Weather and Individual Happiness

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ABSTRACT

This paper investigates the influence of weather on happiness. While previous studies have examined climatic influence by comparing the well-being of people living in different regions, this paper focuses on how daily changes in weather affect individuals living in a single location. The dataset consists of 516 days of data on 75 students from Osaka University. Daily information on outside events, as well as the daily physical condition and individual characteristics of the respondents, are used as controls. Subjective happiness is related to temperature: in a quadratic model, happiness is maximized at 13.9°C. The effects of other meteorological variables—humidity, wind speed, precipitation, and sunshine—are not significant. The sensitivity of happiness to temperature also depends on attributes such as sex, age, and academic department. Happiness is more strongly affected by current temperature than by average temperature over the day. While enjoyment (a positive affect measure) is affected by weather in a similar way to happiness, sadness and depression (negative affect measures) behave somewhat differently.

1. Introduction

This paper seeks to identify the effect of weather on happiness. Although economists are interested in the material factors shaping happiness, such as income (Frey and Stutzer 2002; Clark et al. 2008), happiness is known to depend on a broader range of variables, including education, health, and personal characteristics such as age, gender, ethnicity, and personality (Dolan et al. 2008).

Climate and the natural environment also affect happiness.1 There have been many studies arguing that climate is an important determinant of quality of life2 (see, e.g., Moro et al. 2008; Oswald and Wu 2010). In spite of the importance of climate, a relatively limited number of studies have analyzed its influence on happiness3 (Dolan et al. 2008).

There have been a number of earlier studies on the impact of climate on happiness. Rehdanz and Maddison (2005) analyzed a panel of 67 countries, finding that temperature and precipitation have a significant effect on happiness. Specifically, they found that people prefer higher mean temperatures in the coldest month and lower temperatures in the hottest month. Those living in regions with many dry months prefer more precipitation. Examining the data on Ireland, Brereton et al. (2008) found that wind speed has a significant negative influence on happiness, while the effects of increases in both January minimum and July maximum temperatures

1 Recall the famous lyric by the Carpenters: “Rainy days and Mondays always get me down.”
2 Additional direct evidence for the fact that people regard a pleasant climate as essential for a good life and for personal satisfaction is obtained from a large-scale survey conducted by Osaka University in 2007 and 2008. In that survey, respondents were asked to select a prefecture in which they wished to live and to select the reasons for their choices. Of the 16 possible reasons, “Nice climate and rich natural environment” was tied for the most common.
3 Several articles analyze the effect of climate on life patterns. For example, Maddison (2003) demonstrated that climate is a significant determinant of expenditure patterns. Hoch and Drake (1974) investigated the relation between climate and wages, under the hypothesis that higher money wages compensate for a lower quality of life. Maddison and Bigano (2003) studied the relationship between climate and wage and home price differentials in Italy. Van Praag (1988) researched the dependence of household costs on climatic conditions, and estimated a climate index and climate equivalence scales for European cities. Bigano et al. (2008) analyzed the effect of climate on sea levels and tourism flows.
are positive and significant. Using the first two iterations of the Russian National Panel dataset on 3727 households in 1993 and 1994, Frijters and Van Praag (1998) found that while temperature and precipitation exert a measurable influence on self-reported happiness and on the cost of living in Russia, the effects of climate in that nation are different from those in the rest of Europe, an incongruity that “is probably due to the greater range of climate in Russia.”

Psychologists have studied the relationship between mood and weather.4 Schwarz and Clore (1983) telephoned 84 German subjects on sunny and rainy days to ask about their immediate mood (momentary happiness) and well-being (general life happiness). On sunny days subjects reported higher levels of momentary happiness, while on rainy days mood was lower. This study suggests that momentary happiness depends on current weather. Recently, using three large-scale German surveys, Kämper and Mutz (2013) found that respondents surveyed on days with exceptionally sunny weather reported higher life satisfaction compared with respondents interviewed on days with “ordinary” weather. Using data from a large-scale depression-screening program in the south of the Netherlands, Huibers et al. (2010) reported that the prevalence of major depression and sad mood showed seasonal variation, with peaks in the summer and fall. Eisinga et al. (2011) found that television viewing time in the Netherlands is related to weather.

