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How does risk preference change under the stress of COVID-19? Evidence from Japan

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Abstract
In this study, we investigated whether the risk preference systematically changed during the spread of COVID-19 in Japan. Traditionally, risk preference is assumed to be stable over one's life, though it differs among individuals. While recent studies have reported that it changes with a large event like natural disasters and financial crisis, they have not reached a consensus on its direction, risk aversion, or tolerance. We collected panel data of Japanese individuals in five waves from March to June 2020, which covered the period of the first cycle when COVID-19 spread rapidly and then dwindled. We measured risk preference through questions on the willingness to pay for insurance. The main results are as follows: First, people became more risk tolerant throughout the period; and second, people were more averse to mega risk than moderate risk, with the former correlating more strongly with the individual's perception of COVID-19. The first result may be interpreted as "habituation" to repeated stress, as is understood in neuroscience.

Keywords Risk preference · COVID-19 · Habituation · Panel survey · Japan

JEL Classification D81 · I12

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1 Introduction

In this study, we explored if risk aversion changed in a short period of three months in the context of the coronavirus disease (COVID-19) pandemic.[1] In modern economics, risk preference, time discounting, and social preferences are key concepts that determine the behavior of individuals and, in turn, social outcomes including economic performances. While individuals are characterized as having different preferences, traditional economics assumes that preferences are stable or fixed over their lifespan, which makes the analysis simpler.[2] With the availability of large-scale panel data on individuals' preferences, we empirically examined whether the preferences are stable at the level of an individual. While previous studies have reported stable risk tolerance,[3] we review the recent studies that challenge this assumption.

We first classify the studies on change in risk preference into those that employed surveys and those that used economic experiments.[4] The former are further classified into those investigating the effects of the financial crisis of 2008 and those examining how natural catastrophes or violent conflicts affect risk preferences. The former (on the financial crisis of 2008) largely reported an increase in risk aversion (e.g., Necker & Ziegelmeyer 2016), though Gerrans et al. (2015) reported that the risk tolerance of investors is stable. For example, Guiso et al. (2018) tested whether investors' risk aversion increased following the 2008 crisis and found that it increased substantially. They examined the cause of this change and concluded that it was mainly caused by changes in the utility function involving emotion (fear). Schildberg-Horisch (2018) concluded from the studies investigating the effect of the financial crisis of 2008 that the "evidence rather consistently documents an increase in risk aversion." However, she argued, "it is hard to disentangle whether changes in the willingness to take financial risk reflect changes in risk preferences or beliefs about returns." This is an important critique of these studies, and we examine this point in Subsection 3.3.

Since our study investigated the effect of COVID-19, the latter studies (on natural catastrophes or violent conflicts) could be more comparable to ours than the

[1] Under COVID-19, many papers investigated how to face its health risks. For example, Viscusi (2020) and Hammitt (2020) evaluated the mortality costs under Covid-19.

[2] Therefore, traditional economics generally assume the exogenous preferences, though some theories argue endogenous preferences like Uzawa (1968) and Becker and Mulligan (1997).

[3] For example, using 12,000 respondents in the 1992–2002 Health and Retirement Study, Sahm (2012) found that risk tolerance differs greatly among individuals, but much of the systematic variation is associated with time-constant attributes.

[4] Some studies are difficult to classify into either group. Coates and Herbert (2008) and Kandasamy et al. (2014) are a unique paired study, which demonstrates that the stock traders became more risk averse during the financial crisis of 2008. The former "sampled, under real working conditions, endogenous steroids from a group of male traders in the City of London" and found that "a trade's cortisol rises with both the variance of his trading results and the volatility of the market." Meanwhile, the latter, in a different setting, raised the cortisol levels of the 36 subjects for eight days, so that the participants became more risk averse on the last day.

studies of financial crisis. However, the results are inconclusive.[5] While Voors et al. (2012), in their analysis of the violence between the Hutu and the Tutsi, reported a decrease in risk aversion, Kim and Lee (2014) reported a decrease in risk tolerance while analyzing the effect of the Korean War. Recently, Hanaoka et al. (2018) performed a difference-in- difference (DID) analysis using large-scale annual survey data and found that men who experienced greater intensity of the 2011 Great East Japan Earthquake (GEJE) became more risk tolerant a year after than the group that had not witnessed it. Bu et al. (2020) conducted a survey at the Wuhan University of Science and Technology in two waves in October 2019 and March 2020, in which students were requested to choose between safety and risk assets. A cross-sectional comparison of the data of March 2020 revealed that those who were quarantined in a region more exposed to COVID-19 (Wuhan city) were more risk-loving than those quarantined in significantly less-affected areas. However, the result of the DID analysis using the data of both waves is inconclusive: the cross terms of the greater exposure and Wave 2 dummies were insignificant.

Further, we reviewed the studies that used experimental methods. Typically, they collect subjects and expose them to a stress event, such as requiring them to make a speech or showing horror videos and compare their risk preference with regard to a multiple price list, playing a game, or measure the level of cortisol between the treatment and control groups.[6] Haushofer and Fehr (2014) reviewed seventeen studies and found that fifteen are consistent with the hypothesis that fear and/or stress decrease risk taking, while reduction of fear and/or stress increase it. They concluded, "the majority of the studies show an unambiguous positive effect of fear and anxiety on risk aversion"[7] Another excellent review article, Chuang and Schechter (2015), examined eight studies, and concluded, "most research shows that risk preferences are not stable across different settings or games."

Compared with the previous studies, our study is unique in that we could measure the risk preference in real-time during the first cycle of the spread of COVID-19. This enables us to address the temporal dynamics of risk preference across different stages of stress exposure. We initiated a survey on COVID-19 and collected data on risk preference as well as perceptions and opinions about COVID-19. The

5 Chuang and Schechter (2015) reviewed related literature and concluded that natural disasters such as earthquakes, famines, floods, droughts, hurricanes, and tsunamis have been found to either increase or decrease risk aversion or have no (consistent) effect on risk preferences. Likewise, the effects of conflicts such as civil wars, riots, or political violence show contradictory results.

