GCOE Discussion Paper Series

Global COE Program

Human Behavior and Socioeconomic Dynamics

Discussion Paper No. 171

Weather and Individual Happiness

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January 2011; revised March 2012

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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. Our data set 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 negatively related to temperature and humidity. In a quadratic model, happiness is maximized at 13.9 degrees Celsius. The effects of other meteorological variables—wind speed and precipitation—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 weather conditions than average weather over the day. While sadness and depression (negative affect) are affected by weather in a similar way to happiness, enjoyment (positive affect) behaves somewhat differently.

JEL Classification Number: I31, Q51, Q54
Keywords: happiness, weather, daily web survey, Osaka region

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Running title : Weather and Individual Happines

[*] I am grateful for the insightful comments by two anonymous reviewers of this journal, which triggered a revision and extension of the earlier version. Financial support from the 21st Century Center of Excellence (COE) and Global Center of Excellence (GCOE) programs of Osaka University is gratefully acknowledged.

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), 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 element of quality of life (e.g. see Moro et al. 2008, Oswald and Wu 2010).[2] In spite of the importance of climate, a relatively limited number of studies have analyzed its influence on happiness (Dolan et al. 2008).[3]

A survey of earlier studies on the impact of climate on happiness indicates the current state of this field of inquiry. Rehdanz and Maddison (2005) analyzed a panel of 67 countries and found that temperature and precipitation have a significant effect on happiness. Specifically, people prefer higher mean temperatures in the coldest month and lower temperatures in the

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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.

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 are positive and significant. Using the first two waves of the Russian National Panel data set on 3,727 households in 1993 and 1994, Frijters and van Praag (1998) revealed 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. Recently, using three large-scale German surveys, Kämpfer and Mutz (2011) 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 are unable to assess whether the happiness of an individual responds to daily weather variations. 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 notable exception is Schwarz and Clore (1983), who 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. Barnston (1988), using six-week mood/productivity diaries from 62 students in 1974, report that the weather appears to influence mood and productivity, but only to a small extent.

Recently, three more relevant studies have been published. Denissen et al. (2008) collected mood data for 1,233 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. Kööt 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. They found large individual differences in how people's moods were affected by weather, which may hide the effect of weather on mood as a whole.

A limitation of these studies is the limited number of sampling days: even the longest study covers only six weeks. In order 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, I collected daily data on important individual-level control variables. Though 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 increase 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, and extend the basic equation to incorporate individual attributes. Section 5 concludes.

2. Data and Methods

2.1 The daily web survey

Survey participants consisted of 70 undergraduate and graduate students of Osaka University. 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 November 1, 2006 to March 31, 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.[4] 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

4 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.

was “very happy.” I named this variable *HAPPINESS*.[5]

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, which I named *SLEEP*, *HEALTH*, and *STRESS*. *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 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. *STRESS* was defined by the answer to the following question: “(Q11) Do you feel any stress now?” Answers ranged from 1 (a lot), 2 (a little), 3 (not much), and 4 (none).

[5] In section 4.6, I investigate the effect of weather on affect measures other than self-reported happiness.

Variables were defined so a higher value corresponded to a physical condition presumably more conducive to happiness (better health, less stress, etc.).

2.2 Meteorological data

Weather data was obtained from the website of the Meteorological Agency of Japan. Hourly and daily data on temperature (*TEMPERATURE*), humidity (*HUMIDITY*), wind speed (*WINDSPEED*), precipitation (*PRECIPITATION*), and hours of sunshine (*SUNSHINE*) are available for Osaka city. The hourly data of *TEMPERATURE*, *HUMIDITY*, and *WINDSPEED* 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 (subsection 4.5).

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 are suburbs of Osaka (see Figure 1).[6] 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 is richer. Furthermore, the distance between Toyonaka campus and the Osaka City Hall is only 13 kilometers, 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 subsections 4.1 and 4.3).

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 degrees Celsius, are shown in Figure 2. The climate of Osaka is mild and characterized by four seasons, of which spring and autumn are most loved by residents.[7] Winter is not severe: the average temperature in February, the coldest month, was around 5 degrees Celsius, with almost no snow in the observation years. However, it is hot and humid in summer; the average temperature in August was around 30 degrees during the observation period. Osaka residents often complain about the

6 Out of 75 total subjects, 38 belong to Suita campus, 32 to Toyonaka, and five unknown.
7 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.

high temperature and high humidity of the city in summer. Indeed, the discomfort index (DI) rises to a high value (80) in August.[8] The correlation coefficient between DI and temperature for the observation period is over 0.99, suggesting that high temperatures made people in Osaka uncomfortable.

2.3 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 November 1, 2006 to March 31, 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 degrees Celsius; average humidity, about 60%; average wind speed, 2.4 m/s; average time of sunshine per hour, about 0.2 hours; and average precipitation per hour, 0.12 mm.

The correlations of *P_NEWS*, *HEALTH*, and *STRESS* 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

[8] For an explanation of the discomfort index, see Tselepidaki et al. (1992).

that of *P_NEWS*, suggesting that the effect of weather is relatively limited, if it exists at all.

2.4 Statistical methods

I regress *HAPPINESS* on the variables representing the conditions of the subjects, the meteorological variables, and the day-of-the-week dummies.[9] Thus, the basic equation to be estimated is:

$$HAPPINESS_{i,t} = \alpha_i + \beta_1 PNEWS_{i,t} + \beta_2 MNEWS_{i,t} + \beta_3 SLEEP_{i,t} + \beta_4 HEALTH_{i,t} + \beta_5 STRESS_{i,t} + \sum_{k=1}^{6} \gamma_k DAY\ of\ the\ WEEK\ DUMMY_{i,t}^{k} + \delta_1 TEMPTERATURE_{i,t} + \delta_2 HUMIDITY_{i,t} + \delta_3 WINDSPEED_{i,t} + \delta_4 SUNSHINE_{i,t} + \delta_5 PRECIPITATION_{i,t} + \varepsilon_{i,t}, \quad (1)$$

where α_i is an individual-level fixed effect and $\varepsilon_{i,t}$ is a disturbance term.