Most of these previous studies have examined the effect of climate by comparing the happiness of the residents of different regions or countries. Although the studies conclude that happiness is affected by regional differences in climate, they suffer from a selection bias because people tend to move to places with better weather (Rappaport 2007; Connolly 2013). The relationship might therefore not be causal. In contrast, if the happiness of an individual responds to daily weather variations, there is no ambiguity about the causality. Answering the latter question requires time series data on individual happiness rather than cross-sectional data. Thus, the central question in this study—whether the happiness of individuals varies with daily weather changes—has not yet been definitively answered.

One study that has tried to address the question is that of Barnston (1988), who used six-week mood/productivity diaries from 62 students in 1974 and reported that the weather appears to influence mood and productivity, but only to a small extent.

Recently, four more relevant studies have been published. Denissen et al. (2008) collected mood data for 1233 people over 14 days and found that temperature, wind power, and sunlight influence negative affect. However, the size of the effect of weather on mood was small. Kööts et al. (2011), sampling subjects’ affect for 14 days on 7 occasions per day, found that positive and negative affect were weakly related to temperature, and that positive affect was also related to sunlight. Klimstra et al. (2011) identified weather reactivity types by linking self-reported daily mood across 30 days to objective weather data in the Netherlands. Examining correlations between three indicators of mood (happiness, anxiety, and anger) and three weather variables (temperature, sunshine, and precipitation), they found significant correlations in most cases. Connolly (2013) used the Princeton Affect and Time survey, in which 3982 individuals were contacted several times over four months (repeated cross-sectional data). This data has the advantage of being a fairly representative sample of the entire United States. The paper is unique in including normal weather to control for climate, so that the study examines the effect of deviations from the normal weather. The author analyzed eight affect variables, including happiness as well as satisfaction. She found that temperature influenced the affect of women, but not men.

In sum, the results of this literature are not particularly consistent. This may not be surprising, because climate differs among regions: for example, in dry regions, people should prefer wet weather; in cold regions, higher temperature is preferred; in regions where climate is severe, weather matters a lot, while in mild climates people pay less attention to weather. In addition, these studies differ widely in the weather and mood variables they use, as well as the estimation methods. Therefore it is natural that their results vary. Nonetheless, they agree in their finding that temperature affects mood to a modest degree.

A limitation of these studies is the limited number of sampling days for each individual: even the longest study covers only six weeks. To investigate the effect of weather on happiness or mood, it is desirable to analyze data covering the whole year.

To this end, I conducted a daily web survey to collect data on the levels of happiness of 75 college students over 17 months, resulting in 32 125 observations. Additionally,

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4 Motivated by these psychology studies, economists investigated the relationship between weather and stock returns and risks (Hirshleifer and Shumway 2003; Brahmana et al. 2012; Wang et al. 2012; Hasan et al. 2011; Kang et al. 2010; Levy and Galili 2008; Jacobsen and Marquering 2008; Yoon and Kang 2009). Most of them reported some evidence for the weather effect; for example, Hirshleifer and Shumway (2003) found that sunshine is strongly significantly correlated with stock returns. However, Jacobsen and Marquering (2008) argued that the correlation between weather and stock returns might be spurious.
I collected daily data on important individual-level control variables. Although many studies have concluded that the effect of weather is weak (if it exists at all), controlling for individual factors that are likely to affect happiness (or mood) may alter weather’s effect size. In this paper, daily information on events that occurred on the same day, and on the physical conditions of the respondents, are used as control variables (in addition to fixed individual characteristics, or “attributes”).

The rest of this paper is organized as follows: In section 2, I explain the data and methods. The subsequent section presents the basic estimation results. In section 4, I check the robustness of the results. Section 5 presents conclusions.

2. Data and methods

a. The daily web survey

The survey participants consisted of 70 undergraduate and graduate students at Osaka University.5 We asked these respondents to report their daily happiness and their evaluation of the day’s personal events and news. The survey was conducted from 1 November 2006 to 31 March 2008. Since five subjects did not finish the survey, I added five more subjects in the middle of the survey period, increasing the total number of respondents to 75. At the outset of the web survey, detailed data on the attributes (fixed individual characteristics) of each subject were collected.

Subjects were paid 160 yen per daily survey response. Additionally, those who responded more than 22 days in a month were paid 1300 yen as a bonus, while those who answered more than 27 days received 2600 yen.6 The overall daily response rate was about 89%.

