temperature from the yearly average and the ratio of rainfall to the yearly average in two different cities, Tokyo and Osaka. Chart 3 shows that the weather data of the two cities co-move in many cases, while there are considerable cases in which the weather data move differently. For example, in July 2018, when unusual heavy rain hit the western part of Japan, the rainfall in Osaka was twice that of the usual year, whereas Tokyo saw a smaller amount of precipitation than in the usual year. Since weather conditions are different from region to region, to aggregate the regionally different weather conditions into one indicator, we construct a new index named the "Macro-Weather Index" (hereafter MWI) by taking a weighted average of weather data by prefecture[5], with the prefecture's population being used as the weight (Chart 4)[6]. The seasonality of MWI is eliminated by taking the difference from the average of the same months in the past. Therefore, positive MWIs indicate larger amounts of precipitation and higher temperature than in the usual year.

[Chart 3] Weather in Tokyo and Osaka



Notes: 1. The figures for Tokyo are measured at the meteorological observatory in Chiyoda-ku and those for Osaka are measured in Osaka City.

2. The figures for temperature are the deviation of the monthly average from the average year, and those of precipitation are the ratio of monthly amounts to the average year's amounts.

Source: Japan Meteorological Agency.

[Chart 4] How to create macro weather index

$$MWI_{y,m} \stackrel{\text{def}}{=} \sum_{p=1}^{47} w_{p,y,m} \frac{WI_{p,y,m} - \overline{WI_{p,y,m}}}{\sigma_{p,m}}$$

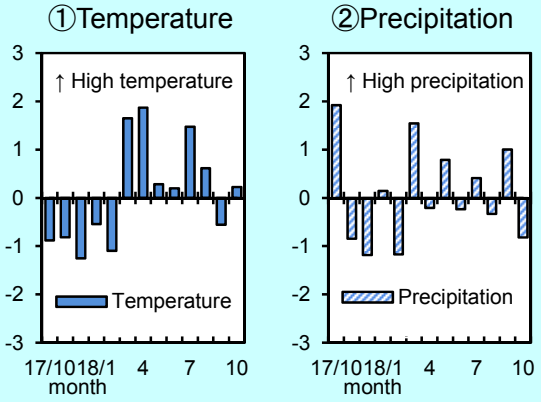
$WI_{p,y,m}$: Weather data on month m year y in prefecture p
$\overline{WI_{p,y,m}}$: 10-year backward moving average of data on each month in each prefecture
$w_{p,y,m}$: Ratio of each prefecture's population to the total
$\sigma_{p,m}$: Standard deviation of the difference between data on each month at each prefecture and its 10-year backward moving average

(1) We take the deviation of weather data at each prefecture from the average on the same month in the past, standardize the figures by their standard deviations, and take their average with the population of each prefecture as a weight.
(2) When we standardize each weather factor, we use the backward 10-year moving average to eliminate the upward trend of the temperature as much as possible due to global warming. The standard deviation is calculated from weather data from January 2000 onward.
(3) Temperature and precipitation are used as weather data.

Looking at the recent development of the MWI of temperature (Chart 5)[7], while the MWI registered positive values in July and August 2018, when there was unusual scorching weather, during the severe winter from November 2017 to February 2018, when a significant amount of snow was observed even in the metropolitan area, the MWI registered a negative

value[8]. Regarding precipitation, the MWI was clearly positive in September 2018, when a large typhoon struck the western part of Japan. However, in July 2018, when heavy rain showers were observed mainly in the western part of Japan, as mentioned above, there was little rainfall in Tokyo and other areas, and the MWI registered only a small positive number.

[Chart 5] Macro Weather Index



Sources: Japan Meteorological Agency; Ministry of Internal Affairs and Communications.

