Multiple-Switching Behavior in Choice-List Elicitation of Risk Preference

Soo Hong Chew, Bin Miao, Qiang Shen, Songfa Zhong*

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Abstract

This study examines multiple-switching behavior (MSB) in choice-list elicitation of risk preference from the perspectives of stochastic choice. We distinguish between "regular" and "irregular" MSB, and show that subjects with more irregular MSB are more likely to violate first order stochastic dominance. In contrast, subjects with more regular MSB are more likely to randomize in repeated choice (Agranov and Ortoleva, 2017), and to concurrently exhibit non-expected utility behavior and reduce compound lottery. Our results suggest the need to diagnose the quality of MSB when applying choice-list elicitations, and distinguish stochastic choice models including random utility and deliberate randomization.

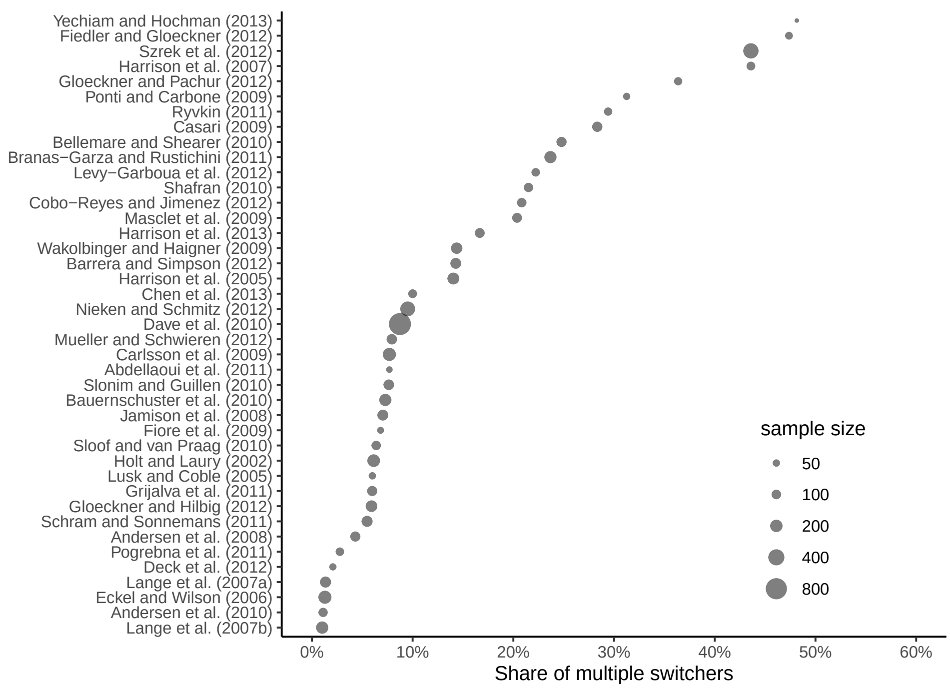
Keywords: *stochastic choice, random utility, deliberate randomization, choice list, risk preference, experiment*
JEL Classification: C91, D81

*Chew: Department of Economics, National University of Singapore, chewsoohong@gmail.com. Miao: Department of Economics, Shanghai University of Finance and Economics, binmiao11@gmail.com. Shen: College of Economics and Management, Zhejiang University of Technology, johnsonzhj@gmail.com, Zhong: Department of Economics, National University of Singapore, zhongsongfa@gmail.com.johnsonzhj@gmail.com. Acknowledgment: To be added.

1 Introduction

Choice list is a common method used in experimental economics and applied research for the elicitation of risk preference. In an influential paper, Holt and Laury (2002) popularize one specific form of choice list which comprises a number of pairs of lotteries arranged in two columns. Starting from the top, the right-hand option becomes increasingly more attractive relative to the left-hand option. Consequently, it is considered 'rational' to start from choosing options on the left and switch to options on the right when approaching the lower part of the list. When there is a single point at which the decision maker switches from the left to the right, this switch point is used to pin down the degree of risk aversion. Yet, it is often the case that subjects switch back and forth multiple times in a choice list, i.e., exhibiting multiple switching behavior (MSB, henceforth). Based on data from a meta-analysis in Filippin and Crosetto (2016), the figure below displays MSB frequency of up to 48 percent across 41 studies with an average of 15 percent.[1]

Figure 1: Summary of MSB Frequency across 41 Studies



Notes: This figure summarizes the frequency of MSB across 41 studies adopting choice-list elicitation of risk preference.