The first question in the daily web survey was “(Q1) How happy are you now?” The respondents answered this question on a scale of 0 to 10, where 0 was “very unhappy” and 10 was “very happy.” I named this variable HAPPINESS.7

Other questions also attempted to assess subjects’ emotional state. Question 5 asked, “What was the most important piece of personal news that you received since responding to the questionnaire yesterday? How do you evaluate this news?” The answer, labeled P_NEWS, could range between −5 and 5, where 5 was “very good” and −5 was “very bad.” Question 7 asked about news received via public news media: “What was the most important piece of news from television or newspapers that you received since responding to the questionnaire yesterday? How do you evaluate this news?” This answer, labeled M_NEWS (for “macro news”), could also range between −5 and 5.

Some questions asked respondents about their physical condition; I named these SLEEP, HEALTH, and NOSTRESS. SLEEP was defined as the answer to the following question: “(Q9) Did you sleep well last night?” An answer of 1 indicated poor sleep; 2, somewhat poor sleep; 3, good sleep; and 4, very good sleep. HEALTH was assessed with the following question: “(Q10) How good is your health now?” The answers ranged from 1 (good), 2 (generally good), 3 (generally not good), to 4 (bad); the variable HEALTH was defined by subtracting the answer to this question from 5. NOSTRESS was defined by the answer to the following question: “(Q11) Do you feel any stress now?” Answers included 1 (a lot), 2 (a little), 3 (not much), and 4 (none). All variables were defined so a higher value corresponded to a physical condition presumably more conducive to happiness (better health, less stress, etc.).

b. Meteorological data

Weather data were obtained from the website of the Meteorological Agency of Japan. Hourly and daily data on temperature (TEMPERATURE), humidity (HUMIDITY), wind speed (WIND_SPEED), precipitation (PRECIPITATION), and hours of sunshine (SUNSHINE) are available for Osaka city. The hourly data of TEMPERATURE, HUMIDITY, and WIND_SPEED are the values taken at the beginning of the hour, PRECIPITATION is the total precipitation over the hour, and SUNSHINE is the fraction of sunshine time over the hour. Since the exact time of each subject’s survey responses was recorded automatically, I matched each individual response with hourly weather data at the time of the response. However, in order to consider the possibility that happiness was influenced by the average weather over the entire day rather than the weather at the time of the survey response, I also included daily averages in the analysis (see section 4c).

Although the exact location of respondents at the time they answered the survey is not known, they were almost certainly in the Osaka region for most of the time, because all subjects were students of Osaka University when the survey was conducted. Osaka University has two campuses, one in Toyonaka and one in Suita, which

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5 Subjects were recruited on campus grounds as well as through a website, so that they are not random or representative samples of Osaka University students.

6 Respondents were also asked to report their happiness every hour over one day (of their choice) per month. Answering this hourly survey was a necessary condition for the monthly bonus.

7 In section 4d, I investigate the effect of weather on affect measures other than self-reported happiness.
are suburbs of Osaka (see Fig. 1). The distance between the two campuses is only about five kilometers, so that the difference in weather between the two is not considerable. Weather data for Suita are not available, while only limited data are available for Toyonaka. One reason to use Toyonaka’s weather data would be that it is the location of one of the campuses. On the other hand, the Osaka weather data are richer. Furthermore, the distance between Toyonaka campus and the Osaka City Hall is only 13 km, so that the weather of these two cities does not differ very much. For these reasons I use the Osaka weather data in my baseline analyses, but I check the robustness of the results with the Toyonaka data when applicable. I conclude that using the meteorological data of Osaka city does not produce large biases in any of my estimates (see the beginning of section 4).

Osaka city is located in the middle of Japan, facing Osaka Bay. The daily average temperatures for the observation period, which ranged between 5° and 30°C, are shown in Fig. 2. The climate of Osaka is mild and characterized by four seasons, of which spring and autumn are most loved by residents. Winter is not severe: the average temperature in February, the coldest month, was around 5°C, with almost no snow in the observation years. However, it is hot and humid in summer; the average temperature in August was around 30°C during the observation period. Osaka residents often complain about the high temperature and high humidity of the city in summer. Indeed, the discomfort index (DI) rises to a high value (80) in August. The correlation coefficient between DI and temperature for the observation period is over 0.99, suggesting that high temperatures made people in Osaka uncomfortable.

Out of 75 total subjects, 38 belong to Suita campus, 32 to Toyonaka, and five are unknown.

