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Risk Breeds Risk Aversion*

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Abstract: We examine whether exposure to a more or less risky environment affects people's subsequent risk-taking behavior. In a laboratory setting, all subjects went through twelve rounds of multiple-price-list decisions between a risky alternative and a safe alternative. In the first six rounds, subjects were randomly assigned to a high-, moderate-, or low-risk environment, which differed in the variances of the lotteries they were exposed to. In the last six rounds, subjects in all treatments made decisions on an identical set of lotteries. We found that subjects who had experienced a riskier environment exhibited a higher degree of risk aversion. Our experimental design allows us to conclude that this effect is driven by the risk environment *per se*, rather than the realized outcomes of the risk. This finding has important theoretical and policy implications.

Key Words: Risk; Risk Aversion; Laboratory Experiment

JEL Classification: D81, C91

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I. Introduction

Economic agents make their optimal risk decisions based on two sets of parameters. One is a set of parameters capturing the riskiness of the environment, while the other is a set of individual-specific risk-aversion coefficients. In canonical models, both are exogenously determined and independent of each other.

However, picture an investor who has just experienced a period of volatile market conditions. Would this experience lead him to become less risk-averse and take up more small-cap stocks, or to become more risk-averse and increase his holdings in safe government bonds? In another domain, a variety of economic and social policies aim to reduce risk factors in economic environments. For instance, many social welfare policies are made to create a safety net for individuals. Would these policies also inadvertently alter people's attitudes toward risk? No matter what the answer is, it seems natural to conjecture interdependence between the risk environment one is exposed to and his risk-taking propensity. Understanding this relationship is important for both policy-makers and economic forecasters, as ignoring the potential interaction effect between these two variables would inevitably err policy decisions or bias market predictions.

While there is a related empirical literature documenting the effects of past experiences on subsequent risk-taking behaviors, including negative macroeconomic shocks (Malmendier and Nagel, 2011; Guiso et al., 2013), traumatic life experiences (Callen et al., 2014; Voors et al., 2012), and natural disasters (Page et al., 2014; Cameron and Shah, 2015; Eckel et al., 2009), the results are rather mixed (see Section II for a literature review). More importantly, in these studies, the effect of exposure to certain environments with risk or uncertainty is inherently entangled with the effect of the particular outcome realization of the

risk or uncertainty.¹ Thus, we cannot simply translate their findings to the effects of risk environments *per se*. In the present study, we test the extent to which exposure to a more or less risky environment influences risk preferences in a controlled laboratory experiment. All subjects participated in twelve rounds of multiple-price-list decisions between a risky alternative (i.e. a lottery) and a safe alternative (i.e. a sure monetary payoff). In the first six rounds, we systematically varied the degree of risk that subjects were exposed to, by offering them relatively high-, moderate-, or low-risk lotteries to decide on. In the last six rounds, however, subjects in all treatments made decisions on an identical set of lotteries so that we could observe whether there was any behavioral difference among the three treatment conditions. This experimental design allowed us to tightly control the riskiness of an environment to identify its causal effect on subsequent risk-taking behavior. To avoid the potential effects of the realized outcomes of lotteries, subjects did not learn the outcomes until the end of the experiment.

Our experimental results show that individuals exhibit a higher level of risk aversion when they experience a riskier environment for a short period of time. More specifically, those who were exposed to high-risk lotteries in the first six rounds chose roughly one additional *Safe* option in the last six rounds than those in the other two conditions. We conducted additional treatments to rule out an alternative explanation that subjects in riskier environments develop a habit of choosing fewer risky options during the manipulation period (i.e. the first six rounds) and they then apply this heuristic in the last six rounds, which our between-subject comparison relies on.

The next section of this paper provides a brief review of the relevant literature. Section III describes our experimental design and procedures. We present and discuss the empirical results in Section IV. The final section concludes.

¹ Indeed, Thaler and Johnson (1990) and Post et al. (2008) both find that individuals become more risk averse once they undergo negative outcomes and less risk-averse after positive ones.

II. Literature Review

There is a large body of empirical literature exploring the effects of past experiences on risk-aversion. Consistent with our results, Malmendier and Nagel (2011) examine whether individuals' past experiences of macroeconomic shocks affect their risk attitude. They find that those who have experienced low stock-market returns throughout their lives either become less likely to participate in the stock market or invest a lower fraction of their liquid assets in stocks. Using repeated surveys of an Italian bank's clients, Guiso et al. (2013) find that investors' risk aversion substantially increased after the 2008 financial crisis. A number of recent studies focusing on the effects of extreme events, such as violence (Callen et al., 2014), combats (Bogan et al., 2013) and natural disasters (Cameron and Shah, 2015), also find that exposure to these traumatic experiences increases risk aversion. For instance, Cameron and Shah (2015) find that people who have experienced a natural disaster perceive their surroundings as riskier and therefore become more risk-averse.

In contrast, several other studies find the opposite results. Nguyen (2011) combines administrative and experimental data from Vietnam and finds that fishermen, who work in a dangerous, risky work environment, appear less risk-averse than those in other occupations. Exposure to extreme events, such as wars (Voors et al., 2012), floods (Page et al., 2014), and hurricanes (Eckel et al., 2009) would induce risk-taking behavior.

While all these studies document post-experience changes in people's risk attitudes, the results are highly mixed. On the one hand, this may reflect the idiosyncrasies of different situations analyzed in the studies. On the other hand, it raises questions as to what underlying factors cause these behavioral changes, as in these studies, the effects of experiencing a certain environment are often intrinsically entangled with the effects of particular realization

of outcomes.² Our study contributes to this literature by highlighting an important factor through which past experience may alter risk preferences. In particular, by isolating the effects of realized outcomes, we show that exposure to risk *per se* increases people's risk-aversion.