At first sight, MSB does not seem rational since it would involve choosing a right-hand option earlier in a list and switching to the left-hand option subsequently as the right-

[1]We would like to thank Antonio Filippin and Paolo Crosetto for sharing with us the data to construct this figure.

hand option becomes more attractive. In spite of its puzzling nature, MSB prevails in the experimental as well as applied literature adopting choice-list elicitation. Reflecting the prevalent view of MSB as choice error, Charness, Gneezy and Imas (2013) write, "*such inconsistent behavior is difficult to rationalize under standard assumptions on preferences*". This view is reflected in several practices to deal with MSB in the experimental and applied literature, such as deleting observations with MSB, training subjects to reduce the frequency of MSB, and enforcing single switch through the response mode. The final section of the paper will relate our findings to these practices.

Despite its prevalence, little has been done to arrive at a more comprehensive understanding of MSB in a choice-list setting. This paper investigates MSB from two perspectives on stochastic choice both theoretically and experimentally, and suggests a method to improve diagnosis of decision making quality. One perspective views choice stochasticity as unconscious behavior of a decision maker stemming from intrinsic randomness in preference arising from unobserved shocks or inability to implement the optimal choice due to "bounded rationality". This view has given rise to a voluminous literature on 'random utility' to capture the stochastic influences on choice behavior. For example, in Luce (1959), the probabilities of choosing different options are proportional to their relative appeal, and these probabilities can be identified with random components in the utilities following specific distributions. Eliashberg and Hauser (1985) consider a specific random expected utility model in which the decision maker has a probability measure over von Neumann–Morgenstern utility functions. On the other hand, bounded rationality reflects an underlying cognitive process which may relate to inattention or miscomprehension when making decisions, resulting in suboptimality or even 'errors' in choices, e.g., the drift diffusion model (Ratcliff, 1978; Ratcliff and McKoon, 2008).[2]

Another perspective views choice stochasticity as being conscious behavior on the part of the decision maker. In particular, a decision maker with convex preference may strictly prefer to randomize among options that are otherwise proximate in preference (Machina, 1985). Such preference necessarily departs from expected utility and satisfies implicitly the reduction of compound lottery axiom (RCLA)—decision maker being indifferent between a compound lottery and its reduction to a simple lottery. A preference for randomization may be driven by the need to minimize regret (Machina, 1985; Dwenger, Kübler, and Weizsäcker, 2018), achieve multiple goals (Marley 1997), and hedge across uncertain tastes (Fudenberg, Iijima and Strzalecki, 2015). Cerreia-Vioglio et al. (2019) refer to stochastic choice generated

[2]Additional models include Ahn and Sarver (2013), Fudenberg, Iijima and Strzalecki (2015), Fudenberg, Strack and Strzalecki (2018), Gul, Natenzon, and Pesendorfer (2015), Gul and Pesendorfer (2006), Guo (2016), Manzini and Mariotti (2014), Marschak (1960), McFadden (2001), etc.

by convex preference as deliberate randomization, and discuss different properties of the stochastic choice functions generated from different channels, including random utility and convex preference.[3]

In this paper, we begin with the theoretical observation that subjects with convex preference may exhibit MSB in a choice list by consciously randomizing between pairs of choices which are close to being indifferent. To examine MSB as a manifestation of deliberate randomization, we conduct two laboratory experiments. Experiment 1 examines whether and how MSB may be linked to deliberate randomization and choice error, utilizing the recent finding in Agranov and Ortoleva (2017) of a majority of their subjects switching between a pair of lotteries knowing that the same pair will be presented thrice in a row and only one of the three pairs will be implemented. Agranov and Ortoleva (2017) argue that the observed switching behavior is not likely to arise unconsciously (e.g., random utility and choice error) and that it supports the notion of deliberate randomization implied by convex preference. We extend Agranov and Ortoleva's (2017) argument and show that convex preference is the only class of models that can jointly account for MSB in a choice-list setting and switching behavior in a repeated-choice setting. This observation motivates the design of Experiment 1 to examine the potential link between MSB in choice list and switching behavior in repeated choice. We also differentiate between two types of choice list: both options are lotteries (lottery choice list, henceforth), and one of the options is a sure payoff (certainty choice list, henceforth). Holt and Laury (2002) exemplify a form of a lottery choice list.[4] With regard to certainty choice list, its appearance can be traced to Cohen, Jaffray and Said (1987). Here, subjects make a series of binary choices between a fixed lottery on the left and a range of sure payoffs arranged in an increasing manner on the right. Subjects make decisions in both lottery choice lists and certainty choice lists. In addition, we include two corresponding forms of repeated choice: lottery repeated choice in which both options are lotteries and certainty repeated choice in which one of the options is a sure payoff. In both the choice-list and repeated-choice settings, we include choices in which one option first-order stochastically dominates (dominance, henceforth) the other in order to identify choice errors in the respective settings.