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8 Sei Shonagon described beautiful scenes set in both of these seasons in her famous book *Makurano Soshi* (The Pillow Book), written in the 10th and 11th centuries.

9 For an explanation of the discomfort index, see Tselepidaki et al. (1992).
c. Descriptive analysis of the data

Table 1 presents the means, standard deviations, and maximum and minimum values of the variables used in this paper, along with the correlation coefficients between HAPPINESS and the other variables. The observation period is from 1 November 2006 to 31 March 2008, and the number of observations is 32,125. The means displayed in the table indicate that personal news is, on average, good (positive), while macro news is generally bad (negative). Average temperature is about 15°C; average humidity, about 60%; average wind speed, 2.4 m s\(^{-1}\); average time of sunshine per hour, about 0.2 h; and average precipitation per hour, 0.12 mm.

The correlations of P\(_\text{NEWS}\), HEALTH, and NOSTRESS with HAPPINESS are quite high. Among the meteorological variables, TEMPERATURE shows the highest correlation with happiness, followed by SUNSHINE; however, the size of these correlations is much less than that of P\(_\text{NEWS}\), suggesting that the effect of weather is relatively limited, if it exists at all.

d. Statistical methods

I regress HAPPINESS on the variables representing the conditions of the subjects, the meteorological variables, the day-of-the-week dummies, and the hour dummies. Thus, the basic equation to be estimated is

\[
\text{HAPPINESS}_{i,t} = \alpha_i + \beta_1 P\_\text{NEWS}_{i,t} + \beta_2 M\_\text{NEWS}_{i,t} + \beta_3 \text{SLEEP}_{i,t} + \beta_4 \text{HEALTH}_{i,t} + \beta_5 \text{NOSTRESS}_{i,t} \\
+ \gamma_1 \text{TEMPERATURE}_{i,t} + \gamma_2 \text{TEMP\_SO}_{i,t} + \gamma_3 \text{HUMIDITY}_{i,t} + \gamma_4 \text{HUMID\_SO}_{i,t} \\
+ \gamma_5 \text{WINDSPEED}_{i,t} + \gamma_6 \text{WIND\_SO}_{i,t} + \gamma_7 \text{SUNSHINE}_{i,t} + \gamma_8 \text{SUN\_SO}_{i,t} \\
+ \gamma_9 \text{PRECIPITATION}_{i,t} + \gamma_{10} \text{PRECIP\_SO}_{i,t} + \sum_{k=1}^{6} \delta_k \text{DAY} \text{ of the WEEK DUMMY}_{i,t} \\
+ \sum_{k=1}^{23} \epsilon_k \text{HOUR DUMMY}_{i,t} + \mu_{i,t},
\]

where variables with _SO are squared terms of corresponding variables (e.g., TEMP\_SO denotes TEMPERATURE \times TEMPERATURE), \(\alpha_i\) is an individual-level fixed effect, and \(\mu_{i,t}\) is a disturbance term.

I also estimate the equation that includes seasonal dummies, where winter is defined as December to February, spring as March to May, summer as June to August, and fall as September to November. However,
the dummies are not significant at all, and the estimates and their significance of other variables are almost unchanged, so that I do not mention these results in later sections.11

I estimate each equation with three models: ordinary least squares (OLS), a fixed effects model, and a random effects model. For each equation I then select a model using a Hausman test (random effects model versus fixed effects model) and an F test of the same constant (OLS versus fixed effects model).12 I report coefficient and p values based on the usual standard errors, as well as p values based on heteroskedasticity—robust standard errors clustered at the individual level.13 Section 4 contains several modifications of the basic regression equation, included as robustness checks.

3. Estimation results of the basic equation

The estimation results are shown in Table 2.14 In column 1, I show the results for the basic Eq. (1) with the squared terms of meteorological variables. All control variables associated with the conditions of the subjects are highly significant, with reasonable signs. The coefficients on P_NEWS, HEALTH, and NOSTRESS are especially large, while M_NEWS and SLEEP also have some impact. Estimates for day-of-the-week dummies reveal that the subjects are significantly happier on Sunday and Saturday than on Thursday. The magnitude of the weekend effect is comparable to that of macro news. Some of the hour dummies are also significant, even with robust standard errors.