6 For example, Cahlíková and Cingl (2017) followed the following procedure: 151 subjects were randomly assigned to treatment and control groups. TSST-G (stress-inducing) protocol that consisted of two parts—a public speaking task and a mental arithmetic task—was conducted on the treatment group, in front of an evaluation committee. Further, whether stress was successfully induced on the treatment group was tested with cortisol levels, heart rate and multidimensional mood questionnaire scores. Risk preferences were elicited for both groups using a simple task, where participants repeatedly chose between a lottery and different safe payments. Certainty equivalent of male of the treatment group was significantly lower at the 10% than control group when attributes are controlled.

7 One of the two "inconsistent" studies, Conte et al. (2013), argues that in each experimental session they opt for a within-subject design, to prevent the confounding effect of subjects' heterogeneity in preference to disturb the effect of emotions on willingness to take risk, while all previous experiments apply a between-subject design.

five waves of the survey, conducted from March to June 2020, clearly showed that people became significantly and largely more risk tolerant between March (Wave 1) and April (Wave 3) when the situation was deteriorating. They continued to become more risk tolerant, but the change became smaller between April and May (Wave 4) and between May and June (Wave 5), when the situation became moderate and died down. Our survey may offer novel evidence compared to the previous studies that were based on the survey method because our respondents were under the stress of COVID-19 and on experiments, because the stress is extremely unpleasant.

Our results are consistent with those of Hanaoka et al. (2018), but not with the studies on the financial crisis of 2008. We examined the reasons for this discrepancy in Subsection 3.3, focusing on the identification of the change in risk preference due to the change in risk during the event. Our point is that the change in risk attitude in economics should be related to the change in the form of utility functions, which is measured by the change in risk taking behavior to a given magnitude of risks. At a glance, our results seem to be inconsistent with those using economic experiments. We discuss the reason in Section 4 by exploring the difference between acute and repeated stress. While economic experiments studied the effects of acute stress, what we study in this paper is the effects of repeated stress of COVID-19 over three months. Studies in neuroscience have reported that while subjects, either humans or rodents, show strong transient response (e.g., cortisol level) to an acute stress, the response decreases as the stress is repeated (through habituation). Since people are believed to be facing repeated stress under COVID-19, our finding that people become more risk tolerant may be interpreted as the result of habituation to repeated stress.

The remainder of this paper is structured as follows: In Section 2, we explain our survey and method of analysis. In Section 3, we present the basic result that people became risk tolerant during the three months of the study period. Further, we show the results on how risk preference differs with regard to mega and moderate risks. Furthermore, we examine the possible cause of the change in risk preference. In Section 4, we discuss why people became more risk tolerant rather than risk averse under COVID- 19, referring to the habituation to repeated stress found in neuroscience. Section 5 concludes.

2 Method

2.1 Survey on COVID-19 in Japan

We collected panel data on perception, preference, expectation, and behavior of Japanese people during the period from March 13 to June 16, 2020, when COVID-19 began to spread and subsequently moved toward recovery. We utilized Intage Inc., a large internet survey company experienced in facilitating academic surveys.[8] The

[8] Prior to the first wave, Intage Inc. asked 20,000 members from their respondent pool whether they would participate in the consecutive surveys for several months.

first wave was conducted from March 13 to 16, when WHO declared COVID-19 pandemic (March 11) and the US declared a national emergency (March 13).[9] With the aim of collecting 4000 responses, we distributed the questionnaire to 7965 individuals, ultimately receiving 4359 responses (a response rate of 54.3%).[10]

The second wave was completed during March 27–30. We received 3495 responses, demonstrating a response rate of 80.2%. The third wave was conducted during April 10–13; the questionnaire was distributed to all respondents from the first wave, and we received 4013 responses (a response rate of 92.2%). In Japan, the situation had become serious at that time: the number of individuals found to be positive to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the deceased were 5347 and 88, respectively. On April 7, the Japanese government declared a state of emergency in seven prefectures including Tokyo and Osaka.

The fourth wave was conducted from May 8 to May 11, and we received 3,996 responses (a response rate of 91.9%). The period may be characterized as the recovery phase, though the situation was still ambiguous. After the declaration of emergency, the situation worsened for a while: on April 16, the regions where emergency law applied expanded to include all prefectures. Then, situation seemed to be getting better.[11] Nevertheless, on May 4, the emergency was extended until the end of May. The fifth wave was conducted from June 12 to June 15, and we obtained 3877 responses (a response rate of 89.4%). The emergency was lifted on May 14, except in 8 out of 47 prefectures; on May 25, it was removed from all over Japan. The country was getting back to a quasi-normal situation.[12]

High response rates of consecutive five waves are a prominent feature of this survey. This is possibly because most of the respondents were particularly interested in the survey of COVID-19. Though it is often worried that people do not have incentive to answer the truth to survey questions, our respondents probably answered more earnestly than usual surveys.

The data are a representative sample of the residents in Japan with respect to sex, age (between 16–79 years), and region.

2.2 Questions and variables on risk preference

In the questionnaire, we posed two questions to elicit whether risk preference changes over time. Specifically, we enquired how much they would pay for an insurance to

[9] In Japan, on March 13, the Act on Special Measures against Pandemic Influenza was passed, which enabled the government to declare a state of emergency if and when required. The cumulative number of positive cases in Japan increased to 675, more than 7 times that on February 20. Though the situation in Japan worsened during these three weeks, the condition in the US and many European countries became more serious: the number of positive cases was 17,660 in Italy and 1,264 in the US.

[10] The cause of relatively lower response rate of the first wave compared with the following four waves was that we planned to collect 4,000 responses at the outset, while the survey company distributed the questionnaires to about 8,000. In the first wave, we collected data on the respondents' fixed attributes.

[11] In Japan, the number of new positive cases per day was 708 on April 10, which reduced to 96 on May 7.

[12] The number of new positive cases reduced to 57 on June 12.

cover possible hypothetical losses. We did not ask how much they would pay for a lottery because we considered that risk preference in the loss domain might be more appropriate to explain preventive behavior.

In addition, we included two questions in the survey to elicit the risk preference toward mega and moderate risks. Mega risk was defined as the possibility of a huge loss of JPY 5 million (approximately USD 50000) with a 0.1% chance of occurrence, while moderate risk is a smaller loss of JPY 100000 (USD 1000) with a 50% probability. We speculated that aversion to mega and moderate risks is systematically different and that the former is more related to preventive behavior against COVID-19. Respondents were requested to select one option from 11 prices (insurance premium) displayed in ascending order. Risk attitude toward mega risk and Risk attitude toward moderate risk denote the selected option (between 1 and 11) for the mega and moderate risk questions, respectively (questions for each variable are shown in Online Appendix A).