Relatedly, Mengel, Tsakas and Vostroknutov (2016) study the effect of exposure to ambiguity and unawareness on risk-taking behavior. They find that those who are exposed to an uncertain environment (imperfect knowledge of the state space) are more risk-averse than those who are not. Different from their study, we study the environment where subjects have perfect knowledge of the state space. Moreover, in their experiment, participants learn the lottery outcome at the end of each round, whereas participants in our experiment do not learn that until the end of the experiment, which allows us to disentangle the effect of the environment from the effect of outcome realization. Another related study is Lusk and Coble (2008) who examine how the presence (as opposed to the absence) of uncorrelated background risk affects people's risk behaviors in a laboratory setting. They find that merely the knowledge that one will *subsequently* participate in a background risk lottery increases risk-aversion, although the increase is quantitatively small. In contrast, we investigate the effect of *previous* exposure to risk. The risk manipulation phase occurs before the main task in our experiment, whereas it takes place after the main task in theirs.

Our work also relates to a growing literature on the stability of risk preference (see, e.g. Chuang and Schechter, 2015, Section 2.2 for a survey). Existing studies have examined whether and how much people's risk preferences differ across time (Andersen et al., 2008), contexts (Barseghyan, Prince and Teitelbaum, 2011), elicitation methods (Chuang and Schechter, 2015; Straznicka, 2012), etc. Our short-run, context-free experiment, which uses a

² Besides, Mengel, Tsakas and Vostroknutov (2016) argue that for those field studies demonstrating the link between macroeconomic shocks or financial crises and risk taking behavior, it is difficult to establish whether such effects are due to an increase in risk aversion or to updated priors or other reasons.

uniform elicitation method, contributes to this literature by revealing that the riskiness of an environment experienced by an individual also influences his risk preferences, which helps explain the instability of risk attitudes over time.

III. Experimental Design and Procedures

All subjects participated in the main experiment for a total of 12 rounds. We employed the multiple price list format popularized by Holt and Laury (2002).³ In each round, subjects were presented with a menu of 13 binary choices (rows) between a lottery (option Left) and a sure outcome (option Right), as shown in Figure 1. The options on the left were identical, while options on the right increased with each row. Across rounds, the options on the left changed.

To examine how an individual's attitude towards risk reacts to prior risk environments, we manipulated the magnitude of risk to which subjects were exposed. Subjects were randomly assigned to one of three treatment groups: HM, LM, and the control treatment MM. In the first six rounds, subjects in treatments HM, MM, and LM were exposed to a set of six lotteries with high risk (set H), moderate risk (set M), and low risk (set L), respectively, with one lottery in each round. In the last six rounds, subjects in all treatments were exposed to the set of six lotteries with moderate risk, set M. That is, subjects in all the different treatment groups made decisions on an identical set of lotteries in the second half of the experiment. Thus, we can make between-subject comparisons to identify the causal relationship between prior risk environments and subsequent risk-taking propensity.

In every round, subjects chose between a lottery $(x, 400-x)$ and a sure outcome (z) in each of the 13 rows. If the subject chose the lottery, he or she would obtain x experimental tokens with half probability and obtain $400-x$ tokens with half probability. If the subject

³ In Holt and Laury (2002), subjects choose between a riskier lottery and a less risky lottery for each row. In our experiment, subjects chose between a lottery and a sure outcome.

chose the sure outcome, he or she would obtain z experimental tokens for sure. The six lotteries and their corresponding sure outcomes in sets H, M and L are depicted in Table 1. Specifically, the six lotteries' outcomes were (400, 0), (395, 5), (390, 10), (385, 15), (380, 20), and (375, 25) respectively in set H, (315, 85), (310, 90), (305, 95), (300, 100), (295, 105), and (290, 110) respectively in set M, and (230, 170), (225, 175), (220, 180), (215, 185), (210, 190), and (205, 195) respectively in set L. Note that all lotteries have an equal mean of 200, with a 50% probability of receiving the better outcome (x) and a 50% probability of receiving the worse outcome ($400-x$). The standard deviation for any lottery with x is $x-200$. Therefore, the average standard deviation of the lotteries is roughly 20% of the lottery mean for set L, 50% for set M, and nearly 100% for set H, representing relatively low-, moderate-, and high-risk environments, respectively.⁴ In each round, the sure outcomes were listed in ascending order, with $z < 200$ for the first nine rows, $z = 200$ in the tenth row, and $z > 200$ for the last three rows.⁵ As a result, a risk-neutral individual would choose the lottery in rows 1-9 and the sure outcomes in rows 11-13, and would be indifferent in round 10. Risk-averse individuals would switch to sure outcomes earlier than risk-neutral individuals.

Subjects may develop some form of heuristics, given that they chose different numbers of lottery options in the first six rounds when we manipulated risk exposure. More specifically, subjects in the HM (LM) condition tended to choose fewer (more) lottery options before switching to the sure outcomes in the first six rounds than those in the MM condition, given the riskier (less risky) nature of the lotteries in the set H (L). It is possible

⁴ Appendix B shows all 12 rounds of the main decision-making task in the HM treatment.