Among the meteorological variables, only temperature and its squared term are significant at the 1% significance level when usual standard errors are applied. If we use robust standard errors, only the squared term of temperature is significant at the 10% level. When only linear terms of meteorological variables are included (with the same control variables), the results are essentially the same; only temperature is negatively significant at the 1% level with usual standard errors (results not shown). Since some meteorological variables are more correlated with each other than with HAPPINESS, a multicollinearity problem is suspected. Thus, I estimate the model again including only one meteorological variable at a time. The results are essentially the same, except that the linear term of humidity is negative at the 10% significance level under usual standard errors (results not shown). These results suggest that of all the variables included, only temperature affects the happiness of the students of Osaka University.15

11 I also estimated the specification that included monthly dummies. In that regression, temperature lost its significance, and the monthly dummy for August was significantly negative. This is probably because monthly dummies and temperature are highly correlated.

12 Since happiness is an ordered variable, it should be estimated with an ordered probit (logit). However, because it is difficult to interpret the effect sizes in such models, and because controlling for individual-level effects is important, I use fixed and random effects models. Ferrer-i-Carbonell and Frijters (2004) show that assuming ordinality or cardinality of happiness scores makes little difference, while allowing for fixed effects does change results substantially.

13 When robust standard errors are estimated, a Hausman test cannot be applied. Thus, I report the result of the model that was selected when estimated with nonrobust standard errors.

14 Estimates of coefficients on 23-h dummies are not shown to avoid making the table too large.

15 The coefficient on sunshine takes negative sign when hour dummies are not included. The reason for this result may be that SUNSHINE takes a zero value during nighttime, during which people tend to be happier (Kahneman et al. 2004). When the equation without hour dummies is estimated using data from 7:00 to 17:00 LT, SUNSHINE becomes insignificant under the usual standard errors (the number of observations is reduced to 12 187).
Based on the estimates of the coefficients of linear and squared temperature, it is revealed that the subjects are the happiest at 13.9°C, which is the average temperature in April and November. However, happiness might depend on temperature in a more highly nonlinear way than can be captured with a quadratic equation. To evaluate the nonlinearity, I define temperature dummies, TEMP_5 for the temperature under 5°C, TEMP_10 for between 5°C and 10°C, TEMP_15 for between 10°C and 15°C, etc.16

The estimation results are presented in column 2 of Table 2. Here TEMP_40 is excluded as the benchmark. The coefficients of the dummies are all positive, and most of them are significant at the 5% level even under the robust standard errors. The coefficient of TEMP_15 is the largest, implying that the happiness is maximized between 10°C and 15°C. The result is consistent with the earlier quadratic regression.

Overall, temperature has the most noteworthy effect among the meteorological variables. Still, the magnitude of the estimate is not large: the change in happiness brought about by an alteration of 20°C is equivalent in size to a change in one point of macro news on a 10-point scale. The result that the effect of meteorological variables is small is consistent with previous studies (Denissen et al. 2008; Barnston 1988).

### 4. Robustness checks and extensions

In this section, I check the robustness of the results obtained in the previous section and extend the basic equation in several ways. First, I assess whether the results

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**Table 2. Estimation results for the basic equation.** (Note: Estimates of coefficients on 23-h dummies are not shown to avoid that the table becomes too large. In column 2, TEMP_40 is excluded as the benchmark. Estimation method is chosen based on the results of the Hausman test and the \(F\) test of the same constant. The \(p\) value is based on the usual standard errors, while the robust \(p\) value is based on heteroskedasticity robust standard errors clustered at the individual level.)

<table>
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<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Robust (p) value</th>
<th>Coefficient</th>
<th>Robust (p) value</th>
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16 TEMP_40 is for over 35°C.
are valid when I use data from Toyonaka city instead of Osaka city for some of the meteorological variables. Since one of the two campuses of Osaka University is in Toyonaka city, it might be the case that subjects spent more time in Toyonaka city than in Osaka city. In a reestimation of the basic model, I use Toyonaka data for temperature, wind speed, and precipitation, and Osaka city data for humidity and sunshine (as these latter two are not available for Toyonaka city). The estimates are quite similar to those in Table 2, implying that using the alternative city data does not affect the results (results not shown). This is not surprising, since the two cities are quite close to each other.