[3]Utility models of decision under risk can be distinguished through whether (strict) convexity can be permitted or not. For example, expected utility, weighted utility (Chew 1983), and betweenness utility (Dekel 1986, Chew, 1989, Gul 1991) belong to the non-convex class while rank-dependent utility (Quiggin 1982), quadratic utility (Chew, Epstein and Segal, 1991) and cautious expected utility (Cerreia-Vioglio, Dillenberger, and Ortoleva, 2015) can exhibit convexity.

[4]Other forms of lottery choice list can be found, e.g., the probability matching method for ambiguity premium elicitation in Kahn and Sarin (1988) in which subjects choose between betting on an unknown urn and known urns with different compositions. Bleichrodt, Pinto, and Wakker (2001) consider an alternative certainty choice list with increasingly arranged winning probabilities of the binary lotteries with the same outcomes while the sure amount is kept fixed.

We observe that the frequency of MSB is 6.2 percent in certainty choice list, and 7.8 percent in lottery choice list. The corresponding frequencies of switching behavior are 26.1 percent in lottery repeated choice and 29.7 percent in certainty repeated choice. In addition, MSB in choice list is significantly correlated with switching behavior in repeated choice. To differentiate among the MSB patterns resulting from the different motives, we distinguish between regular MSB and irregular MSB. Under *regular MSB*, subjects initially choose options on the left and eventually switch to options to the right, regardless of how they switch back and forth in the middle portion of the list. We refer to the rest of the three cases of MSB as *irregular MSB*. These include the two cases of subjects starting from and ending up choosing options on the same side, and the remaining case of initially choosing options on the right and eventually switching to options on the left. We include in this latter case the possibility of a single switch which starts from the right and ends up on the left. For certainty choice list, the regular MSB frequency is 2.8 percent compared to 3.5 percent for the three types of irregular MSB. For lottery choice list, the frequency of regular MSB is 6.6 percent versus 2.1 percent for irregular MSB. We further observe that regular MSB in certainty choice list (lottery choice list) is significantly correlated with the switching behavior in certainty repeated choice (lottery repeated choice), but not for dominance violations in a repeated choice setting. By comparison, irregular MSB in certainty choice list (lottery choice list) is not significantly correlated with the switching behavior in certainty repeated choice (lottery repeated choice), and is significantly correlated with dominance violations in repeated choice setting. Overall, these results suggest that regular MSB is linked to convex preference along with switching behavior in repeated choice, while irregular MSB is more likely to result from random utility or choice error.

In Experiment 2, we further examine MSB, regular MSB in particular, in relation to the two necessary conditions of convex preference discussed earlier, namely, non-expected utility (NEU) behavior and conformance to RCLA. We adopt certainty choice list to elicit the certainty equivalents for five lotteries that vary in probabilities and outcomes, including moderate prospect, moderate hazard, longshot prospect, longshot hazard, and even-chance mixed lottery, and examine the corresponding frequencies of MSB. At the same time, we include choice tasks in a probability triangle to examine whether subjects exhibit NEU behavior and compound lotteries to examine whether they conform to RCLA.

The observed frequencies of MSB display an interesting hump pattern. For the even-chance mixed lottery, the MSB frequency is 23.2 percent (regular: 12.3%, irregular: 10.9%) which is at least three times higher than the MSB frequencies for the two gain lotteries—moderate prospect (regular: 3.6%, irregular: 3.4%), and longshot prospects (regular: 2.1%, irregular: 3.9%)—and the two loss lotteries—moderate hazard (regular: 1.3%, irregular:

2.0%) and longshot hazard (regular: 0.7%, irregular: 2.3%). Moreover, subjects with more regular MSB are more likely to satisfy RCLA and exhibit NEU behavior concurrently. By contrast, we do not observe such a link for irregular MSB. The overall message from these findings is in line with that from Experiment 1: regular MSB is likely to be induced by deliberate randomization involving convex preference.