I estimate all the equations with three models: ordinary least squares (OLS), a fixed effects model, and a random effects model, and then for each regression select a model using a Hausman test (random effects model vs. fixed effects model) and an F-test of the same constant (OLS vs. fixed effects model).[10] Section 4 contains several modifications of the basic regression equation, included as robustness checks.

[9] In subsection 4.4, I check whether the results are robust to inclusion of respondent attributes in the regression.

[10] 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 the fixed and random effects models.

3. Estimation results of the basic equation

The estimation results are shown in Table 2. In the first column, I show the results for the basic equation (1).[11] All control variables associated with the conditions of the subjects are highly significant, with reasonable signs. The coefficients on *P_NEWS*, *HEALTH*, and *STRESS* 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 Monday. The magnitude of the weekend effect is comparable to that of macro news.

Among the meteorological variables, temperature, humidity, and sunshine are significant at the 5% level. The estimated coefficients of temperature and humidity take a negative sign, implying that the students of Osaka University are happier when the temperature and humidity are lower. The coefficient on sunshine also takes a negative sign.

In the second column of the table, I present the results when all control variables are omitted.[12] The adjusted R-squared falls from 0.628 to 0.0024, confirming the importance of the control variables. However, the sign and significance of the estimates of the meteorological variables does not change much, suggesting that the meteorological variables are not correlated with the control variables; temperature, humidity, and sunshine are negative and significant at

[11] In this case, the fixed effects model was selected.
[12] In this case, the random effects model was selected.

the 1% level, while the other variables are not significant.

The finding that subjects liked lower temperatures is consistent with our intuition, since summer in Osaka is generally perceived to be too hot. However, it does not seem reasonable to assert that temperature has a linear negative influence, because the temperature in winter is rather low in the Osaka region. Thus, it is reasonable to assume that there is a temperature within the observed range that maximizes happiness. To assess this, I add squared temperature (*TEMP_SQ*) to the basic specification; the estimation results are shown in the third column of Table 2. The linear term and the squared term are significantly positive and negative, respectively, at the 1% level. This result implies that the subjects are the happiest at 13.9 degrees Celsius, which is the average temperature in April and November.

The result that longer sunshine time lowers happiness contradicts our intuition. The reason of this result may be that *SUNSHINE* takes a zero value during nighttime, during which people tend to be happier (Kahneman et al., 2004). To assess this effect, I added hour dummies for each hour of the day to the basic equation. Subjects were significantly happier from 19:00 to 23:00 than during the daytime. The coefficients on *SUNSHINE* and *HUMIDITY* became insignificant when hour dummies were included, while that on *TEMPERATURE* remained significantly negative at the 1% level (results not shown). When hour dummies were added to the model with no control variables, the coefficient on *SUNSHINE* became significantly positive.

In addition, I re-estimated the basic equation while excluding all data reported at night. Estimates using data from 7:00 to 17:00 are presented in the fourth column of Table 2. The number of observations was reduced to 12,187. While temperature remained significant at the 5% level, *SUNSHINE* became insignificant. Given these results, I conclude that the negative coefficient on *SUNSHINE* is spurious, and merely reflects the fact that people are happier at night.

Since some meteorological variables are more correlated with each other than with *HAPPINES*S, a multicollinearity problem is suspected. Thus, I re-estimated the model including only one meteorological variable at a time. The coefficient on humidity became insignificant, while the other coefficients did not change much (results not shown).

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 degrees Celsius is equivalent in size to a change in one point of macro news on a ten-point-scale. This result 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 are valid when I use data from Toyonaka city instead of Osaka city for some of the meteorological variables. Second, I separate the total period into “summer” and “winter” seasons and check if the result in the previous section on temperature is confirmed. Third, since the exact location of respondents is not known, I examine if lack of this information brings about large biases. Specifically, I utilize the information on days when the respondents travel and on days when they attend classes to infer whether subjects stayed near the Toyonaka-Osaka region during the bulk of the observation period. Fourth, I extend the model to incorporate variables representing the attributes (fixed individual characteristics) of respondents - sex, age, living standard, body mass index, etc. I examine not only the effect of these variables on happiness, but also their effects on the sensitivity of happiness to weather. Fifth, I estimate the basic equation with daily meteorological data instead of hourly data. Finally, 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.

4.1 Examination of possible bias due to the use of Osaka city data instead of Toyonaka city data

Let me begin with the analysis using the Toyonaka city data. 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. Thus, it is interesting to check the size of the biases arising from the use of Osaka city weather data instead of Toyonaka city data. In a re-estimation of the basic model, I use Toyonaka data for temperature (*T_TEMPRETURE*), wind speed (*T_WINDSPEED*), and precipitation (*T_PRECIPITATION*), and Osaka city data for humidity and sunshine (as these latter two are not available for Toyonaka city). The estimation results are presented in the left-hand columns of Table 3. The estimates are quite similar to those in Table 2, implying that using the alternative city data does not affect the results. The right-hand columns of Table 3 show the results when the data from Osaka city, *HUMIDITY* and *SUNSHINE*, are deleted; the estimates are again quite similar. This is not surprising, since the two cities are quite near, so that the correlation between the Osaka and Toyonaka data is 0.992 for temperature, 0.495 for wind speed, and 0.389 for precipitation. These results support, at least partially, the use of the meteorological data of Osaka city, even though respondents' exact locations are not known.