The effect of the weather on consumption

In this section, we analyze the impact of the weather on personal consumption using MWIs. We use an MWI of precipitation as well as two MWIs of temperature, in the summer (May to August) and winter (November to January). This is because the influence of the temperature on personal consumption varies by season[9], as can be seen in the comments of "Economy Watchers survey". To evaluate how weather conditions affect economic activity, we employ a commonly used regression analysis from the perspective of simplicity. Specifically, we use the ordinary least square model by using seasonally adjusted total CAI and consumption by type and item of the CAI as dependent variables. We use the month-on-month difference in MWIs: (1) precipitation, (2) summer temperature, and (3) winter temperature and some control variables as explanatory variables[10]. It is noted that the results of this regression analysis are largely consistent with those by a time series model called the vector auto regression (VAR) model (see the BOX).

The estimated results in Chart 6 show that the rainfall and temperature in the summer and winter have significant effects on total consumption. Looking at a sign of the effects, an increase in precipitation and a rise in temperature in the winter reduce consumption, while a rise in temperature in the summer increases consumption. In addition, the summer temperature affects consumption more than twice the winter temperature.

[Chart 6] Estimation results of regression analyses

①By type

		Dependent variables (m/m % chg.)			
		CAI	Durables	Non-Durable	Services
m/m chg. of MWI	precipitation	-0.19 ***	-0.33	-0.18 **	-0.20 ***
	summer temperature	0.39 ***	0.67 *	0.70 **	0.07
	winter temperature	-0.15 **	-0.64	-0.27 **	0.06

②By item

		Durable		Non-Durable	
		Household Applicance	Automobile	Food and Beverage	Clothing
m/m chg. of MWI	precipitation	0.31	-0.85 *	-0.15 **	-0.41 *
	summer temperature	1.34 ***	0.62	0.08	0.59 *
	winter temperature	-0.87 *	-0.48	-0.28 *	-0.84 **

		Services			
		Dining out	Travel	Taxi	Enter-tainment
m/m chg. of MWI	precipitation	-0.35 **	-0.61 **	0.60 ***	-0.50 **
	summer temperature	0.31 *	-0.36	0.48 **	-0.08
	winter temperature	0.20	-0.40	-0.33	0.93 **

Notes: 1. The shading in the tables indicate statistically significant variables. ***, **, * are significant at the 1%, 5%, and 10% level, respectively.

2. The figures for the consumption activity index adjust travel balance. It is noted, however, that figures by type and item include inbound tourism consumption and exclude outbound tourism consumption. The data was released on December 7, 2018.

3. The estimation period is from January 2003 to October 2018.

Sources: Japan Meteorological Agency; Ministry of Health, Labour and Welfare; Ministry of Internal Affairs and Communications; Bank of Japan; Bloomberg.

Looking at consumption by type, though the sign of the coefficients of MWIs for durable goods is the same as that for total CAI, only the summer temperature is statistically significant. However, when

we estimate the effects for durable goods by item, the temperature in the winter as well as in the summer is statistically significant for household appliances. This might be because the consumption of air conditioners and electric fans increases as the summer temperature rises, and the consumption of heating equipment such as air conditioners and stoves is encouraged due to a drop in temperature in the winter. Precipitation has a significant negative effect on the consumption of automobiles and it is likely that the number of customers visiting automobile dealers declines on rainy days.

A rise in rainfall and temperature in the winter basically depresses non-durable consumption[11], including food and beverages as well as clothing, which constitute non-durable goods, and a rise in temperature in the summer has positive effects on consumption. For example, an increase in rainfall could reduce sales of food and clothing by discouraging consumers from going to supermarkets, department stores and clothing stores. In addition, it is likely that a fall in the winter temperature increases sales of ingredients for making hot soup and winter clothing, such as coats.