We defined Absolute risk aversion toward mega risk and Absolute risk aversion toward moderate risk as estimated absolute risk aversion (ARA; Pratt 1964) for the mega and moderate risk questions, respectively. Following Cramer et al. (2002), absolute risk aversion was calculated as:

$$-\frac{U''}{U'} = \frac{2\ (price - aZ)}{aZ^2 - price^2} \tag{1}$$

where Z is the value of loss, a is the probability of the occurrence of loss, and *price* is the insurance premium of the selected option.[13] Absolute risk aversion toward mega risk (Absolute risk aversion toward moderate risk) was defined as the value calculated in (1) based on the question of mega (moderate) risk.

2.3 Regression analysis

The aim of this study is to find whether risk preference changed across the five waves of our survey. To this end, we focused on the within-individual variation and estimated the following equation using fixed effects model:

$$Risk\ Preference_{i,t} = b_0 + b_1 WAVE2_t + b_2 WAVE3_t + b_3 WAVE4_t + b_4 WAVE5_t$$

$$+e_i + u_{i,t}, \tag{2}$$

where *WAVEt* (t=2 to 5) is a dummy variable that takes 1 at the tth wave, and 0 otherwise. *ei* represents the fixed effect and $u_{i,t}$ is the random disturbance term. Significant positive (negative) *b1* to *b4* indicate that people become more risk averse (tolerant). *Risk_Preference* represents Risk attitude toward mega risk, Risk attitude

[13] Note that Eq. (1) is derived from our question on insurance, which elicits ARA in a loss domain, and is therefore different from the formula for ARA shown in Cramer et al. (2002), who derive it from a lottery scenario, thereby estimating ARA in a gain domain.

toward moderate risk, Absolute risk aversion toward mega risk, and Absolute risk aversion toward moderate risk.

3 Results

3.1 Did risk preference change under COVID-19?

Table 1 presents the means of the four measures of risk preference: Risk attitude toward mega risk, Risk attitude toward moderate risk, Absolute risk aversion toward mega risk, and Absolute risk aversion toward moderate risk. Descriptive statistics can show whether people are risk tolerant in loss domain as prospect theory predicts, whether people are more risk averse toward mega risks than toward moderate risks, and whether people adapted or habituated to the repeated stresses under COVID-19. It reveals that the mean of Risk attitude toward mega risk and Risk attitude toward moderate risk of all waves is 2.80 and 2.69, respectively. As the expected value of the losses of moderate and mega risks is tantamount to Option 9 (JPY 50000) and Option 3 (JPY 5000) in the questions, this suggests that most people were risk tolerant to both moderate and mega risks.[14] Figure 1 illustrates the distribution of the responses. With regard to moderate risk, only 2.8% of the respondents were risk averse, while 97% were risk tolerant; on the other hand, 25% were risk averse and 58% were risk tolerant in response to the questions on mega risk. The result that most people are risk tolerant in a loss domain is consistent with the literature (Kahneman & Tversky 1979; Schoemaker 1990; Tversky & Kahneman 1992), and it implies that people prefer an undetermined loss to a certain loss.[15]

Now, we proceed to examine how the risk preferences have changed. In Table 1, the mean of all the indices for risk preference declined monotonically through the waves, which is visually confirmed in Figure 1, indicating that people became more risk tolerant.[16] These changes in means were significant at the 1% level between adjacent waves except for between Waves 3 and 4. The change was large and salient between Waves 1 and 3 and became smaller thereafter.

Figure 2 depicts the distribution of the change in from Wave 1 to Wave 5. It reveals that the distribution skewed to the left: 44% of the respondents increased their risk choice, while 19% lowered it.

[14] Though the mean of Absolute risk aversion toward mega risk is positive, its mode is negative.

[15] Schoemaker (1990) reported that 59% (30%) of the subjects in his economic experiment are risk tolerant (averse) in a loss domain, while 17% (76%) were risk tolerant (averse) in a gain domain.

[16] Stability of risk aversion has been measured by correlation and regression between waves of surveys and experiments (Chuang & Schechter, 2015). In our data, the correlation coefficient between two adjacent waves of Risk attitude toward mega risk was 0.55, and the regression coefficient on the lagged dependent variable was 0.81, implying that it decreased across the waves. Risk attitude toward moderate risk showed similar results. The correlation coefficient and regression coefficient for Absolute risk aversion toward mega risk were 0.34 and 0.31, respectively.

Table 1 Descriptive statistics of variables representing risk preference

Variable	Risk attitude toward mega risk					
	ALL	wave 1	wave 2	wave 3	wave 4	wave 5
Observation	19740	4359	3495	4013	3996	3877
Mean	2.687	3.090	2.888	2.546	2.498	2.396
Standard Deviation	1.786	2.021	1.862	1.680	1.643	1.569
Minimum	1	1	1	1	1	1
Maximum	11	11	11	11	11	11
t-test			0.0000	0.0000	0.1988	0.0046
Variable	Absolute risk aversion toward mega risk					
	ALL	wave 1	wave 2	wave 3	wave 4	wave 5
Observation	19559	4290	3454	3991	3968	3856
Mean	3.08E-07	6.29E-07	4.23E-07	2.27E-07	1.64E-07	8.21E-08
Standard Deviation	1.98E-06	2.50E-06	2.13E-06	1.85E-06	1.71E-06	1.47E-06
Minimum	-4.00E-07	-4.00E-07	-4.00E-07	-4.00E-07	-4.00E-07	-4.00E-07
Maximum	1.27E-05	1.27E-05	1.27E-05	1.27E-05	1.27E-05	1.27E-05
t-test			0.0001	0.0000	0.1102	0.0239
Variable	Risk attitude toward moderate risk					
Observation	19740	4359	3495	4013	3996	3877
Mean	2.799	3.240	3.078	2.626	2.572	2.466
Standard Deviation	1.935	2.131	2.016	1.831	1.788	1.747
Minimum	1	1	1	1	1	1
Maximum	11	11	11	11	11	11
t-test			0.0006	0.0000	0.1826	0.0077
Variable	Absolute risk aversion toward moderate risk					
Observation	19740	4359	3495	4013	3996	3877
Mean	-1.77E-05	-1.69E-05	-1.72E-05	-1.80E-05	-1.81E-05	-1.83E-05
Standard Deviation	4.41E-06	5.25E-06	4.72E-06	4.09E-06	3.88E-06	3.70E-06
Minimum	-2.00E-05	-2.00E-05	-2.00E-05	-2.00E-05	-2.00E-05	-2.00E-05
Maximum	1.43E-05	1.43E-05	1.43E-05	1.43E-05	1.43E-05	1.43E-05
t-test			0.0018	0.0000	0.233	0.0661

t-test indicates the *p*-value of the equality of the means between the wave and the previous wave