4.2 Effect of temperature is opposite in summer and winter

In section 3, it was demonstrated that happiness increases with temperature up to about 14 degrees Celsius, and then decreases. This result leads to the prediction that in summer people like lower temperatures, while in winter they prefer higher temperatures. To see if this is really the case I divide the total observation period into two seasons, warm ("summer") and cold ("winter"), and re-estimate the basic equation; the former period is from May 16 to November 15, while the latter includes the remainder of the sample period.[13]

The estimation results are presented in Table 4. In the first columns, the results for "summer" are shown. Most of the estimates are similar to those in Table 2, confirming the basic results. However, although the key coefficient of *TEMPERATURE* takes a negative sign, it is insignificant at the 10% level. In the second column, I show the estimates when meteorological variables other than *TEMPERATURE* are omitted. The coefficient on *TEMPERATURE* becomes significantly negative at the 5% level, supporting the prediction. In the table's third column, the results for "winter" are presented. The coefficient on *TEMPERATURE* is significantly positive at the 5% level, again confirming the prediction. When meteorological variables other than *TEMPERATURE* are omitted, the result is unchanged. These results indicate that people in the Osaka region do not like higher temperatures in summer, but do like them in winter, as one would expect.[14]

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13 Note that the total period started in "winter" time and ended in "winter" time sixteen months later; thus, the "winter" sample consists of two separated periods, while the "summer" time consists of one consecutive period.

14 I also re-did the estimation dividing the total period into three subperiods: "winter" defined as January to March, "summer" defined as July to September, and "other seasons" (spring and

4.3 Analysis using data on travel and class attendance

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, in subsection 4.1, 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 two additional location variables that give 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. One hundred and forty seven 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

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autumn). The coefficient for winter was positive and that for summer was negative, but they were insignificant at the 10% level. The reason for these insignificant results is probably that variation of temperature is small within each season.

personal event. Therefore, it is reasonable to suppose that subjects' responses were made near the Osaka region, unless they explicitly noticed that they were traveling.

When I add a cross term between *TEMPERATURE* and a travel dummy (equal to unity if a respondent was traveling and zero otherwise) to the basic equation, the coefficient of the cross dummy is positive (p-value of 23%). Although the significance level is low, the result suggests that the effect of *TEMPERATURE* became smaller when subjects made a trip, suggesting that deleting the traveling samples strengthens the sensitivity of happiness to temperature. In addition, estimation results when deleting traveling samples produces almost identical results to those shown in Table 2, suggesting that the results in the previous section are robust (results not shown). Estimation results for the basic equation using *only* traveling samples (N=147) are shown in the left-hand columns of Table 5. While *P_NEWS* and *STRESS* are significant and positive, all meteorological variables, including *TEMPERATURE* and *SUNSHINE*, are insignificant; this is exactly what one would expect, although it may also arise from the small sample.

From December 1, 2007 to March 31, 2008, I collected data on whether respondents attended class on the day of the response. The total number of responses during this period is 7,459, while the number during which students attended class is 2,342. It is essentially certain that students were in the Osaka area when the "attended class" responses were made.

To measure the effect of attending class on happiness and on its sensitivity to temperature, I added a dummy variable *CLASS* that takes a value of unity if a subject attended class on the day of response and zero otherwise, as well as a cross term between *TEMPERATURE* and the *CLASS* dummy (*CLASS***TEMP*), to the basic equation; the estimation results are presented in the middle columns of Table 5. The coefficients on the variables of news and physical conditions are quite similar to those in Table 2. The coefficient on *CLASS* is negative, but not significant at the 10% level, suggesting that attending a class might have lowered happiness. As for the meteorological variables, one notable result is that the coefficient on *TEMPERATURE* is positive and significant at the 10% level, suggesting that higher temperature relates to higher happiness. This is reasonable because the sample period is in the winter season. Day-of-the-week dummies are not significant here. This is also reasonable, because the period includes a two-week New Year vacation and term examinations in early February, followed by one and a half months of spring vacation, so that the distinction between weekdays and weekends was not very important during the period. The cross term is positive but insignificant, suggesting that attending class does not affect the sensitivity of happiness to temperature. This last result has an important implication for the current paper. Reports on days on which subjects attended a class were definitely sent from Toyonaka-Osaka region. The result that class attendance does not affect my estimates suggests that subjects also stayed in the

Toyonaka-Osaka region on most of the days when they had no classes. This result is consistent with the report that subjects made only 147 responses while traveling.

Weekdays and weekends might see different effects on the sensitivity of happiness to meteorological variables. To assess this, I added a cross term between *TEMPERATURE* and a weekend dummy to the basic equation; the estimation results are presented in the right-hand columns of Table 5. The cross term is not significant at all, indicating that the sensitivity of happiness to temperature does not differ between weekdays and weekends.

To reiterate, the effect of temperature in Osaka city on happiness when respondents were traveling is smaller than when they were not. In addition, the sensitivity to temperature does not differ based whether or not subjects attended class on the day or whether it was a weekday or weekend. These results suggest that the subjects made most of their answers while in the Toyonaka-Osaka region, so that biases from day-to-day location changes is very small.

4.4 Effects of attributes on the sensitivity of happiness to temperature

At the start of the web survey in 2006, I sent a paper questionnaire to the 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

(*DMAN*), age (*AGE*), current living standard ranked from 0 to 10 (*LIVING*), living standard when subjects were 15 years old (*LIVING15*), a variable coding the highest education level that subjects' fathers finished (*F_ACADEMIC*, which takes larger values for higher education levels), an equivalent variable for subjects' mothers (*M_ACADEMIC*), smoking habit (*SMOKING*) ranging from 1 (do not smoke) to 6 (more than two boxes per day), body mass index (*BMI*), strength of religious belief on a five-point scale (*RELIGION*), 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 (*SCIENCE*).

Descriptive statistics for these variables are presented in Table 6. Out of 55 respondents who answered all the questions, the number of males is 38 (69%). Age ranges from 18 to 28 years old, with an average of 21.5. Only three subjects smoke, and these are all light smokers. *BMI* ranges between 15 and 33, with an average of 20.8. Most of the subjects are not deeply religious.

Estimation results for the model when these attributes are included are presented in Table 7. The number of observations decreases to 20,131. The left-hand columns show the results of OLS estimation.[15] The coefficients on all the variables of the basic equation are qualitatively the same as those in Table 2, except that the coefficient on *HUMIDITY* becomes insignificant

[15] Since the attributive variables have only one observation per subject, fixed effects models that include these variables cannot be estimated.

and that no coefficients on day-of-the-week dummies are significant.