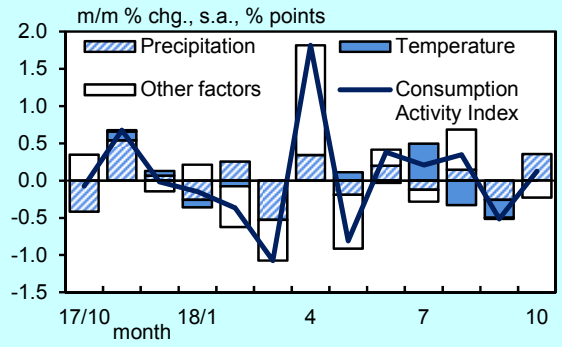
On the other hand, regarding service consumption as a whole, only precipitation is statistically significant. However, looking at the results by item, the demand for eating out is likely to increase when the temperature in the summer rises. Meanwhile, with regard to the demand for taxis, a rise in precipitation and temperature in the summer has a significantly positive effect. This is probably because people who usually move on foot use taxis on rainy days or hot summer days. For travel and leisure demand, an increase in rainfall would suppress consumption by discouraging consumers from going out. Finally, a rise in temperature in the winter has significantly positive effects on demand for entertainment, and this is because a warm day in the winter would encourage people to go out.

Impact of weather factors on recent private consumption

Here, we analyze how the weather factors affected private consumption in the past year or so, based on the estimation result using the total CAI as the dependent variable (Chart 7). It is confirmed that estimated results show that the weather factors have considerable explanatory power for monthly fluctuations in private consumption.

Looking at the periods when weather factors had large impacts on consumption, October to November 2017 saw a large contribution to consumption. October 2017 registered the highest precipitation in the western part of Japan since the statistics started to be recorded, with a large amount of rainfall across the nation, which exerted downward pressure on private consumption. In November, private consumption rebounded.

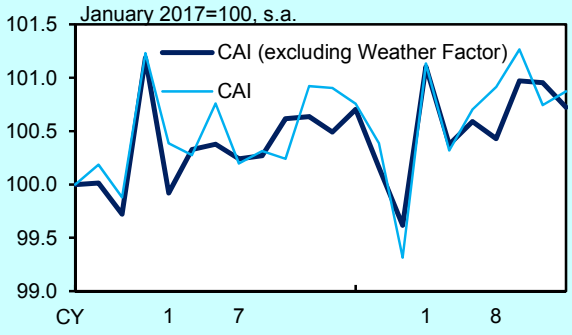
[Chart 7] Decomposition of Consumption Activity Index (Real)



Notes: 1. Other factors indicate the sum of the contributions of explanatory variables other than MWIs and the residual.
2. Figures adjust travel balance. The data was released on December 7, 2018.

Sources: Japan Meteorological Agency; Ministry of Health, Labour and Welfare; Ministry of Internal Affairs and Communications; Bank of Japan; Bloomberg.

[Chart 8] Consumption Activity Index excluding weather factors



Note: Figures adjust travel balance. The data was released on December 7, 2018. The figures for CAI excluding weather factors are calculated by subtracting the contribution of the weather factor in Chart 7 from the month-on-month change in CAI.

Source: Bank of Japan.

In July 2018, the high temperature across the nation had positive impacts on consumer spending. Though the MWI of temperature was positive in August 2018, it fell compared to July 2018. Therefore, it exerted downward pressure on the month-to-month

change in private consumption. On the other hand, in September 2018, in addition to the rebound from the higher temperature in August, there was a large amount of rainfall due to typhoons, which reduced private consumption.

Looking at the level of the CAI that was removed of weather factors (Chart 8), the monthly fluctuations are somewhat flattened. In this way, the method in this paper is useful not only to grasp the weather factors that affect private consumption but also to judge its underlying trend. However, the CAI excluding the weather factors remains volatile, suggesting that it is also necessary to pay attention to factors other than the weather in judging the underlying trend of private consumption.

Concluding Remarks

In this paper, we construct an MWI representing comprehensive weather conditions across the country by compiling regional weather data by prefecture and analyze the effect of weather factors on private consumption. Based on our analysis, we conclude that a rise in precipitation reduces personal consumption; an increase in temperature in the summer has positive effects, while an increase in temperature in the winter has negative effects on consumption. We also analyzed that the effects on consumption of weather factors vary by type and item.