Finally, Table 2 presents the estimates of Equation (2) using the fixed effect model, which shows the within variation of individuals.[17] All the coefficients of the wave dummies were significantly negative at the 1% level, and they became monotonically larger, indicating that people became risk tolerant across the waves. Wald

[17] The random effects model shows almost the same estimates, although the Hausman test rejects the RE model at the 1% level.

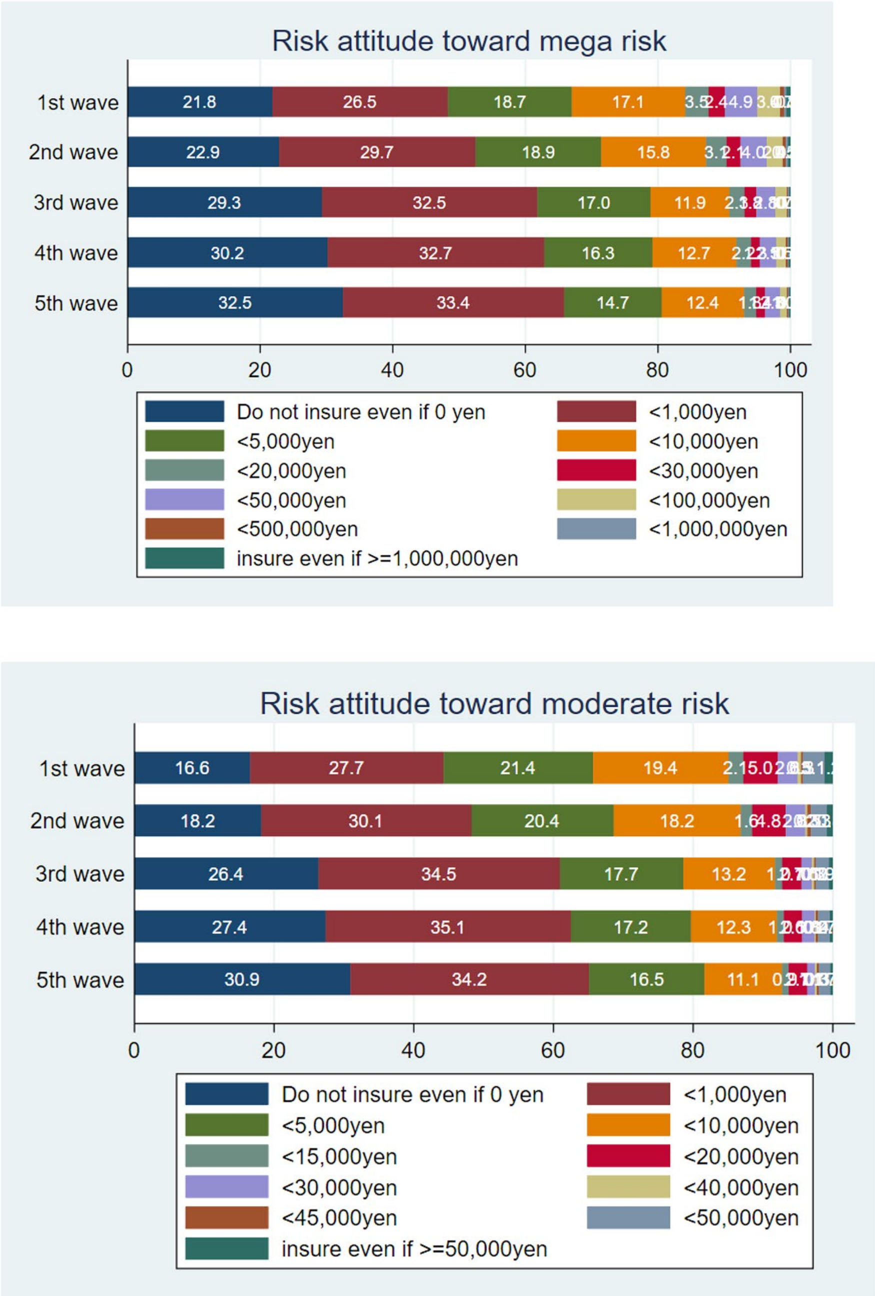

Fig. 1 Distribution of the answers of risk attitude toward moderate and mega risks by wave

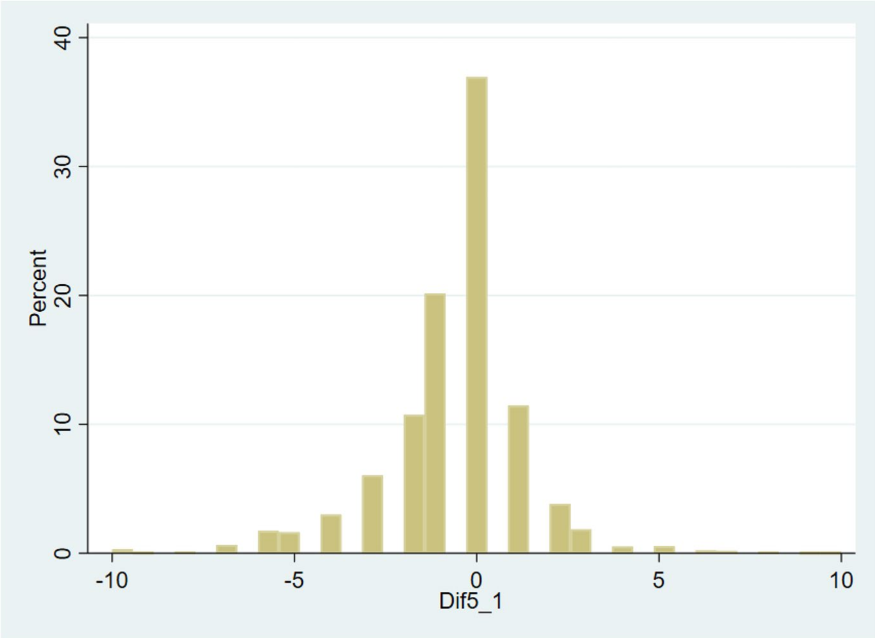

Fig. 2 Change in risk preference between the first and fifth waves. Note: Dif5_1 is defined as Risk attitude toward mega risk at Wave 5 – Risk attitude toward mega risk at Wave 1

tests (the bottom rows in Table 2) revealed that the change between adjacent waves were significant except for that between Waves 3 and 4 for moderate risk.