Most of the attributes are significant, and the signs of their coefficients are consistent with intuition and with previous studies (e.g. Frey and Stutzer 2002). Females are happier than males, and younger students are happier than older students. Higher current and past standards of living are positively correlated with happiness. Those whose mothers have more education are happier, while for fathers the result is the opposite.[16] The coefficient on *SMOKING* is negative but insignificant (possibly due to the fact that there were no heavy smokers). Higher *BMI* is correlated with higher happiness. Religious people are happier. Those who belong to science departments are unhappier than those affiliated with humanities and social science departments.

It is interesting to ask whether the sensitivity of happiness to weather conditions differs depending on a respondent's attributes. To check this, I constructed cross terms between the attributes and *TEMPERATURE* and added these to the extended equation shown in Table 7. The estimation results are presented in Table 8. Estimates for variables of physical condition and day-of-the-week dummies are omitted to save space, since they are almost the same as those in Table 7. In the first column, cross terms between female and male dummies and *TEMPERATURE* (*DWOMAN**TEMP* and *DMAN**TEMP*) are added. Interestingly, only males prefer low temperatures, while females are not affected by temperature, which is consistent with

16 This result is not easy to interpret.

the result of Barston (1988).

In the second column, cross terms between *TEMPERATRE* and academic department dummies (*SCIENCE**TEMP* and *HUMANITY**TEMP*) are added. Science majors are negatively affected by higher temperatures, while humanities majors show insignificant sensitivity. This may simply be due to the fact that science majors contain a much higher percentage of males than humanities departments.

In the third column, a cross term between *AGE* and *TEMPERATURE* is added. The cross term is significantly negative at the 5% level, indicating that older students dislike high temperatures more. In the fourth column, a cross term between living standard and *TEMPERATURE* is added; however, living standard does not affect sensitivity to temperature.

In sum, the sensitivity of happiness to temperature does depend on certain individual attributes.

4.5 Hourly weather data vs. 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 re-estimated the basic equation with daily weather data.

Estimation results using daily data for Osaka city are presented in the left-hand columns of Table 9. In the table, a daily average weather variable is identified with a "*D_*" at the beginning of the variable name. *D_TEMPERATURE*, *D_HUMIDITY*, and *D_WINDSPEED* are daily averages, while *D_SUNSHINE* and *D_PRECIPITATION* are total daily amounts.

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, *D_TEMPERATURE* is only noteworthy at the 1% significance level (Table 9); the other four variables are not significant at all. Comparing these results with those obtained with hourly data suggests that hourly data have a stronger effect on *HAPPINESS* than do daily average data, and that the effect of temperature is the most robust.

To further examine the former suggestion, I estimated a regression incorporating both hourly and daily meteorological variables, shown in the right-hand columns of Table 9. Hourly data are significant for humidity and sunshine, while daily data are not, suggesting that the former has more explanatory power. For temperature, both hourly and daily data are insignificant; however, the hourly data have a negative coefficient (p-value of 15%), while the daily data take a positive sign. These results support the notion that hourly data have more explanatory power, suggesting that happiness depends on current weather rather than on average weather over a day.

4.6 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*, *PLEASURE*, and *DEPRESSION* are shown. The correlation coefficients between *HAPPINESS* and these three variables range from 0.4 to 0.6. The correlations between these affect 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 other measures of affect.

In Table 10, I present regression results for the basic model using these three measures as the dependent variable. Results for negative affect variables, *SADNESS* and *DEPRESSION*, are consistent with the results for *HAPPINESS*, in that temperature has a negative effect on happiness. However, *SUNSHINE* has positive effects on *SADNESS* and *DEPRESSION*. On the other hand, positive affect, *PLEASURE*, behaves somewhat differently. Higher temperature correlates with higher *PLEASURE*, which is the opposite of the outcome for *HAPPINESS*. Thus, the effects of meteorological variables on well-being depend on how well-being is measured.

5. Conclusions

This paper investigates the time-series dependence of happiness on weather for individuals living in a single location, while most earlier studies examine 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 covers 17 months, which is much longer than the six 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, which allow more robust controls than in past studies.

Empirical analysis reveals that happiness is negatively related to temperature in a linear model, and is maximized at 13.9 degrees Celsius in a quadratic model. Humidity and sunshine also have a negative effect on happiness; however, the result for sunshine is found to be spurious: the effect is entirely due to the fact that sunshine is zero at night and people are happier at night. The other meteorological variables, wind speed, and precipitation, do not significantly affect happiness.

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 and class attendance, I showed that the use of Osaka city weather data does not produce large biases. In addition, using detailed data on subjects' attributes, I found that the sensitivity of happiness to temperature depends on attributes such as sex, age and academic major. It is also the case that happiness is more strongly affected by current hourly weather than by averaged weather over the entire day. Finally, while negative affect is affected by weather in a similar way to happiness, positive affect behaves in a somewhat different manner.

References

Barnston, A. G. (1988). The effect of weather on mood, productivity, and frequency of emotional crisis in a temperate continental climate. *International Journal of Biometeorology*, 32, 134-143.

Bigano, A., Bosello, F., Roon, R., & Tol, R. S. J. (2008). Economy-wide impacts of climate change: A joint analysis for sea level rise and tourism. *Mitigation and Adaptation Strategies for Global Change*, 13, 765–791.

Brereton, F., Clinch, J.P., & Ferreira, S., (2008). Happiness, geography and the environment. *Ecological Economics*, 65 (2), 386-396.

Denissen, J. J. A., Butalid, L., Penke, L., & van Aken, M. A. G. (2008). The effects of weather on daily mood: A multilevel approach. *Emotion*, 8, 662–667.

Dolan, P., Peasgood, T., & White, M. (2008). Do we really know what makes us happy? A review of the economic literature on the factors associated with subjective well-being. *Journal of Economic Psychology*, 29, 94–122.