The MWIs in this paper contribute to enhancing the accuracy of assessing the underlying trend of private consumption by eliminating weather factors. However, even if weather factors are excluded, the monthly fluctuations in consumption remain large and it is necessary to pay attention to factors other than the weather in judging the underlying trend of private consumption. For example, it is useful to check bargain sales at department stores and unusual patterns of holidays as well as schedules of when popular passenger cars will be sold. Thus, for assessing the underlying trend of private consumption, it is necessary to utilize various kinds of factors such as data and anecdotal information from companies.

BOX: Vector Auto Regression (VAR) Model Analysis using MWI

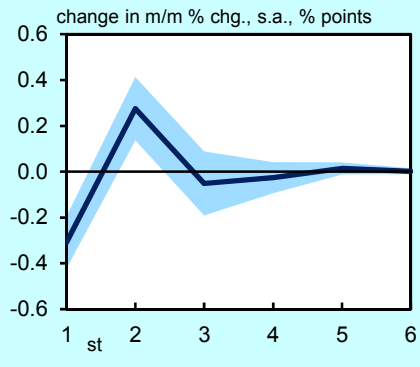
According to the regression analysis in the main text, it is assumed that the impact of weather factors on the level of private consumption does not extend beyond the same month (i.e., assuming that the growth rate of consumption will rebound in the following month since consumption will be restored to the original level in the following month). In reality, however, weather factors are likely to affect the levels from the next month onward. Moreover, regression analysis uses other variables such as fresh food prices as control variables, which is equivalent to ignoring the second round effect on consumption through the change in fresh food prices. To overcome the limitation, in this BOX, we employ an analysis that uses the vector auto regression (VAR) model, which can take complicated effects into account, including the second round effect.

The variables used here are the same as the regression analysis in the main text, where three MWIs, precipitation, summer temperature, and winter temperature, are used[i]. The impulse response of the CAI to the MWI change demonstrates that in a month when the MWI of precipitation rises, the growth rate of the CAI decreases and then rebounds in the next month (BOX Chart 1). The influence on consumption of a rise in the MWI of temperature is similar, which confirms that the results of the regression analysis in the main text are largely robust. However, when the temperature rises in the winter, it is observed that the magnitude of the rebound in consumption in the next month seems to be weak. This implies that once the demand for clothing such as coats is lost due to a warm winter, it is difficult to recover the lost sales within the same winter.

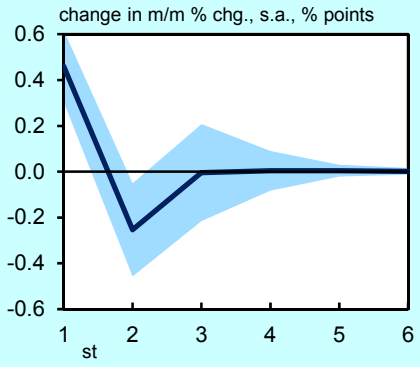
Conducting the variance decomposition of the CAI (BOX Chart 2), we can see that weather variation accounts for about 20 to 30% of the monthly fluctuations in the CAI. This also confirms that the weather factors affect private consumption to a large extent.

[Box Chart 1] Impulse response of CAI (in real term) to MWI

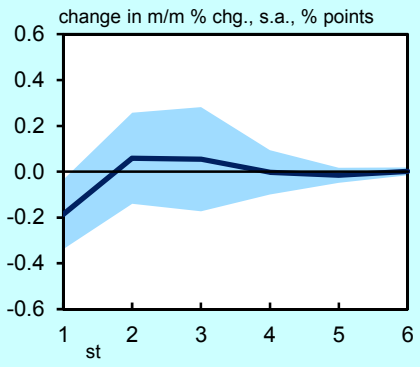
(1) Response to an increase in precipitation



(2) Response to an increase in temperature in summer



(3) Response to an increase in temperature in winter



Note: Response to a 1-unit increase in the MWI. Shading represents the 90th percentile confidential band.

Sources: Japan Meteorological Agency; Ministry of Health, Labour and Welfare; Ministry of Internal Affairs and Communications; Bank of Japan; Bloomberg.