The phenomenon of becoming more risk tolerant is confirmed for any subgroup categorized by sex, age, income, and education (Online Appendix B).

3.2 Risk preference toward mega and moderate risks

Traditionally, risk preferences are regarded as context-invariant, which means that an individual has a single utility function defined over final wealth states and applied to every domain. However, some studies have investigated whether the risk preference may be different across domains (Anderson & Mellor 2009; Barseghyan et al., 2011; Einav et al., 2012).[18] In this study, we postulate that people may be more averse to the mega risks than to the moderate risks because the former could potentially destroy their lives, while the latter are experienced in everyday life.

Though both the measures of risk preference were similar to each other,[19] in this subsection, we report how they are different, and which one is more suitable to explain

[18] Weber et al. (2002) concluded as follows: "As expected, respondents' degree of risk taking was highly domain-specific, i.e., not consistently risk-averse or consistently risk seeking across all content domains." Schoemaker (1990) also reported the various domain effects.

[19] Their correlation coefficient was 0.58.

Table 2 Estimates of Eq. (2): The main results

VARIABLES	Risk attitude toward mega risk	Risk attitude toward moderate risk	Absolute risk aversion toward mega risk	Absolute risk aversion toward moderate risk
wave2	-0.183***	-0.162***	-1.85e-07***	-3.72e-07***
	(0.0324)	(0.0342)	(4.54e-08)	(8.92e-08)
wave3	-0.529***	-0.600***	-3.52e-07***	-1.08e-06***
	(0.0301)	(0.0323)	(4.26e-08)	(8.38e-08)
wave4	-0.571***	-0.634***	-4.19e-07***	-1.14e-06***
	(0.0307)	(0.0309)	(4.14e-08)	(7.82e-08)
wave5	-0.662***	-0.730***	-4.87e-07***	-1.29e-06***
	(0.0309)	(0.0323)	(4.09e-08)	(8.08e-08)
Constant	3.073***	3.222***	5.66e-07***	-1.69e-05***
	(0.0206)	(0.0216)	(2.86e-08)	(5.66e-08)
Observations	19740	19740	19740	19740
R-squared	0.050	0.059	0.014	0.030
Number of Individuals	4359	4359	4359	4359
Wald test (P-value)				
wave2 = wave3	0.0000	0.0000	0.0000	0.0000
wave3 = wave4	0.0745	0.1606	0.0335	0.2706
wave4 = wave5	0.0001	0.0000	0.0329	0.0046
wave2 = wave5	0.0000	0.0000	0.0000	0.0000

The dependent variables are indicated in the top row. The estimation method is the fixed effects (FE) model. The robust standard errors clustered based on the individual respondent are presented. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ "Wald test" shows the *p*-value with which type one error or the equality of the wave dummies is rejected. The coefficients on wave dummies represent within-individual changes from the wave 1

individual behavior under COVID-19. First, respondents were more risk averse to mega risk than to moderate risk as we have already confirmed in Subsection 3.1.[20]

Table 3 presents correlation coefficients between risk preferences and perception of COVID-19. In the analysis of the perception variables, we use Expectation of symptoms when the person infected with SARS-CoV-2 (Expected symptom), Expectation of probability to be infected in a month (Expected probability), expectation of the spread of COVID-19 (Expected spread), willingness to buy a hypothetical vaccine (Willingness to vaccine), and current feeling of fear (Extent of fear).[21] A positive correlation is expected between risk preference and these variables. Specifically, the health belief model predicts positive relationship among prevention behavior (Willingness to vaccine), perception of infectious disease (Expected symptom, Expected probability), and risk preference (Rosenstock et al., 1988; Tsutsui et al., 2012).

[20] Table 1 shows that means of Absolute risk aversion toward mega risk and Absolute risk aversion toward moderate risk are 3.08E-07 and -1.77E-05, respectively.

[21] Refer to Online Appendix A for the questions for each variable.

Table 3 Correlation coefficients between risk preferences and perceptions of COVID-19

	Risk attitude toward mega risk	Risk attitude toward moderate risk	Absolute risk aversion toward mega risk	Absolute risk aversion toward moderate risk
Expected symptom	0.0329	-0.0108	0.0230	-0.0059
p-value	0.0000	0.1305	0.0013	0.4094
Expected probability	0.0226	-0.0289	0.0273	-0.0169
p-value	0.0015	0.0000	0.0001	0.0173
Expected spread	0.0402	0.0227	0.0375	0.0146
p-value	0.0000	0.0015	0.0000	0.0406
Willingness to vaccine	0.1944	0.1322	0.1294	0.0995
p-value	0.0000	0.0000	0.0000	0.0000
Extent of fear	0.0322	-0.0050	0.0203	-0.0101
p-value	0.0000	0.4814	0.0046	0.1558

The correlation coefficient and its significance (*p*-values) are shown in the upper and lower rows, respectively

Loewenstein (2000) argued that fear can increase risk aversion, while Kuhnen and Knutson (2005) showed its neural correlates.

While Risk attitude toward mega risk and Absolute risk aversion toward mega risk are positively and significantly correlated with all the variables, Risk attitude toward moderate risk and Absolute risk aversion toward moderate risk are negatively correlated with Expected symptom, Expected probability, and Extent of fear. In addition, though Risk attitude toward moderate risk and Absolute risk aversion toward moderate risk are positively correlated with Expected spread and Willingness to vaccine, the correlation coefficients were smaller than Risk attitude toward mega risk and Absolute risk aversion toward mega risk. These results suggest that preference toward mega risk is more related to the individual's perception of COVID-19.