⁵ Specifically, given x , the better outcome of the lottery in the round, in any row i , where $i \in \{1, 2, \dots, 13\}$, the following equation shows how the value of z_i was determined.

$$z_i = \begin{cases} 400 - x + \frac{200 - (400 - x)}{10} \cdot i, & \text{if } i \leq 10 \\ 200 + \frac{(x - 200)}{5} \cdot (i - 10), & \text{if } i > 10 \end{cases}$$

For instance, given $x=210$, the sure outcomes z_i 's are 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 202, 204, 206, respectively. See also Table 1 for the more details.

that “auto-pilot” subjects chose fewer (more) lottery options in the last six rounds simply because they developed the habit of doing so in the first six rounds. If this is the case, the treatment effect could be driven by the heuristic rather than the risk environment they experienced. To refute this alternative explanation, we used two *additional* treatment conditions, HM' and LM', in which we tried to equalize the average numbers of lottery options chosen in the first six rounds among HM', MM, and LM' to observe whether the treatment effect is robust to the heuristic. These two treatment conditions were on an ad-hoc basis, because the design choice of HM' and LM' was based on the average numbers of lottery options chosen in HM, MM, and LM conditions. After we conducted all HM, MM, and LM sessions, we observed that the average number of lottery options per round was 5.88 in HM, 6.99 in MM, and 7.60 in LM in the first six rounds. Therefore, we formed HM' and LM' simply by adding/dropping one row at the top of the choice menu in the first six rounds of the HM and LM conditions, respectively. Table 2 depicts the lotteries and the sure outcomes of the first six rounds in HM' and LM' conditions.⁶ This design ensures the (approximate) equality of the average number of lottery options chosen in the first six rounds among the HM', MM, and LM' conditions, and should provide compelling evidence to refute the alternative explanation, if the treatment effect persists.

A few other experimental particulars of interest are worth mentioning. First, subjects were presented with lotteries and sure outcomes algebraically in the instructions (without any specified values), to mitigate possible expectation effect. (See the experimental instructions in Appendix A for details.) Second, the order of the six lotteries in the H, M and L sets was all randomized to counterbalance the order effect. Finally, subjects were paid according to

⁶ For each of the first six rounds in treatment LM', we drop the first row of the menu, based on that of treatment LM, so that subjects would make one fewer lottery choice and switch earlier accordingly. For each of the first six rounds in treatment HM', compared to that in treatment HM, we added a row at the top of the choice menu with the sure outcome being small enough to ensure that subjects would choose the lottery option in the first row. Refer to Table 2 for more details.

one single randomly selected decision to avoid both the portfolio effect and the wealth effect.⁷

A total of 243 undergraduate students at Nanyang Technological University in Singapore participated in the experiment, of whom 66 participated in the HM treatment, 42 participated in the MM treatment, 71 participated in the LM treatment, 34 in the HM' treatment and 30 in the LM' treatment.⁸ No subject participated in the experiment more than once. Each session lasted roughly 35 minutes and proceeded in the following manner. Once subjects arrived at the computer lab, experimenters assigned them a random seat. After all subjects signed the consent form, they were given computerized instructions while the experimenter read them aloud. The main experiment then began. A post-experiment questionnaire was also given to collect information on demographic characteristics. The outcomes of the lotteries chosen by the subject were not disclosed to the subject until the end of the experiment. Subjects were paid in cash before they left the lab, with the exchange rate of 15 experimental tokens to one Singapore dollar (S\$1). The average monetary earning was S\$15.97 (roughly equivalent to US\$11), including the guaranteed S\$3 participation fee.⁹ The experiment was programmed using Z-tree (Fischbacher, 2007).

IV. Experimental Results

In this section, we first present the main statistical results, which are primarily based on subjects' decisions in the last six rounds of the main task, when they made decisions on an identical set of choices. We then explore two alternative explanations for our main results.

⁷ Subjects in the HM, MM, and LM groups made a total of 156 binary decisions (13 decisions in one round $\times$ 12 rounds). Subjects in the HM' group made 162 binary decisions, while subjects in the LM' group made 150 decisions.

⁸ Our aim is to identify whether a high-risk or low-risk prior environment has an effect on subsequent risk-taking behaviors. Thus, we recruited more subjects for the HM and LM treatments than the MM treatment. HM' and LM' are treatments for robustness check.

⁹ The hourly rate for an undergraduate student assistant in Singapore is between \$6-\$9. Hence, given the length of a session, the incentive offered in this study is more than twice as much as other available options.

Next, we present results from a regression analysis. Lastly, we discuss possible mechanisms driving the effect.

For each round, if he or she prefers receiving the outcome z_i to the lottery, a *rational* individual should prefer any sure outcome $z_j > z_i$ to the lottery.¹⁰ Therefore, in each round, any rational choices would exhibit a pattern like *Lottery*, ..., *Lottery*, *Safe*, ..., *Safe* where *Lottery* indicates that the individual chose the lottery while *Safe* indicates that the individual chose the sure outcome. That is, there should be no more than one switch point in each round.¹¹ Overall, 92.3% of the observations are considered “rational.” By Fischer’s exact test and the chi-squared test, the frequency of “rational choices” is not significantly different among any two of the five treatment groups (92.4% in HM, 92.5% in MM, 93.2% in LM, 90.2% in HM’ and 91.9% in LM’). While our analysis will focus on the observations with “rational choices,” the results remain qualitatively similar even if we include all observations.

Table 3 gives an overview of the average and median numbers of *Lottery* options chosen throughout the experiment. Given rational choices, these results also indicate the average or median switch point chosen. The average numbers of *Lottery* choices in the first six rounds for HM, MM, and LM are 5.88, 6.99, and 7.60 respectively, while the average numbers are 6.42 for HM’ and 6.80 for LM’. A series of Mann-Whitney tests show that there is no significant difference in the average number of *Lottery* choices in the first six rounds between any pairs of the MM, HM’, and LM’ treatment conditions (p values > 0.5), indicating that our *ad-hoc* treatment conditions successfully ensured (approximately) the same switch points chosen among the HM’, MM, and LM’ conditions during the risk manipulation period.

¹⁰ Otherwise, at least one of the following properties of rationality is violated: (1) completeness, (2) transitivity, and (3) more is better.