Second, in section 4a, since the exact location of respondents is not known, I examine whether this lack of information causes large biases. Specifically, I utilize the information on days when the respondents travel to infer whether subjects stayed near the Toyonaka–Osaka region during the bulk of the observation period. Third, I extend the model to incorporate variables representing the attributes (fixed individual characteristics) of respondents—sex, age, living standard, body mass index, etc. I also examine how the results differ between males and females (section 4b). Fourth, I estimate the basic equation with daily meteorological data instead of hourly data in section 4c. Finally, in section 4d, I determine if the meteorological variables have the same effect on alternative positive and negative affect variables (such as sadness, pleasure, and depression) that they have on happiness.

a. Analysis using data on travel

One potential problem with the survey data is that the location of respondents at the time of response is not recorded. However, the respondents are all students of Osaka University, so that they live within a relatively small region, near the Toyonaka–Suita area, over which hourly weather is almost uniform. Indeed, at the beginning of this section, I confirmed that the use of Toyonaka or Osaka city data does not change the results at all. Thus, the use of Osaka data is acceptable and does not lead to large biases, except on days when respondents traveled away from the area. In this subsection, I will further examine the robustness of the results, utilizing an additional location variable that gives some indication of respondents’ locations.

In the questionnaire, I asked the respondents to rank the importance of their most important personal event on that day, and to identify the event. 147 answers listed travel as the most important event. This is a small number out of the total of 32,125 answers (0.5%). This does not mean that these are all the trips the subjects made over the sample period, since in most cases they stopped responding to the survey while they were traveling for a long time, especially when they went abroad. On the other hand, subjects probably reported their trips when they could, because traveling represents an important personal event. Therefore, it is reasonable to suppose that subjects’ responses were made near the Osaka region, unless they explicitly stated that they were traveling.

Estimation omitting “traveling” observations produces almost identical results to those shown in Table 2, but the coefficients on temperature dummies become slightly more significant, suggesting that the results in the previous section are robust and that excluding travel days gives more accurate estimates of temperature. The result indicates that the subjects made most of their answers while in the Toyonaka–Osaka region, so that biases from day-to-day location changes are very small.

b. Effects of attributes: Who are more responsive to temperature, males or females?

At the start of the web survey in 2006, I sent a paper questionnaire to respondents to investigate their attributes (fixed individual characteristics). Thus, it is possible to examine whether the inclusion of these attributes as regressors changes the estimates of the basic model from section 3. The variables that I add to the basic model are a dummy variable for male sex, age, current living standard ranked from 0 to 10, living standard when subjects were 15 years old, a variable coding the highest education level that subjects’ fathers finished, an equivalent variable for subjects’ mothers, smoking habit ranging from 1 (do not smoke) to 6 (more than two boxes per day), body mass index, strength of religious belief on a five-point scale, and a dummy variable for area of academic study that takes a value of unity when respondents belong to science departments and 0 when they are affiliated with humanities or social science departments.

Inclusion of these attribute variables did not alter the results of basic equations very much, and the signs of the coefficients on most of the attribute variables are consistent with intuition and with previous studies (e.g., Frey and Stutzer 2002; results not shown).

While Barnston (1988) found that males are more responsive to weather than females in the United States, Connolly (2013) recently found the opposite. Thus, it is interesting to check which result describes our analysis in Japan. Estimation results of the basic equation for split samples of males and females are presented in Table 3.17 Looking at the estimates of temperature

17 In these estimations, a Hausman test reported negative $\chi^2$ values, implying that the test cannot be applied for this case. Thus, I arbitrarily reported the results of the fixed effects model, which were quite similar to those of the random effects model.
dummies, it is revealed that those for males are larger and more significant than those for females, implying that only males prefer low temperatures, while females are not affected by temperature; this is akin to the result of Barnston (1988).

c. Hourly weather data versus daily average weather data

Various specifications, including the basic equation, have so far been estimated with hourly weather data on the right-hand side. However, it might be the case that happiness is influenced more by overall weather over the course of a day than by weather at the exact time of the survey. To investigate this possibility, I reestimate the basic equation with daily weather data. Estimation results using daily data for Osaka city are presented in column 1 of Table 4. In the table, a daily average weather variable is identified with a prefix “D_” at the beginning of the variable name. Here D_TEMPERATURE, D_HUMIDITY, and D_WINDSPEED are daily averages, while D_SUNSHINE and D_PRECIPITATION are total daily amounts.18

The estimates for the control variables, including day-of-the-week dummies, are almost identical to the estimates in the specifications using hourly weather data. However, the estimates for meteorological variables are somewhat different. Among them, temperature and its squared term are only significant under the usual (non-robust) standard errors, but neither is significant at 10% level under the robust standard errors. Comparing these

18 Daily weather is the averaged data on the day when respondents made the reports. Although it is more appropriate to use the average for 24 h preceding the survey response, calculation of this proved difficult. The use of daily data of this paper, therefore, may underestimate the effect of daily weather.
results with those obtained with hourly data suggests that hourly data have a stronger effect on HAPPINESS than do daily average data.