3.3 Is the economic situation the cause for the change in risk preference?

Though few people might doubt that the change in risk preference is caused by COVID- 19, determining the direct cause is less unambiguous. One might assume that the cause is an increase in financial risk because our measure of risk preference is based on the choice of the financial position (Schildberg-Horisch, 2018). However, financial risk does not seem to be the main cause because the economic situation did not decline until after the declaration of emergency on April 4[22]; meanwhile, people became risk tolerant by the third wave. In addition, if the cause is an increase in financial risk, it will reinforce our conclusion because the deterioration of income or an increase in financial risk tends to decrease risk-taking behavior (Coval & Shamway 2005; Thaler, 1999), such that our measurement would have

[22] The year-over-year cash payroll increase was 0.1% in March 2020, while the year-over-year decline was 0.7%, 2.3%, and 2.0% in April, May, and June, respectively.

been biased toward more risk averse behavior. Once such biases were corrected, the result of becoming more risk tolerant would have been strengthened. Schildberg-Horisch's (2018) critique suggests that it is essential to measure risk preference using a question asking respondents' risk choice where the magnitude of the risk is stable over the observation period. Using the individual's willingness to buy a hypothetical vaccine (Willingness to vaccine) as the measure of risk preference in our study would not have been appropriate because the subjective health risk increased dramatically with the threat of COVID-19 (Online Appendix C).

In spite of the argument in the preceding paragraph, we cannot deny the possibility that people's expectation of their future financial situation may affect our measure, and that those who really suffered a decrease in their revenues might bias our measure. In all the waves, we asked respondents about their income expectations in 2020,[23] which allowed us to examine how the change in financial risks affected our measure of risk preference.

The leftmost columns of Table 4 present the results of categorizing the respondents into those with high or low expectations of income in 2020. In both groups, all the coefficients of the wave dummies were significantly negative and their absolute values increased over time. These results suggest that the expectation of their future income is not a major factor affecting change in risk preference.

Moreover, from Wave 3 to Wave 5, we asked if the respondents' income got worse compared with the situation in December 2019.[24] Using the five-point Likert scale (where 1=improved very much; 2=improved; 3=unchanged; 4=deteriorated; and 5=deteriorated very much), about 7% of the respondents chose 5, and 25% chose 4, while those who chose 1 or 2 comprised only 2.5%. We split the samples into those who chose 4 or 5 (Income was deteriorated) and others (Income was unchanged), and estimated Equation (2) for both groups. The estimates for Waves 3–5 are shown in Columns 3–5 of Table 4. It reveals that both groups exhibited a decline in their risk aversion. In Columns 7 and 8, we show the estimates for the five waves assuming that the income position in Waves 1 and 2 are the same as those reported in Wave 3. The estimates were all significantly negative for both groups, indicating that our results are robust even when the effect of the change in financial risks is considered.

3.4 Are the stress and fear of COVID-19 the causes for the change in risk preference?

If the stress of COVID-19 is the cause of the decline in risk aversion, the change in risk preference may be smaller for people who felt less stress. As a proxy for the magnitude of stress, we used Expected symptom, Expected probability, and Extent of fear. Specifically, we divided respondents into three groups— Low expected symptom, Middle expected symptom, and High expected symptom (similarly for

23 Refer to "Expectation of income in 2020" in Online Appendix A.

24 Refer to "Change in income under COVID-19" in Online Appendix A.

Table 4 Effect of the deterioration of current income and expectation of future income on the estimates of Eq. (2)

	Expectation of income		Current income deterioration				
			Using the data of Wave 3 to wave 5			Using the data of 5 waves	
VARIABLES	High expectation of income in 2020	Low expectation of income in 2020	All samples	Income was deteriorated	Income was unchanged	Income was deteriorated	Income was unchanged
wave2	-0.253***	-0.152***				-0.189***	-0.177***
	(0.0614)	(0.0420)				(0.0577)	(0.0391)
wave3	-0.615***	-0.502***				-0.584***	-0.502***
	(0.0567)	(0.0397)				(0.0543)	(0.0362)
wave4	-0.627***	-0.582***	-0.0396*	-0.0528	-0.342***	-0.631***	-0.534***
	(0.0583)	(0.0413)	(0.0236)	(0.0462)	(0.0273)	(0.0576)	(0.0384)
wave5	-0.709***	-0.669***	-0.123***	-0.145***	-0.430***	-0.711***	-0.616***
	(0.0567)	(0.0429)	(0.0255)	(0.0501)	(0.0275)	(0.0585)	(0.0385)
Constant	3.159***	3.042***	2.596***	2.526***	2.871***	3.090***	3.059***
	(0.0388)	(0.0273)	(0.0591)	(0.0291)	(0.00757)	(0.0378)	(0.0249)
Observations	7565	12175	11886	3895	15845	6162	13578
R-squared	0.054	0.051	0.004	0.005	0.024	0.058	0.043
Number of Individuals	2935	3818	4245	1989	4359	1989	3563

The dependent variable is Risk attitude toward mega risk. The estimation method is the fixed effects (FE) model. The robust standard errors clustered based on the individual respondent are presented. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ 'High expectation of income in 2020' is those who chose 1 (= improve by more than 4%), 2 (= improve between 1% and 3.99%), 3 (= almost unchanged), while 'Low expectation of income in 202' is those who chose 4 (= drop between 1% to 3.99%), 5 (= drop between 4% and 9.99%), and 6 (= drop by more than 10%) for the expectation of their income in 2020. 'Income was deteriorated' is those who chose 4 (= deteriorated) or 5 (= deteriorated very much), while Income was unchanged is those who chose 1 (= improved very much), 2 (= improved), or 3 (= unchanged) for the evaluation of their current income compared with December 2019

Expected probability, and Extent of fear) —and estimated Equation (2) for each group. The results are presented in Table 5. Comparing Low expected symptom with High expected symptom, all the coefficients of the wave dummies are larger for the High group than the Low group, even if insignificant, suggesting that the magnitude of the change toward risk tolerance is stronger for High expected symptom group. The same result was confirmed by the comparison of the Expected probability and of Extent of feargroups. These results suggest that the stress arising from COVID- 19 may be a factor influencing the decline in risk aversion.