¹¹ Experimental studies which use the multiple price list method to elicit risk or time preferences find that some subjects switch back and forth from row to row, a phenomenon known as multiple switch points (e.g. Andersen et al., 2006). Holt and Laury (2002) document that roughly 10 percent of the observations exhibited multiple switching from an undergraduate student subject pool.

Our primary interest lies in decisions made in the second half of the main task, during which every subject was exposed to the six common set M lotteries in a random order. Following Holt and Laury (2002), the number of *Safe* options (sure outcomes) chosen in a round is used as an indicator of risk aversion. According to standard economic theory, there should be no difference in subjects' risk aversion among the treatment groups. Figure 2 illustrates the main treatment effect. Apparently, subjects in the HM and HM' groups tend to choose more *Safe* options than those in other groups. For all six decision rounds, the average numbers of *Safe* choices in the HM/HM' groups are higher than those in the MM, LM, and LM' groups.¹² A similar pattern, but to a lesser degree, can be observed when comparing the MM and LM/LM' groups. While the average numbers of *Safe* choices in the MM group are still higher than those in the LM/LM' groups for the majority of the six decision rounds, the gap appears to be smaller.

Table 4 summarizes the results of the Mann-Whitney tests. We first partitioned the dataset for rounds 7-12 by lottery. The upper panel compares the HM, MM, and LM groups. The number of *Safe* choices in the HM group is higher than in the LM group for each lottery at the 5% significance level, and is higher than in the MM group in decisions involving lotteries 300, 305, 310, and 315 at the 10% significance level; the number of *Safe* choices in the MM group is higher than in the LM group for lottery 290 at the 10% significance level. The last column of Table 4 shows that the lottery-averaged number of *Safe* choices is significantly higher in the HM group than in the MM group (p value <0.1) and in the LM group (p value <0.01).¹³

¹² Meanwhile, the average numbers of *Safe* choices in the HM' group appear to be higher than in the HM group.

¹³ The lottery-averaged number of *Safe* choices means a subject's average number of *Safe* choices in the last six rounds. For reasons of comparability, we exclude subjects who made any irrational decisions in the last six rounds for the analysis in the last column of Table 4.

The middle panel of Table 4 compares the HM', MM, and LM' groups, for which the switch points in the first six rounds do not significantly differ. The comparisons provide very similar results. The number of *Safe* choices in the HM' group is significantly higher than in the LM' group for all lotteries except lottery 295 at the 10% significance level, and is higher than in the MM group in decisions involving lotteries 300, 305, and 310 at the 5% significance level; the number of *Safe* choices in the MM group is higher than in the LM' group for all lotteries except lottery 310, while the differences are not statistically significant. Finally, the last column of the middle panel reports a similar pattern of results from tests of the lottery-averaged number of *Safe* choices, and shows that the lottery-averaged number of *Safe* choices is significantly higher in the HM' group than in the MM and LM' groups (p values <0.01).

The bottom panel of Table 4 reports results from a comparison between the HM and HM' groups, and between the LM and LM' groups. Between the LM and LM' groups, there is no significant difference in the number of *Safe* choices in any of the six lotteries, or in the lottery-averaged number of *Safe* choices (p values >0.1). Between the HM and HM' groups, the difference in the number of *Safe* choices is statistically insignificant in all lotteries except lottery 305, where the difference is significant at the 10% level. The lottery-averaged number of *Safe* choices is higher in the HM' group than in the HM group, but the difference is only marginally significant (p value $=0.10$).

Overall, the results suggest that exposure to a riskier environment reduces an individual's subsequent willingness to take risk. Note that the results are not driven by the realization of lottery outcomes, as subjects did not receive feedback on the lottery's realized outcome until the end of the experiment.

We interpret the larger number of *Safe* choices in the treatments with higher prior risk as an indication that exposure to a riskier environment increases one's risk aversion. Two other alternative explanations are possible, however. One is that subjects may have been on autopilot or adopted a simple heuristic in the latter rounds of the experiment. The subjects in the HM treatment group, who chose fewer *Lottery* options in the first six (riskier) rounds (as shown in Table 3), would accordingly also choose fewer *Lottery* options in the last six rounds. We address this issue based on two sets of evidence. First, data on subjects' reaction time helps to partially refute this possibility. Intuitively speaking, if an individual is on autopilot or using a simple heuristic, the time needed for decision-making would be short. Figure 3 presents average reaction time throughout the experiment. The downward trend suggests that subjects spent less and less time making decisions on similar lotteries as the experiment proceeded. However, when they perceived sharp changes in lottery risk (round 7 in HM, HM', LM and LM'), the subjects' reaction time spiked significantly. This implies that they stopped responding with little forethought (if they were even on "autopilot" to begin with) and reconsidered how best to respond to the new environment. In contrast, the reaction time continued to decline over time in treatment MM, where subjects experienced the same set of lotteries in the first six rounds and the last six rounds. Second, the additional *ad-hoc* treatment conditions (HM' and LM') provide direct evidence to refute the "autopilot" explanation. As shown in Figure 2 and Table 4, even after we control for the number of lottery options chosen in the first half of the decision task, subjects in the HM' (LM') group still made more (fewer) *Safe* choices in the second half of the decision task than in the MM group. This suggests that the treatment effect is robust to the design choice and not driven by a heuristic that subjects develop in the first half of the decision task.