Eisinga, R., Franses, P. H. & Vergeer, M. (2011). Weather conditions and daily television use in the Netherlands, 1996–2005, *International Journal of Biometeorology,* 55, 555–564.

Frey, B. S., & Stutzer, A. (2002). What can economists learn from happiness research? *Journal of Economic Literature,* 40(2), 402–435.

Frijters, P., & Van Praag, B. M. S. (1998). The effects of climate on welfare and well-being in Russia. *Climatic Change*, 39, 61–81.

Hoch, I., & Drake, J. (1974). Wages, climate, and the quality of life. *Journal of Environmental Economics and Management*, l, 268–295.

Huibers, M.J.H., Esther de Graaf, L., Peeters, F. P. M. L., & Arntz, A. (2010). Does the weather make us sad? Meteorological determinants of mood and depression in the general population. *Psychiatry Research*, 180, 143–146.

Kahneman, D., Kruger, A. B., Schkade, D. A., Schwartz, N., & Stone, A.A. (2004). A survey method for characterizing daily life experience: The day reconstruction method. *Science*, 306, 1776-1780.

Kämpfer, S. & Mutz, M. (2011). On the sunny side of life: Sunshine effects on life satisfaction. *Social Indicators Research*, available online.

Klimstra, T. A., Frijns, T., Keijsers, L., Denissen, J. J. A., Raaijmakers, Q. A. W., van Aken, M. A. G., Koot, H. M., van Lier, P. A. C. & Meeus, W. H. J. (2011). Come rain or come shine: Individual differences in how weather affects mood. *Emotion*, 11 (6), 1495–1499.

Kööt, L., Realo, A., & Allik, J. (2011). The influence of the weather on affective experience: An experience sampling study. *Journal of Individual Differences*, 32 (2), 74-84.

Maddison, D. J. (2003). The amenity value of climate: The household production function approach. *Resource and Energy Economics*, 25, 155–175.

Maddison, D. J., & Bigano, A. (2003). The amenity value of the Italian climate. *Journal of Environmental Economics and Management*, 45, 319–332.

Moro, M., Brereton, F., Ferreira, S., Clinch, J. P. (2008). Ranking quality of life using subjective well-being data. *Ecological Economics*, 65(3): 448-460.

Oswald, A. J. and Wu, S. (2010). Objective confirmation of subjective measures of human well-being: Evidence from the U.S.A. *Science*, 327 (5965), 576-579.

Rehdanz, K., & Maddison, D. (2005). Climate and happiness. *Ecological Economics*, 52, 11–125.

Schwarz, N. and Clore, G. L. (1983). Mood, misattribution and judgments of well-being: information and directive functions of affective states. *Journal of Personality and Social Psychology*, 45, 513-23.

Tselepidaki, I. M., Santamouris, C. M., & Poulopoulou, G. (1992). Analysis of the summer discomfort index in Athens, Greece, for cooling purposes. *Energy and Buildings*, 18, 51–56.

Van Praag, B. M. S. (1988). Climate equivalence scales. *European Economic Review*, 32, 1019–1024.

Table 1. Descriptive statistics

	Mean	Std Dev	Minimum	Maximum	CORRELATION with *HAPPINESS*	*SADNESS*	*ENJOYMENT*	*DEPRESSION*
HAPPINESS	5.867	1.972	0	10	1			
SADNESS	3.172	0.853	1	4	0.501	1		
ENJOYMENT	2.450	0.907	1	4	0.597	0.357	1	
DEPRESSION	3.075	0.949	1	4	0.448	0.728	0.362	1
P_NEWS	0.522	2.355	−5	5	0.644	0.415	0.542	0.439
M_NEWS	−0.415	2.043	−5	5	0.183	0.112	0.117	0.137
SLEEP	2.616	0.976	1	4	0.172	0.190	0.080	0.161
HEALTH	2.270	0.787	1	4	−0.308	−0.289	−0.233	−0.307
STRESS	2.005	0.911	1	4	0.403	0.392	0.298	0.427
TEMPERATURE	15.103	8.126	−0.1	36.9	−0.044	−0.030	−0.021	−0.038
HUMIDITY	61.245	14.344	15	94	−0.001	−0.006	0.009	0.001
WINDSPEED	2.385	1.306	0	9.9	−0.008	−0.0001	−0.007	−0.009
SUNSHINE	0.201	0.366	0	1	−0.031	−0.004	−0.053	−0.015
PRECIPITATION	0.117	0.807	0	26	0.0002	−0.003	−0.0002	−0.004

Note: The number of observations is 32125.

Table 2. Estimation results for the basic equation

Variable	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
P_NEWS	0.397	[.000]			0.397	[.000]	0.374	[.000]
M_NEWS	0.065	[.000]			0.065	[.000]	0.063	[.000]
SLEEP	0.029	[.001]			0.028	[.001]	0.038	[.007]
HEALTH	−0.227	[.000]			−0.227	[.000]	−0.302	[.000]
STRESS	0.322	[.000]			0.322	[.000]	0.406	[.000]
SUNDAY	0.051	[.044]			0.053	[.036]	0.066	[.130]
TUESDAY	0.046	[.066]			0.046	[.066]	−0.010	[.811]
WEDNESDAY	0.030	[.228]			0.029	[.245]	0.037	[.363]
THURSDAY	0.005	[.833]			0.006	[.818]	−0.009	[.831]
FRIDAY	0.048	[.056]			0.048	[.056]	0.016	[.702]
SATURDAY	0.064	[.010]			0.065	[.010]	0.066	[.120]
TEMPERATURE	−0.003	[.003]	−0.009	[.000]	0.012	[.002]	−0.003	[.035]
TEMP_SQ					−0.00042	[.000]		
HUMIDITY	−0.001	[.039]	−0.002	[.004]	−0.001	[.058]	−0.002	[.100]
WINDSPEED	−0.003	[.620]	0.007	[.331]	−0.001	[.837]	0.003	[.701]
SUNSHINE	−0.080	[.000]	−0.144	[.000]	−0.076	[.001]	0.002	[.951]
PRECIPITATION	0.001	[.929]	0.000	[.969]	−0.002	[.831]	−0.014	[.466]
Constant			6.158	[.000]				
Adjusted R^2	0.628		0.002		0.628		0.651	
Number of observations	32123		32123		32123		12187	
Hausman test		[.0006]		[.2046]		[.0011]		[.0044]
Estimation method	FIXED		RANDOM		FIXED		FIXED	

Note: On the basis of the results of the Hausman test and the F-test of the same constant, estimates of the random effects models are presented in the second columns and estimates of the fixed effects model in the other columns.