4 Discussion

The current study was unique in measuring peoples' risk preference five times in three months when the spread of COVID-19 rapidly became fierce and then declined. Within variation of respondents unequivocally showed that they became more risk tolerant over the period. In this section, we discuss how our result is consistent with previous literatures, and why people became risk tolerant. Previous studies have been classified into three: (I) investigating the effect of the financial crisis of 2008 based on panel surveys, most of which reported that people became more risk averse after the crisis; (II) investigating the effect of natural disasters based on panel surveys that reported varied results; and (III) using economic experiments, most of which reported that subjects became more risk averse immediately after the stress exposure.

We pointed out the possibility of the discrepancy from the studies in (I) in Subsection 3.3, wherein we stated that the change in their risk preference might not be identified from the change in financial risks. In contrast, our study investigated the effect of health risks (COVID-19) on risk preference (elicited by a question on insurance decisions), and therefore may be immune to the identification problem between risk preference and change in risk.

The question arises on how our result could be consistent with the studies in (III). Intuitively, people who face a large risk experience heightened fear, which makes them more risk averse being consistent with the results of economic experiments. In neuroscience, rodents respond to acute stress in the same way: their level of stress markers, such as corticosterone (corresponding to cortisol in humans), soar with acute stress. However, it is also known that when animals are exposed daily to the same stressor (such as bodily restraint, cold, novel environment, water immersion without swimming, and loud noise) for several days or a few weeks, a reduction of the response has very often been observed, which implies habituation to repeated stress. Pitman et al. (1988) found that with intense stress imposed by a repeated four-limb prone restraint, the plasma corticosterone response rises on the first and the second day and habituates over a period of seven days. In experiments, rodents that are stressed generally 30-60 min every day show the spike of plasma corticosterone with the treatment; however, it returns to the normal level before the treatment of the next day. Though plasma corticosterone responds to the treatment every day, its spike gets smaller after a few days. This habituation has been confirmed across laboratories (Grissomet al., 2007; Marti & Armario, 1998; Viay & Sawchenko, 2002). Furthermore, the frequency (De Boer et al., 1990) and the severity (Rabasa et al., 2015) of the stressors can be a

Table 5 Change in risk preference of high- and low-stress groups: Estimates of Eq. (2)

VARIABLES	Low expected symptom	Middle expected symptom	High expected symptom	Low expected probability	Middle expected probability	High expected probability	Low extent of fear	Middle extent of fear	High extent of fear
wave2	-0.152*	-0.183***	-0.259*	-0.188***	-0.187***	-0.222***	-0.187***	-0.209***	-0.195***
	(0.0795)	(0.0404)	(0.1430)	(0.0653)	(0.0603)	(0.0726)	(0.0703)	(0.0674)	(0.0586)
wave3	-0.481***	-0.513***	-0.638***	-0.508***	-0.531***	-0.579***	-0.495***	-0.564***	-0.561***
	(0.0850)	(0.0373)	(0.1330)	(0.0636)	(0.0618)	(0.0649)	(0.0666)	(0.0629)	(0.0536)
wave4	-0.570***	-0.564***	-0.697***	-0.534***	-0.555***	-0.657***	-0.533***	-0.561***	-0.588***
	(0.0867)	(0.0376)	(0.1320)	(0.0598)	(0.0602)	(0.0683)	(0.0680)	(0.0612)	(0.0539)
wave5	-0.665***	-0.656***	-0.767***	-0.624***	-0.642***	-0.796***	-0.646***	-0.659***	-0.716***
	(0.0836)	(0.0384)	(0.1340)	(0.0581)	(0.0619)	(0.0708)	(0.0651)	(0.0638)	(0.0593)
Constant	2.792***	3.128***	3.192***	2.951***	3.128***	3.157***	3.001***	3.016***	3.189***
	(0.0470)	(0.0261)	(0.1070)	(0.0352)	(0.0449)	(0.0481)	(0.0413)	(0.0431)	(0.0382)
Observations	3403	13986	2351	5984	7698	6058	5341	6590	7809
R-squared	0.051	0.049	0.046	0.05	0.044	0.053	0.048	0.051	0.05
Number of Individuals	1590	3887	959	2491	3154	2319	2339	3093	2898

The dependent variable is Risk attitude toward mega risk. The estimation method is the fixed effects (FE) model. The robust standard errors clustered based on the individual respondent are presented. *** $p<0.01$, ** $p<0.05$, * $p<0.1$ 'Low expected symptom' is those who chose 1 or 2; 'Middle expected symptom,' 3 or 4; and 'High expected symptom,' 5 or 6. 'Low expected probability' is those who answered less than 10%; 'Middle expected probability,' more than and equal to 10% and less than 50%; and 'High expected probability,' more than 50%. 'Low extent of fear' is those who chose 1 or 2; 'Middle extent of fear,' 3; and 'High extent of fear,' 4 or 5 major modulator of the stress adaptation induced by repeated stress, that is, habituation occurs sooner if the stressors are more frequent and severe. Herman et al. (2016) reviewed studies on neural mechanism, especially the hypothalamus-pituitary-adrenocortical axis as a major mechanism of stress adaptation.

The habituation has been confirmed among humans by mainly using repeated psychosocial stress, such as public speaking and mental arithmetic in front of an audience (Gerra et al., 2001; Gunnar et al., 1989; Kirschbaum et al., 1995; Schommer et al., 2003; Wüst et al., 2005).[25] Typically, adult subjects are gathered two to several times with various intervals ranging from one day to several weeks.[26] [24] Many studies measured plasma and salivary concentration of cortisol immediately before the tests and at their end on experimental days. Though habituation was found in most of the studies with humans, the recent studies investigated inter-individual variations to find that some individuals do not show habituation. For example, using twin pairs, Wüst et al. (2005) found that though 52% of the subjects show habituation, 16% show sensitization. This finding is consistent with our result (shown in Figure 2) that 44% of the respondents became more risk tolerant, while 19% became more risk averse.