To further examine the former suggestion, I estimated a regression incorporating both hourly and daily temperature variables, shown in column 2 of Table 4. Hourly temperature and squared temperature are significant, while daily values are not, suggesting that the hourly data have more explanatory power. These results strengthen the finding that happiness may be more strongly affected by current hourly weather than by averaged weather over the entire day.

d. Impact of weather on other affect variables

In the questionnaire, I solicited additional measures of positive and negative affect. The first of these is “(Q2) Are you sad now?” Possible responses to this question are 1 (sad), 2 (somewhat sad), 3 (somewhat not sad), and 4 (not sad). I define the variable SADNESS as the answer to this question. The second is “(Q3) Are you enjoying life now?” Possible responses are 1 (enjoying life), 2 (somewhat enjoying life), 3 (somewhat not enjoying life), and 4 (not enjoying life). I define the variable ENJOYMENT as 5 minus the answer to this question. Finally, respondents were asked “(Q4) Are you depressed now?” They had four possible responses: 1 (very depressed), 2 (somewhat depressed), 3 (somewhat not depressed), and 4 (not depressed). I define the variable DEPRESSION as the answer to this question. Note that all of these variables are defined so that a higher value indicates a more positive affect. It is interesting to ask how these variables are affected by the weather.

In Table 1, descriptive statistics for SADNESS, ENJOYMENT, and DEPRESSION are shown. The correlation coefficients between HAPPINESS and these three variables range from 0.4 to 0.6. The correlations between these effect variables and the various conditions of the subjects are quite similar to those of HAPPINESS. However, the correlations of these affect measures with the meteorological variables are slightly different from those of HAPPINESS. For example, the correlation with humidity is positive for ENJOYMENT and DEPRESSION, while it is negative for SADNESS.
I estimate the basic model using these three measures as the dependent variable. The control variable NEWS and physical conditions have quite similar impacts on these affect variables as on HAPPINESS. Only the results for ENJOYMENT are somewhat similar to the results for HAPPINESS, in that TEMPERATURE has a positive effect on affect, while its squared term affects affect negatively (column 1 of Table 5). On the other hand, the meteorological variables and their squared terms are not significant at all for SADNESS and DEPRESSION, when the basic equation is assumed (results not shown). These results suggest that the link between meteorological and affect variables may be weaker than the link with HAPPINESS, and that ENJOYMENT is relatively similar to HAPPINESS compared with SADNESS and DEPRESSION.

However, when we delete the squared terms of the meteorological variables and hour dummies, TEMPERATURE has negative significant coefficients under usual standard errors, implying that colder temperature brings about less sadness and depression (columns 2 and 3 of the table).

5. Conclusions

This paper investigates the time series dependence of happiness on weather for individuals living in a single location, while most earlier studies examined the effects of differing climates on geographically dispersed populations. Although there are some studies that focus on how daily weather affects mood, the present study is unique in that the data cover 17 months, which is much longer than the 6 weeks or less covered in previous studies. Additionally, this study includes detailed data on the individual attributes, physical conditions, and daily experiences of the respondents, allowing more robust controls than in past studies.

Empirical analysis reveals that happiness is maximized at 13.9°C in a quadratic model. The other meteorological variables, humidity, wind speed, precipitation, and sunshine do not significantly affect happiness. Our result that temperature weakly affects happiness is consistent with most of the previous studies that investigated within-person effects of weather on mood (Barnston 1988; Denissen et al. 2008; Koons et al. 2011; Klimstra et al. 2011; Connolly 2013).

I check the robustness of my results in various ways. The survey I use does not identify the exact...
locations of respondents; however, all of the respondents were students of Osaka University, so that they stayed near campus for most of the sample period. Using subjects’ reports on travel, I showed that the use of Osaka city weather data do not produce large biases. In addition, I found that males are more sensitive to temperature than females. It is also the case that happiness is more strongly affected by current hourly temperature than by average temperature over the entire day. Finally, while positive affect is affected by temperature in a similar way to happiness, negative affect behaves in a somewhat different manner.

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