The other possibility is that subjects in the MM treatment group, who made decisions on the same set of lotteries (set M) in the second half of the experiment as they did in the first

half of the experiment, may have behaved differently (inconsistently) when they played the set M lotteries for the second time. However, we found that, for a given lottery, on average about 72% of the subjects in treatment MM made nearly identical decisions (i.e. the difference in the number of *Safe* options chosen is equal to or less than 1). In addition, for all lotteries in set M except lottery 300, the Wilcoxon signed-rank test fails to reject the null hypothesis that a subject chose equal numbers of *Safe* choices in the first half of the experiment and in the second half of the experiment (at the 5% significance level), suggesting that MM subjects behaved consistently throughout the experiment.¹⁴

Regression analysis

Given that our multiple-round experiment generated a balanced panel dataset and that other independent variables may disturb our results, we conducted regression analysis to examine the marginal effect of prior exposure to risk environments on subsequent risk-taking behavior. Recall that the standard deviation of lottery x is $x-200$. Therefore, the average standard deviation of the lotteries in rounds 1-6 is 17.5 in treatments LM and LM', 102.5 in treatment MM, and 187.5 in treatments HM and HM'. The increment of lottery risk, measured by average standard deviation, is 85 between LM (LM') and MM as well as between MM and HM (HM'). We thus created a discrete variable, *PriorRisk*, indicating the magnitude of prior risk an individual is exposed to. It takes the values of 0, 1, and 2 for treatments LM (LM'), MM, and HM (HM') respectively.

Table 5 presents the regression results using data from the last six rounds with “rational” choices, where standard errors are clustered by subject. The dependent variable is the number of *Safe* choices chosen in a round. In column (1), we regressed it on *PriorRisk*, x of the lottery on which the player was making a decision, as well as period dummy variables.

¹⁴ For the lottery with $x=300$, subjects chose slightly more *Safe* options in the first six rounds than in the last six rounds (on average 6 vs. 5.4).

Column (2) further controls for demographic variables including gender (*Male* equals 1 if the subject is male and 0 otherwise), ethnicity (*Chinese* equals 1 if the subject is Chinese, the main ethnic group in Singapore, and 0 otherwise), major (*Econ* equals 1 if the subject is an Economics or Business major and 0 otherwise), and experience (*Experience* equals 1 if the subject has previous experience in financial investment and 0 otherwise).¹⁵ Column (3) further includes two dummy variables, *Morerows* and *Lessrows*. *Morerows* (*Lessrows*) equals one if we added (removed) one row at the beginning of the choice menu in the first six rounds, as described earlier, and zero otherwise. Therefore, *Morerows* is equal to one for the HM' group only and *Lessrows* is equal to one for the LM' group only. Column (4) is the same as Column (3), except that we replace the period dummies with a dummy variable *Last-3*, which equals one for the last three rounds and zero otherwise, and the interaction term between *Last-3* and *PriorRisk*. These two variables will be used to test the persistence of the treatment effect, if any.

In all these regressions, the coefficients of *PriorRisk* are positive and statistically significant at conventional levels. The coefficient measures the treatment effect of exposing subjects to an additional 85 units of lottery risk (i.e. 85 tokens) in rounds 1-6 on the number of *Safe* options chosen in rounds 7-12. The range of the coefficients implies that an increase of 85 units of lottery risk experienced in the first six rounds would lead to roughly additional 0.5 *Safe* choices per round for the decisions in the last six rounds. Meanwhile, the coefficients of *Morerows* and *Lessrows* in columns (3) and (4) are statistically insignificant. Additional regression analysis from Table 5 is detailed in Appendix C.

The statistical results in Table 4 suggest that the treatment effect of prior exposure to risk might not be linear. It appears that the effect of high risk relative to moderate risk is

¹⁵ Of our subjects, 56% were male, 91% were Chinese, 23% were Economics or Business majors, and 17% had previous experience in financial investment.

larger than the effect of moderate risk relative to low risk. Table 6 reports regression results, in which we decompose *PriorRisk* to dummy variables indicating different levels of risk. In columns (1) and (2), we repeat the regressions in columns (1) and (2) in Table 5 replacing *PriorRisk* with two dummy variables, *High* and *Low*. *High* (*Low*) equals one if and only if the subject was exposed to the set H (L) lotteries in the first half of the session. In other words, *High* is equal to one for the HM and HM' groups and zero otherwise and *Low* is equal to one for the LM and LM' groups and zero otherwise. We find that the coefficients of *High* are positive and statistically significant, implying that relative to exposure to moderate risk, previous exposure to high risk leads to more *Safe* choices in the second half of the session. The coefficients of *Low* are negative but statistically insignificant, suggesting that previous exposure to low risk (relative to moderate risk) leads to fewer *Safe* choices on average in the second half of the session, but the effect is weak. These findings confirm the asymmetric effects of previous exposure to different risk environments on subsequent risk-taking behavior. Moreover, the F tests show that, in both columns, the coefficients of *High* and *Low* are significantly different from each other, with p values lower than 0.0003.

Columns (3) and (4) in Table 6 further decompose *High* to treatment dummy variables HM and HM', and *Low* to treatment dummy variables LM and LM'. Consistent with the previous results, the coefficients of LM and LM' are both negative and statistically insignificant. The coefficients of HM' are positive and significant at the 5% level, while the coefficients of HM are positive but insignificant (p value=0.12 and 0.16 in the two columns respectively.)¹⁶ Nevertheless, for each of the columns, F tests show that the coefficient of HM is significantly different from the coefficients of LM (p values<0.07) and LM' (p values<0.02), suggesting that the subjects in treatment HM make significantly more *Safe*

¹⁶ Introducing interaction terms between period dummies and *High* or *Low* to columns (1) and (2) or introducing interaction terms between period dummies and the four treatment dummies to columns (3) and (4) does not change the results qualitatively. In addition, most coefficients of the period dummies and interaction terms remain insignificant.

choices than those in the treatments LM and LM' in the second half of the experiment.¹⁷ However, there is no significant difference between the coefficients of HM and HM' in either column (3) or column (4) (p values > 0.1).¹⁸

Possible mechanisms

In this subsection we will discuss our conjectures on the possible mechanisms by which the risk environment affects risk-taking behavior from the psychological and evolutionary perspectives. One factor that may account for this change in behavior is the stress or fear that may arise in a high-risk environment. The psychological literature shows that uncertainty is a powerful stressor (e.g. Monat, Averill and Lazarus, 1972; Zakowski, 1995) and stress modulates risk behavior (e.g. Porcelli and Delgado, 2009; Mather, Gorlick, and Lighthall, 2009; Buckert et al., 2014). Kandasamy et al. (2014) suggest an underlying physiological mechanism, showing that an increased level of cortisol (a stress hormone) comparable to that of real traders when faced with uncertainty and market volatility made subjects less willing to take risk. In our experiment, the high-risk environment may make subjects feel more stressed and even fearful about the outcome. Such emotional reactions may have carried over into the second half of the main task.