Table 3. Estimation results using Toyonaka city data for temperature, wind speed, and precipitation

Independent Variable	Coefficient	P-value	Coefficient	P-value
P_NEWS	0.397	[.000]	0.397	[.000]
M_NEWS	0.065	[.000]	0.065	[.000]
SLEEP	0.029	[.001]	0.028	[.001]
HEALTH	−0.227	[.000]	−0.227	[.000]
STRESS	0.322	[.000]	0.321	[.000]
SUNDAY	0.052	[.040]	0.056	[.027]
TUESDAY	0.047	[.062]	0.047	[.059]
WEDNESDAY	0.030	[.223]	0.030	[.228]
THURSDAY	0.006	[.799]	0.009	[.726]
FRIDAY	0.049	[.051]	0.050	[.045]
SATURDAY	0.065	[.009]	0.067	[.007]
T_TEMPERATURE	−0.002	[.006]	−0.003	[.000]
HUMIDITY	−0.001	[.048]		
T_WINDSPEED	−0.004	[.368]	−0.003	[.413]
SUNSHINE	−0.079	[.000]		
T_ PRECIPITATION	−0.003	[.653]	−0.004	[.536]
Adjusted R^2	0.628		0.628	
Number of observations	32111		32111	
Hausman test		[.0015]		[.0008]
Estimation method	FIXED		FIXED	

Note: *T_TEMPERATURE*, *T_WINDSPEED*, and *T_PRECIPITATION* indicate that the data are those of Toyonaka city.
On the basis of the results of the Hausman test and the F-test of the same constant, estimates of the fixed effects model are presented.

Table 4. Estimates for summer and winter samples

	Summer				Winter			
Independent Variable	Coefficient	P−value	Coefficient	P−value	Coefficient	P−value	Coefficient	P−value
P_NEWS	0.383	[.000]	0.383	[.000]	0.416	[.000]	0.417	[.000]
M_NEWS	0.076	[.000]	0.077	[.000]	0.059	[.000]	0.059	[.000]
SLEEP	0.016	[.234]	0.016	[.256]	0.026	[.020]	0.025	[.024]
HEALTH	−0.168	[.000]	−0.167	[.000]	−0.222	[.000]	−0.222	[.000]
STRESS	0.261	[.000]	0.260	[.000]	0.330	[.000]	0.330	[.000]
SUNDAY	0.046	[.256]	0.052	[.203]	0.051	[.125]	0.052	[.115]
TUESDAY	0.046	[.256]	0.045	[.262]	0.054	[.103]	0.054	[.097]
WEDNESDAY	0.040	[.321]	0.038	[.335]	0.037	[.261]	0.035	[.291]
THURSDAY	0.010	[.803]	0.011	[.784]	0.006	[.857]	0.010	[.772]
FRIDAY	0.045	[.271]	0.049	[.222]	0.045	[.170]	0.046	[.163]
SATURDAY	0.093	[.022]	0.096	[.017]	0.049	[.131]	0.049	[.133]
TEMPERATURE	−0.003	[.153]	−0.005	[.031]	0.005	[.024]	0.004	[.036]
HUMIDITY	−0.0004	[.685]			−0.001	[.069]		
WINDSPEED	−0.0003	[.977]			−0.004	[.537]		
SUNSHINE	−0.074	[.053]			−0.074	[.010]		
PRECIPITATION	0.001	[.938]			0.008	[.727]		
Adjusted R^2	0.647		0.672		0.647		0.647	
Number of observations	11187		11187		17745		17745	
Hausman test		[.0012]		[.0006]		[.0024]		[.0012]
Estimation method	FIXED		FIXED		FIXED		FIXED	

Table 5. Effect of class attendance and weekend on the sensitivity to temperature

Independent Variable	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
P_NEWS	0.521	[.000]	0.431	[.000]	0.397	[.000]
M_NEWS	−0.010	[.872]	0.060	[.000]	0.065	[.000]
SLEEP	−0.099	[.451]	0.014	[.362]	0.029	[.001]
HEALTH	−0.198	[.217]	−0.158	[.000]	−0.227	[.000]
STRESS	0.505	[.000]	0.187	[.000]	0.322	[.000]
CLASS			−0.101	[.123]		
SUNDAY	0.520	[.191]	0.017	[.702]	0.053	[.157]
TUESDAY	0.560	[.187]	−0.035	[.423]	0.046	[.066]
WEDNESDAY	0.077	[.871]	0.031	[.474]	0.030	[.228]
THURSDAY	0.095	[.812]	−0.006	[.897]	0.005	[.833]
FRIDAY	0.581	[.127]	0.025	[.558]	0.048	[.056]
SATURDAY	0.452	[.231]	0.046	[.284]	0.066	[.076]
TEMPERATURE	0.004	[.771]	0.007	[.072]	−0.002	[.014]
*CLASS*TEMP*			0.003	[.670]		
*WEEKEND*TEMP*					−0.0001	[.950]
HUMIDITY	−0.006	[.512]	−0.001	[.244]	−0.001	[.039]
WINDSPEED	0.099	[.260]	0.006	[.487]	−0.003	[.618]
SUNSHINE	0.247	[.634]	−0.159	[.000]	−0.080	[.000]
PRECIPITATION	−0.154	[.592]	−0.030	[.282]	0.001	[.929]
Constant	4.969	[.000]				
Adjusted R2	0.398		0.761		0.628	
Number of observations	147		7459		32123	
Hausman test		[.3275]		[.0003]		[.0010]
Estimation method	RANDOM		FIXED		FIXED	

Note: In the left-hand columns, estimation results are presented where *only* traveling days are used.