[Box Chart 2] Variance Decomposition of CAI

	contribution of weather factors to the variance decomposition	rainfall	summer temperature	winter temperature
one-month ahead	22.4%	10.1%	10.6%	1.7%
two-months ahead	29.4%	15.8%	12.0%	1.6%

Sources: Japan Meteorological Agency; Ministry of Health, Labour and Welfare; Ministry of Internal Affairs and Communications; Bank of Japan; Bloomberg.

[i] Specifically, the MWI of the rainfall amount, the summer temperature, and the winter temperature, the seasonally adjusted month-to-month ratio of the fresh food price, the monthly ratio of the stock price, the seasonally adjusted monthly rate of the real employment income, and the consumption activity index seasonally adjusted to last month's ratio were used. We use the optimum lag (2 months) selected according to an information criterion. Weather factors are treated as exogenous variables.

∗ Currently at the Kagoshima Branch.

[1] As for the consumption activity index, see the Bank's research paper "Revision of the Consumption Activity Index to Address the 2008 SNA and Improve Accuracy" published in April 2018.

[2] For the details, see the speech "Monetary Policy and the Economic Recovery" delivered in April 2014.

[3] The following paper written by economists at the Federal Reserve Bank of Chicago analyzed the effects of weather change on the U.S. economy from the 2013 year-end to the beginning of 2014.

Bloesch, J., and F. Gourio [2015] "The Effect of Winter Weather on U.S. Economic Activity," *Federal Reserve Bank of Chicago Economic Perspectives*, 39, Number 1.

Moreover, the following paper by an economist at the Federal Reserve Bank of San Francisco conducted panel regressions using data by region and industry to analyze the effect of weather fluctuations on employment.

Wilson, D. J. [2017] "The Impact of Weather on Local Employment: Using Big Data on Small Places," Federal Reserve Bank of San Francisco Working Paper Series.

[4] For the details of the analysis, see BOX 4 of the Outlook for Economic Activity and Price in April 2016.

[5] Although there are multiple observation points for each prefecture, basically, data in the prefectural capital are used, and if the data availability period of the point is not sufficient, the data of other points are used.

[6] In Bloesch and Gourio [2015] referred to in Footnote 3, the weather data in each state are averaged with the weight being the share of the number of non-agricultural employees in each state.

[7] The MWI of precipitation looks like white noise. On the other hand, once the MWI of temperature rises, it tends to rise in the following month, with the autocorrelation coefficient being about 0.3. Note that the MWI of precipitation and the MWI of temperature are almost uncorrelated.

[8] Regarding the characteristics of the weather in each region, year and month, we refer to the press release presentation materials by the Meteorological Agency.

[9] "Temperature in summer" is a variable that takes the temperature of each month from May to August, and zeroes for other months. "Temperature in winter" is a variable that takes the temperature of each month from November to January, and zeroes for other months. As a robustness check, for various combinations, such as considering May - September as the summer or November - February as the winter, we compare the explanatory power of the respective combinations by an information criterion etc. and confirm that the variable used in the main text has the most explanatory power for the consumption activity index. The regression analysis used in this paper assumes that temperature does not affect private consumption except in the summer and winter, and the validity of this assumption is verified.

[10] In addition to three weather-related variables, real employee income, stock prices, fresh food prices etc. were used as explanatory variables. Real employee income is the total cash payment of monthly labor statistics multiplied by the number of employees of the labor force survey, deflated by the consumer price index. As the stock prices, the stock index in the Tokyo Stock Exchange is used. In addition, dummy variables representing certain events such as the consumption tax increase and East Japan great earthquake disaster are also added. The consumption activity index is the real value adjusting travel balance. The consumption activity index, real employee income, and fresh food prices were the month-to-month rate of changes in seasonally adjusted values. Stock prices are the month-to-month rate of changes in original series.

[11] Non-durable goods in the consumption activity index include items classified as semi-durable goods in GDP statistics, such as clothing items.

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