In addition, we conjecture that our findings on the effect of prior exposure to risk on risk preference have evolutionary roots. During the long evolutionary process, when the environment involves very high risk, survival, rather than expected return maximization, is

¹⁷ For each column, the coefficient of HM' is also significantly different from the coefficients of LM (p values < 0.05) and LM' (p values < 0.003).

¹⁸ Given a subject's unique switch point for a lottery, we can calculate the subject's expected certainty equivalence for the lottery. Certainty equivalence indicates the guaranteed return that a subject is willing to accept instead of taking the lottery, which could provide a different angle on subjects' risk-taking behavior. To complement the above analysis, we calculated expected certainty equivalence for each subject and each lottery in the second half of the session, and ran regressions with certainty equivalence as the dependent variable. Appendix D details the analysis and reports the results, which support the above findings.

the top priority for individuals. A higher level of risk aversion, which prevents individuals from risking their lives, would be a better survival tactic in the presence of very high risk.¹⁹

Our findings also point to the main motivation of this paper – the importance of disentangling the effect of the risk environment *per se* from the effect of the idiosyncratic realizations of outcomes garnered from the risk environments. As discussed in Section II, a growing line of literature focuses on how individuals’ past experiences in financial crises, violence, combats, etc. shape risk attitude. The effects of personal experiences suggest that individuals are able to “learn” from outcomes, the realizations of such risk. However, this may not be sufficient for survival in highly risky environments where one singular bout of bad luck may lead to a deleterious outcome. By contrast, the ability to learn from and adapt to the environment itself would be more crucial for survival in a highly risky environment. The effect we report from the experiment is suggestive of the subjects’ capability to “learn” from the environment *per se*; the riskiness of an environment itself influences one’s risk attitude.

V. Concluding Remarks

In the present study, we experimentally examined the effect of prior risk environments on people’s subsequent risk-taking behaviors in laboratory settings. We found that subjects were more risk-averse after they were exposed to a relatively high-risk environment. Our experimental design allows us to conclude that the effect comes from the risk environment *per se* rather than realized outcomes. We would like to highlight that the risk involved in the experiment is limited to the uncertainty of lottery outcomes. Not only were the incentives involved rather small, but the subjects were also exposed to the environment for a very short time period. Although these settings may lack elements of real-

¹⁹ Relatedly, from a functional-evolutionary perspective, Ohman (1986) shows that fear originates in a predatory defense system whose function is to allow animals to avoid and escape predators. This suggests that the emotions associated with high risk, like fear and stress, are also evolutionarily adaptive strategies conducive to survival in a high-risk environment.

world risk environments, we were able to observe changes in subjects' risk behaviors even within a short-lived laboratory setting. Thus, we surmise that the impact of risk environments on risk-taking behavior could be even larger in the real world.

Our main finding identifies a direction that could be pursued in future research. In the models of decision-making under uncertainty, risk aversion is typically exogenously determined and independent of the volatility of the risk environment an individual is exposed to. (For example, in the expected utility theory, risk aversion is solely determined by the curvature of the utility function.) However, our key finding suggests an interaction effect between two variables: the riskiness of an environment and risk-aversion. Theoretical economists should consider incorporating this relationship in models of decision-making under uncertainty. Additionally, our results suggest that exogenous changes in the riskiness of the environment may cause unanticipated changes in risk-aversion. This knowledge can help policy-makers and economic forecasters when designing optimal policies and making market predictions. For example, after a period of market volatility, investors may become more risk-averse, requiring a higher risk premium and perhaps causing further market volatility.

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Figures and Tables

Figure 1: Screenshot of one round in the main task

Period

1 of 12

Remaining time [sec]: 174

Please select "left" or "right" in each of the following row

Left	Right	Decision
You have 50% chance winning 375 and 50% chance winning 25	You will receive 43 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 60 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 78 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 95 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 113 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 130 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 148 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 165 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 183 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 200 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 235 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 270 for sure	left ☐ ☐ right
You have 50% chance winning 375 and 50% chance winning 25	You will receive 305 for sure	left ☐ ☐ right

OK

Figure 2: Choices of *Safe* options in rounds 7-12 by treatment

Notes: Figure 2 displays the average number of *Safe* choices for each lottery (characterized by x) in rounds 7-12 by treatment, for choices with no more than one switch point.

Figure 3: Average reaction time by treatment

Notes: Figure 3 illustrates the average reaction time in each round of the main task. Reaction time is the elapsed time between the presentation of the lottery and sure outcome options and the submission of the final decisions. The average reaction time gradually declines over rounds; however, a significant jump occurs in Round 7 of the LM, LM', HM and HM' groups.