The observation period for the results shown in the middle columns is from December 1, 2007 to March 31, 2008. The coefficient on *TEMPERATURE* is positive, since the estimation period is “winter”.

Table 6. Descriptive statistics of attribute variables

	Mean	Std Dev	Minimum	Maximum
DMAN	0.691	0.466	0	1
AGE	21.545	2.026	18	28
LIVING	5.236	1.563	1	8
LIVING15	5.400	1.461	2	8
F_ACADEMIC	5.745	2.382	2	11
M_ACADEMIC	4.618	1.769	1	9
SMOKING	1.055	0.229	1	2
BMI	20.841	2.883	15.397	33.412
RELIGION	1.473	1.052	1	5
SCIENCE	0.600	0.494	0	1

Note: The number of observations is 55.

Table 7. Estimates of the model incorporating attribute variables

Independent Variable	Coefficient	P-value	Coefficient	P-value
P_NEWS	0.426	[.000]	0.398	[.000]
M_NEWS	0.084	[.000]	0.092	[.000]
SLEEP	0.075	[.000]	0.062	[.000]
HEALTH	−0.312	[.000]	−0.248	[.000]
STRESS	0.263	[.000]	0.268	[.000]
SUNDAY	0.013	[.703]	0.023	[.478]
TUESDAY	0.035	[.313]	0.025	[.435]
WEDNESDAY	0.021	[.540]	0.017	[.591]
THURSDAY	−0.005	[.883]	−0.015	[.650]
FRIDAY	0.031	[.378]	0.030	[.359]
SATURDAY	0.056	[.108]	0.062	[.058]
TEMPERATURE	−0.004	[.001]	−0.003	[.006]
HUMIDITY	0.001	[.434]	−0.001	[.382]
WINDSPEED	0.000	[.960]	0.005	[.434]
SUNSHINE	−0.054	[.061]	−0.097	[.001]
PRECIPITATION	0.002	[.881]	0.007	[.540]
DMAN	−0.734	[.000]	−0.771	[.000]
AGE	−0.013	[.014]	−0.029	[.479]
LIVING	0.095	[.000]	0.126	[.045]
LIVING15	0.016	[.092]	0.031	[.671]
F_ACADEMIC	−0.017	[.004]	−0.023	[.621]
M_ACADEMIC	0.089	[.000]	0.058	[.300]
SMOKING	−0.073	[.124]	−0.266	[.421]
BMI	0.044	[.000]	0.044	[.119]
RELIGION	0.194	[.000]	0.215	[.010]
SCIENCE	−0.130	[.000]	−0.056	[.779]
Constant	4.610	[.000]	5.012	[.000]
Adjusted R^2	0.526		0.523	
Number of observations	20131		20131	
Estimation method	OLS		RANDOM	

Table 8. Interaction between weather and attributes

Independent Variable	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
*DWOMA*TEMP*	0.002	[.352]						
*DMAN*TEMP*	−0.005	[.000]						
*SCIENCE*TEMP*			−0.006	[.000]				
*HUMANITY*TEMP*			0.002	[.212]				
TEMP					0.021	[.061]		
*AGE*TEMP*					−0.001	[.031]		
TEMP							0.000	[.953]
*LIVING*TEMP*							−0.001	[.334]
HUMIDITY	−0.001	[.362]	−0.001	[.367]	−0.001	[.382]	−0.001	[.376]
WINDSPEED	0.005	[.434]	0.005	[.447]	0.005	[.457]	0.005	[.438]
SUNSHINE	−0.098	[.000]	−0.094	[.001]	−0.097	[.001]	−0.097	[.001]
PRECIPITATION	0.007	[.534]	0.007	[.530]	0.007	[.540]	0.007	[.530]
DMAN	−0.668	[.001]	−0.773	[.000]	−0.772	[.000]	−0.770	[.000]
AGE	−0.029	[.480]	−0.029	[.474]	−0.012	[.767]	−0.029	[.479]
LIVING	0.125	[.047]	0.126	[.045]	0.126	[.045]	0.135	[.034]
LIVING15	0.032	[.660]	0.032	[.661]	0.031	[.671]	0.031	[.670]
F_ACADEMIC	−0.023	[.618]	−0.023	[.615]	−0.023	[.614]	−0.023	[.623]
M_ACADEMIC	0.059	[.296]	0.058	[.301]	0.058	[.298]	0.058	[.300]
SMOKING	−0.266	[.421]	−0.271	[.413]	−0.269	[.416]	−0.263	[.426]
BMI	0.044	[.120]	0.044	[.117]	0.044	[.118]	0.044	[.120]
RELIGION	0.214	[.011]	0.214	[.011]	0.215	[.011]	0.215	[.010]
SCIENCE	−0.059	[.771]	0.069	[.735]	−0.057	[.779]	−0.056	[.781]
Constant	4.946	[.000]	4.933	[.000]	4.656	[.000]	4.962	[.000]
Adjusted R^2	0.524		0.524		0.523		0.524	
Number of observations	20131		20131		20131		20131	
Estimation method	RANDOM		RANDOM		RANDOM		RANDOM	

Note: The results for the control variables representing physical conditions and weekday dummies are omitted here to save space. They are almost identical to those of the random effects model in Table 7.