People under COVID-19 for a period of three months can be viewed as facing repeated stress rather than an acute stress. Therefore, our results of becoming more risk tolerant during the spread of COVID-19 can be viewed as a habituation process.[27]

To further develop the theory of habituation, it is important to distinguish the risk preference from a response to a risk—for example, risk-taking behavior and the level of cortisol—both theoretically and empirically. Risk preference represents the sensitivity of an individual to a stress and cannot be observed directly. We need to hypothesize that the response to a stress depends on risk preference and the magnitude of the risk. In experiments, keeping the magnitude of a stress constant, the response (e.g., cortisol level) to the stress can represent the sensitivity to the stress. Based on this theory, habituation is understood as the reduction of such sensitivity. Nevertheless, we will pursue the physiological substance (correlates) of risk preference. Neuroscience will find that habituation may correspond to a physiological modification of corticoid receptors, although such evidence has not been accumulated yet.[28] Until its discovery, though risk preference was unambiguously defined as a characteristic of an individual in the field of economics, identifying its change based on the change in risk is not easy in the real world (see Subsection 3.3).

[25] Deinzer et al. (1997) used repeated parachute jumps as a stressor.

[26] Gunnar et al. (1989) examined forty-nine healthy newborns twice responding to discharge examinations performed on two consecutive days. Significant elevations in cortisol were observed only in response to the first discharge examination. No significant elevation in cortisol was noted for the second discharge examination.

[27] Becker and Mulligan (1997) offer a theory of the short-term adaptation of preferences (time preference): individuals can become more patient than the endowed level. Their idea has an affinity with the habituation process.

[28] Rabasa et al. (2015) note the following: "The neurobiological processes underlying adaptation to daily repeated stress are poorly known. Stress-induced glucocorticoid release is not a necessary requisite for the induction of adaptation as it is still observed in adrenalectomized rats maintained with low levels of corticosterone, but these hormones may play a partial role acting through both mineralocorticoid (MR) and glucocorticoid (GR) receptors in the pPVTth to induce adaptation.".

The nature of one's risk preference after COVID-19 is difficult to predict because the relationship between the level of risk preference under stress and that when the stress is withheld is not known.[29] However, if risk preference corresponds to a function of corticoid receptors, it will remain at the modified level as long as the function will be the same. On a related note, the risk preference before COVID-19 began to spread should be the same as the level at its outset. Though risk preference did not change at the outset, people felt strong fear and indulged in risk-averse behavior because they faced massive stress. Thereafter, people gradually became more risk tolerant, as we observed in this study.

Unfortunately, we do not have any evidence of the risk preference immediately before the outset of COVID-19 because we started the survey on March 13 when COVID- 19 had already spread in Japan. However, Hanaoka et al. (2018) found that the men who experienced high intensity of GEJE became more risk tolerant than the others. Their finding suggests that risk preference did not change at the outset of the stress because if the respondents' risk aversion became stronger on facing GEJE, they would have observed higher risk aversion in 2012 than in 2011. In addition, they reported that the change toward risk tolerance continued, at least, until 2016, suggesting that risk preference did not return to the level prior to GEJE for a long time.

A report on the levels of risk preference in the loss domain during a normal period in Japan could provide further evidence. In a large-scale survey conducted from 2011 to 2013 in Japan, we asked the same question with regard to moderate risk: "How much will you pay for insurance for a 50% chance of losing JPY 100000 (USD 1000)?" Nine choices ranging from JPY 1000 to 50000 were presented. The mean of the absolute risk aversion of the answers to this question was -8.13E-06 in 2011, -8.44E-06 in 2012, and - 8.76E-06 in 2013, respectively. They are higher than the values of Absolute risk aversion toward moderate risk of Wave 1 (-1.69E-05) to Wave 5 (-1.83E-05), indicating that Japanese were more risk averse prior to COVID-19, being consistent with the finding of Hanaoka et al. (2018) and our postulation of habituation.

5 Conclusions

In this study, we investigated whether the risk aversion remained stable or systematically changed over the period of the spread of COVID-19 in Japan. Unlike most previous studies, this study is unique as it collects real-time data of people under the stress of being infected with an unknown virus for three months. A representative sample of around 4000 Japanese individuals responded to a web survey in five

[29] Incidentally, however, there have been studies on how habituation affects the response to a later stress. Thompson and Spencer (1966) emphasized that the effect of the repeated stress does not affect after the stress is withheld (spontaneous recovery). However, recent studies have found some contradicting results (Grissom & Bhatnagar, 2009).

waves from March 13 to June 16, 2020. Waves 1 to 3 covered the period when the situation was deteriorating severely, while Waves 4 and 5 were conducted during the period of recovery and subsequent decline of spread.[30] In the questionnaire, we asked two questions on the willingness to pay for an insurance that covers mega and moderate risks. The answers to either question unequivocally indicated that people became more risk tolerant throughout the period, while the change was lesser during Waves 4 and 5.

In addition, we showed that people were more averse to mega risk than to moderate risk, and that the former correlated more strongly than the latter with the individual's perception of COVID-19 and experience of fear. Further, we found that the change in people's income position and their expectation of future income might not be the main cause of becoming more risk tolerant; moreover, the perception and fear associated with COVID-19 might be the cause.

We also discussed how our result could be consistent with the economic experiments that showed that humans become more risk averse immediately after an acute stress. Since our respondents are thought to have been faced with the repeated stress of COVID-19 rather than an acute stress, the result of being more risk tolerant can be interpreted as a habituation process to repeated stress, as is well established in neuroscience. Further investigation is needed to confirm this interpretation.

In this study, we argued that change in risk aversion should relate to the change in utility function, which has its correlates in brain system. We adopted general form of utility function and found that people were risk tolerant under COVID-19, and they habituated to the situation as the situation was prolonged. However, we did not investigate the mechanism of these phenomena. The works by Viscusi and his coauthors (e.g. Evans & Viscusi, 1991, 1993; Viscusi, 2019) studied how adverse health effects influence utility functions. Using specific functional forms, such as logarithmic utility and CARA utility, they reported reasonable estimates with the data of cancer patients. Such an approach may be a clue of our future study to investigate the mechanism of the change in utility function.

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Availability of data and material Yes.

[30] The situation worsened again in July, which is beyond the scope of this study.

Code availability Yes.

Declarations

Conflicts of interest Yoshiro Tsutsui and Iku Tsutsui-Kimura declare that either of them has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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