Table 1: Lotteries and sure outcomes in HM, LM and MM conditions

Set	Lottery		Sure Outcome (z)												
	x	400-x	1	2	3	4	5	6	7	8	9	10	11	12	13
Set H	400	0	20	40	60	80	100	120	140	160	180	200	240	280	320
	395	5	25	44	64	83	103	122	142	161	181	200	239	278	317
	390	10	29	48	67	86	105	124	143	162	181	200	238	276	314
	385	15	34	52	71	89	108	126	145	163	182	200	237	274	311
	380	20	38	56	74	92	110	128	146	164	182	200	236	272	308
	375	25	43	60	78	95	113	130	148	165	183	200	235	270	305
Set M	315	85	97	108	120	131	143	154	166	177	189	200	223	246	269
	310	90	101	112	123	134	145	156	167	178	189	200	222	244	266
	305	95	106	116	127	137	148	158	169	179	190	200	221	242	263
	300	100	110	120	130	140	150	160	170	180	190	200	220	240	260
	295	105	115	124	134	143	153	162	172	181	191	200	219	238	257
	290	110	119	128	137	146	155	164	173	182	191	200	218	236	254
Set L	230	170	173	176	179	182	185	188	191	194	197	200	206	212	218
	225	175	####	180	####	185	####	190	####	195	####	200	205	210	215
	220	180	182	184	186	188	190	192	194	196	198	200	204	208	212
	215	185	####	188	####	191	####	194	####	197	####	200	203	206	209
	210	190	191	192	193	194	195	196	197	198	199	200	202	204	206
	205	195	####	196	####	197	####	198	####	199	####	200	201	202	203

Notes: This table shows all lotteries and their corresponding sure outcomes in sets H, M and L. The numbers 1, 2, 3, ..., 13 at the top indicate the rows in a round.

Table 2: Lotteries and sure outcomes in first six rounds of HM' and LM' conditions

	Lottery		Sure Outcome (z)													
	x	$400-x$	1	2	3	4	5	6	7	8	9	10	11	12	13	14
First six rounds in HM'	400	0	10	20	40	60	80	100	120	140	160	180	200	240	280	320
	395	5	15	25	44	64	83	103	122	142	161	181	200	239	278	317
	390	10	20	29	48	67	86	105	124	143	162	181	200	238	276	314
	385	15	24	34	52	71	89	108	126	145	163	182	200	237	274	311
	380	20	29	38	56	74	92	110	128	146	164	182	200	236	272	308
	375	25	34	43	60	78	95	113	130	148	165	183	200	235	270	305
First six rounds in LM'	230	170	176	179	182	185	188	191	194	197	200	206	212	218	-	-
	225	175	180	####	185	####	190	####	195	####	200	205	210	215	-	-
	220	180	184	186	188	190	192	194	196	198	200	204	208	212	-	-
	215	185	188	####	191	####	194	####	197	####	200	203	206	209	-	-
	210	190	192	193	194	195	196	197	198	199	200	202	204	206	-	-
	205	195	196	####	197	####	198	####	199	####	200	201	202	203	-	-

Notes: The table shows all lotteries and their corresponding sure outcomes in the first six rounds of HM' and LM' conditions. Compared to Set L in Table 1, for the first six rounds in the LM' condition, we simply drop the first row of the menu. Compared to Set H in Table 1, for the first six rounds in the HM' condition, we added a row at the top of the choice menu with the sure outcome being equal to $(400-x+z_1)/2$, where z_1 is the first sure outcome in the original menu.

Table 3: Average and median numbers of Lottery choices by treatment

Treatment		Rounds 1-6						Rounds 7-12					
HM	x	375	380	385	390	395	400	290	295	300	305	310	315
	Mean	5.79	6.21	5.93	5.75	5.54	6.08	6.44	6.82	6.78	6.38	6.32	6.11
	Median	6	6	6	6	5.5	6	6	7	7	6	6	6
MM	x	290	295	300	305	310	315	290	295	300	305	310	315
	Mean	7.53	6.92	6.97	6.61	7.13	6.76	7	7.28	7.6	7.15	7.6	6.85
	Median	8	7.5	7	6	8	7	8	8	8	8	8	7
LM	x	205	210	215	220	225	230	290	295	300	305	310	315
	Mean	7.11	7.64	7.83	8	7.45	7.58	7.84	7.78	7.56	7.21	7.21	7.5
	Median	8	9	9	9	9	9	9	9	9	8	7.5	8
HM'	x	375	380	385	390	395	400	290	295	300	305	310	315
	Mean	6.53	6.31	6.22	6.13	6.4	6.94	6.21	6.23	5.9	4.79	5.45	5.74
	Median	7	6	6	6	7	8	7	7.5	6	6	6	6
LM'	x	205	210	215	220	225	230	290	295	300	305	310	315
	Mean	6.2	7.44	6.66	7.11	6.46	6.92	7.96	7.59	7.68	7.52	7.43	7.32
	Median	7	8	7	8	6.5	8	8	8	8	8	7.5	7

Notes: Table 3 presents the average and median numbers of *Lottery* choices, for choices with unique switch points.

Table 4: Difference in the average number of Safe choices between treatments in Rounds 7-12

	Lottery (x)						Average
	290	295	300	305	310	315	
HM-MM	0.56	0.46	0.82*	0.77*	1.28**	0.74*	0.81*
HM-LM	1.39***	0.95**	0.78***	0.82**	0.89**	1.39***	0.99***
MM-LM	0.84*	0.49	-0.04	0.05	-0.39	0.65	0.18
HM'-MM	0.79	1.05	1.7**	2.36***	2.15***	1.11	2.02***
HM'-LM'	1.75*	1.36	1.78**	2.73***	1.98**	1.58**	2.32***
MM-LM'	0.96	0.31	0.08	0.37	-0.17	0.47	0.3
HM'-HM	0.23	0.59	0.88	1.59*	0.87	0.37	1.21*
LM'-LM	-0.12	0.19	-0.12	-0.31	-0.22	0.18	-0.12

Notes: The values (except those in the last column) indicate the difference in the average number of Safe choices between two treatment groups for each lottery in rounds 7-12, for choices with unique switch points. For example, 0.56 in the top left corner of the table means that, given choices in Lottery 290 in the second half of the main task, the average number of Safe choices in the HM group is higher than that of the MM group by 0.56. For the last column, we calculate the average number of Safe choices in these six rounds for each subject who made rational choices in all the six rounds, and report the averaged difference across treatment groups in this lottery-averaged number. *, **, and *** represent significance at 10%, 5%, and 1% levels, respectively, under the two-tailed Mann-Whitney test.