Table 9. Estimation results using daily average weather data

Variable	Coefficient	P-value	Coefficient	P-value
P_NEWS	0.397	[.000]	0.396	[.000]
M_NEWS	0.066	[.000]	0.065	[.000]
SLEEP	0.027	[.002]	0.028	[.001]
HEALTH	−0.228	[.000]	−0.227	[.000]
STRESS	0.323	[.000]	0.324	[.000]
SUNDAY	0.055	[.032]	0.053	[.040]
TUESDAY	0.051	[.046]	0.051	[.044]
WEDNESDAY	0.030	[.225]	0.030	[.225]
THURSDAY	0.007	[.770]	0.007	[.790]
FRIDAY	0.046	[.072]	0.047	[.067]
SATURDAY	0.068	[.007]	0.066	[.009]
TEMPERATURE			−0.007	[.158]
D_TEMPERATURE	−0.003	[.005]	0.004	[.410]
HUMIDITY			−0.002	[.041]
D_HUMIDITY	−0.001	[.427]	0.001	[.468]
WINDSPEED			−0.001	[.909]
D_WINDSPEED	−0.003	[.754]	−0.003	[.765]
SUNSHINE			−0.080	[.001]
D_SUNSHINE	−0.001	[.662]	0.002	[.513]
PRECIPITATION			0.000	[.977]
D_ PRECIPITATION	0.001	[.476]	0.001	[.432]
Adjusted R^2	0.627		0.627	
Number of observations	31632		31632	
Hausman test		[.0004]		[.0021]
Estimation method	FIXED		FIXED	

Note: Daily data are indicated with a “*D_*” at the beginning of a variable name.

Table 10. Estimation results for alternative affect variables

Dependent Variable	*SADNESS*		*PLEASURE*		*DEPRESSION*	
Independent Variable	Coefficient	P–value	Coefficient	P–value	Coefficient	P–value
P_NEWS	0.115	[.000]	0.157	[.000]	0.132	[.000]
M_NEWS	0.004	[.038]	0.016	[.000]	0.003	[.204]
SLEEP	0.029	[.000]	−0.007	[.101]	0.029	[.000]
HEALTH	−0.025	[.000]	−0.136	[.000]	−0.063	[.000]
STRESS	0.190	[.000]	0.175	[.000]	0.286	[.000]
SUNDAY	0.003	[.821]	0.033	[.011]	0.006	[.688]
TUESDAY	0.007	[.567]	−0.025	[.050]	0.029	[.036]
WEDNESDAY	0.016	[.186]	0.004	[.782]	0.008	[.539]
THURSDAY	0.028	[.026]	−0.012	[.327]	0.018	[.192]
FRIDAY	0.008	[.527]	0.022	[.082]	0.026	[.057]
SATURDAY	0.0003	[.982]	0.049	[.000]	0.008	[.544]
TEMPERATURE	−0.001	[.032]	0.001	[.079]	−0.001	[.024]
HUMIDITY	−0.0003	[.231]	−0.0005	[.104]	−0.0002	[.590]
WINDSPEED	−0.00002	[.995]	−0.00001	[.998]	−0.003	[.289]
SUNSHINE	0.019	[.091]	−0.052	[.000]	0.042	[.001]
PRECIPITATION	0.001	[.908]	−0.004	[.356]	−0.003	[.561]
Constant	2.721	[.000]			2.489	[.000]
Adjusted R^2	0.254		0.544		0.296	
Number of observations	32123		32123		32123	
Hausman test		[.2016]		[.0135]		[.2874]
Estimation method	RANDOM		FIXED		RANDOM	

Figure 1.   Map of three locations: two campuses of Osaka University and Osaka city

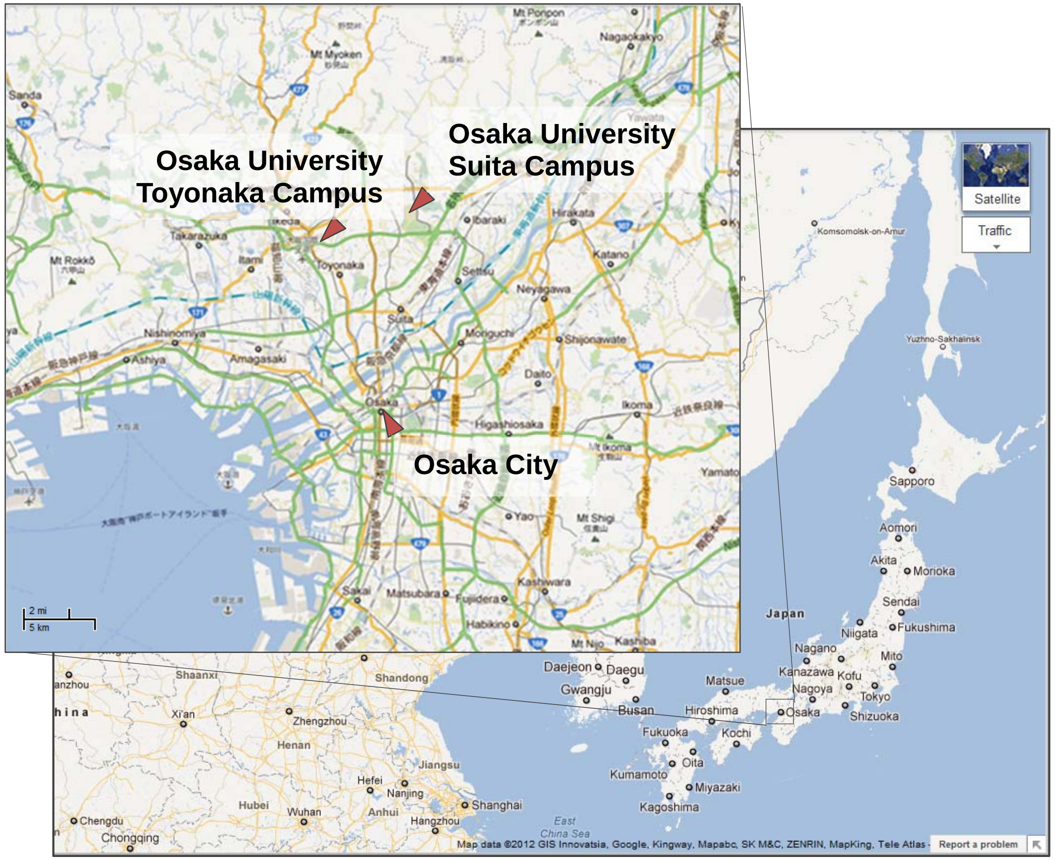

Figure 2.　Average temperature of Osaka city