Table 5: Effects of previous exposure to risk on the number of Safe choices

	(1)	(2)	(3)	(4)
<i>PriorRisk</i>	0.6512*** (0.1871)	0.5551*** (0.1810)	0.4130* (0.2270)	0.4909** (0.2324)
<i>x</i>	0.0195*** (0.0057)	0.0192*** (0.0057)	0.0193*** (0.0058)	0.0193*** (0.0057)
<i>Morerows</i>			0.6828 (0.5545)	0.6781 (0.5541)
<i>Lessrows</i>			-0.2187 (0.4441)	-0.2188 (0.4437)
<i>Last-3</i>				0.2370 (0.1676)
<i>PriorRisk</i> × <i>Last-3</i>				-0.1561 (0.1281)
<i>Period-7</i>	-0.0585 (0.1840)	-0.0647 (0.1849)	-0.0692 (0.1858)	
<i>Period-8</i>	-0.1786 (0.1566)	-0.1982 (0.1581)	-0.2042 (0.1603)	
<i>Period-9</i>	0.0817 (0.1608)	0.0617 (0.1601)	0.0608 (0.1607)	
<i>Period-10</i>	0.1071 (0.1400)	0.1086 (0.1406)	0.1112 (0.1408)	
<i>Period-11</i>	-0.0652 (0.1255)	-0.0709 (0.1259)	-0.0758 (0.1265)	
<i>Male</i>		-1.462*** (0.3292)	-1.453*** (0.3287)	-1.455*** (0.3284)
<i>Chinese</i>		-0.8947 (0.6350)	-0.8399 (0.6211)	-0.8387 (0.6205)
<i>Econ</i>		0.0316 (0.3662)	0.0111 (0.3705)	0.0099 (0.3702)
<i>Experience</i>		0.2733 (0.4795)	0.2411 (0.4768)	0.2414 (0.4763)
Observations	1370	1370	1370	1370
R ²	0.044	0.101	0.107	0.106

Notes: Observations that are in rounds 7-12 and have one unique switch point are included. Column (1) regresses the numbers of Safe choices on *PriorRisk*, *x*, and period dummy variables. Column (2) includes demographic variables. Column (3) further includes dummy variables of *Morerows* and *Lessrows*. Column (4) replaces the period dummies with *Last-3*, and includes the interaction term between *PriorRisk* and *Last-3*. Standard errors clustered at the individual level are reported in parentheses. *, **, and *** represent significance at 10%, 5%, and 1% levels, respectively.

Table 6: Asymmetric effects of previous exposure to risk on the number of Safe choices

	(1)	(2)	(3)	(4)
<i>High</i>	1.020** (0.4812)	0.8835* (0.4633)		
<i>Low</i>	-0.2835 (0.4852)	-0.2293 (0.4607)		
<i>HM</i>			0.7748 (0.4975)	0.6837 (0.4868)
<i>LM</i>			-0.2623 (0.5391)	-0.1460 (0.5163)
<i>HM'</i>			1.523** (0.6554)	1.299** (0.6165)
<i>LM'</i>			-0.3345 (0.5148)	-0.4315 (0.4869)
<i>x</i>	0.0196*** (0.0057)	0.0193*** (0.0057)	0.0197*** (0.0058)	0.0194*** (0.0058)
<i>Period-7</i>	-0.0588 (0.1841)	-0.0648 (0.1850)	-0.0626 (0.1848)	-0.0694 (0.1859)
<i>Period-8</i>	-0.1809 (0.1567)	-0.2000 (0.1582)	-0.1867 (0.1587)	-0.2054 (0.1603)
<i>Period-9</i>	0.0793 (0.1611)	0.0597 (0.1605)	0.0793 (0.1615)	0.0592 (0.1611)
<i>Period-10</i>	0.1071 (0.1400)	0.1087 (0.1407)	0.1104 (0.1403)	0.1110 (0.1410)
<i>Period-11</i>	-0.0674 (0.1262)	-0.0729 (0.1266)	-0.0719 (0.1266)	-0.0770 (0.1270)
<i>Male</i>		-1.453*** (0.3290)		-1.450*** (0.3284)
<i>Chinese</i>		-0.9026 (0.6350)		-0.8565 (0.6235)
<i>Econ</i>		0.0413 (0.3631)		0.0318 (0.3695)
<i>Experience</i>		0.2503 (0.4783)		0.2205 (0.4750)
<i>F-test statistic: HM and LM have equal coefficients</i>			5.10	3.35
<i>p- value</i>			0.0248	0.0684
<i>F-test statistic: HM and LM' have equal coefficients</i>			6.64	7.22
<i>p- value</i>			0.0106	0.0077
Observations	1370	1370	1370	1370
R ²	0.046	0.103	0.051	0.108

Notes: Observations that are in rounds 7-12 and have one unique switch point are included. Column (1) regresses the numbers of Safe choices on High, Low, x, and period dummy variables. Column (2) includes demographic variables. Columns (3) and (4) repeat the regressions in (1) and (2) while decomposing High and Low to HM, HM', LM and LM'. Standard errors clustered at the individual level are reported in parentheses. *, **, and *** represent significance at 10%, 5%, and 1% levels, respectively.