Our findings shed light on different perspectives of stochastic choice underpinning MSB. While random utility models may be compatible with MSB in a choice list, they are not consistent with switching behavior in repeated choice as pointed out in Agranov and Ortoleva (2017). The observed link between regular MSB and switching behavior in repeated choice in Experiment 1 supports models with convex preference but not random utility models. Moreover, irregular MSB, given its association with dominance violation, is more in line with the popular view of MSB as reflecting choice error. This distinction is further supported in Experiment 2 with the observed correlation between RCLA and NEU behavior with regular MSB but not with irregular MSB. In addition, MSB and switching behavior in repeated choice remains pervasive when one option in a binary choice is deterministic. This enables us to further discriminate between models of convex preference and to favor globally convex models, including rank-dependent utility (Quiggin 1982) and quadratic utility (Chew, Epstein and Segal, 1991), rather than cautious expected utility model (Cerreia-Vioglio, Dillenberger and Ortoleva, 2015) which is incompatible with preference for randomization between a lottery and a sure amount. Finally, we demonstrate in an appendix how one convex preference model—cumulative prospect theory (Tversky and Kahneman, 1992)—can account for the hump pattern of a substantially higher MSB frequency of even-chance mixed lottery through a loss-averse utility function.

Our findings have direct application in relation to the practice of grouping MSB data together with dominance violation as choice error. Given the correlation between irregular MSB and dominance violation and the correlation between regular MSB and NEU behavior and RCLA, it seems sensible to treat regular MSB as part of the elicited choice data and group irregular MSB together with dominance violation as a revised measure of choice error. Adopting this new measure of choice error which excludes regular MSB can help recover volumes of previously deleted data in numerous published papers as well as enable more efficient coding of observed behavior in future experimental and applied studies employing a choice-list approach to elicit risk preference.

2 Theoretical Background

This section provides the theoretical background of our experiment. Denote by F and G lotteries, which are distributions on the set of monetary outcomes X. We focus on the qualitative predictions of different models in terms of whether they are compatible with stochastic choice in a binary choice problem denoted by $\{F, G\}$. We first consider deterministic models without considering random components in the utility or mistakes/errors in the decision making process, and then proceed to incorporate randomness/mistakes into consideration. Note that in repeated-choice setting, $3 \times \{F, G\}$, with only one of the choices being randomly implemented, stochastic choice may result in choosing different lotteries in the three identical problems thereby generating *switching behavior*. In choice-list setting, one (or two) of the lotteries gradually change from the top to the bottom of the list, resulting in a sequence of similar binary choice problems $\{F, G\}$, $\{F', G'\}$, $\{F'', G''\}$, and choice stochasticity can lead the decision maker to exhibit MSB.

2.1 Models without Randomness/Mistakes

Under deterministic models, should a decision maker have *preference for randomization*—preferring probability mixtures of two lotteries to each of the lotteries, she is willing to randomize between two lotteries and hence generating 'conscious' stochastic choice in a binary choice problem $\{F, G\}$. Consider the benchmark expected utility model, it is linear in the probabilities in that the utility of α-mixture between F and G equals the α-weighted average of the utilities for F and G:

$$\mathbf{U}_{EU}\left(\alpha F + (1-\alpha) G\right) = \alpha \mathbf{U}_{EU}(F) + (1-\alpha)\mathbf{U}_{EU}(G).$$

As such, expected utility precludes preference for randomization and is unable to generate choice stochasticity. In fact, expected utility belongs to a broader class of models of decision making under risk—the *betweenness* models—that is incompatible with preference for randomization. In particular, the (non-)betweenness class of models admit (non-)linear indifference curves in the probability space, and subsequently we analyze the predictions of some representative models in each class.

Models with Betweenness

The independence axiom underpinning expected utility requires preservation of preference ranking between lotteries F and G after mixing with a common third lottery. The betweenness axiom (Chew, 1983, 1989; Dekel, 1986) relaxes the independence axiom by restricting the common third lottery to be either F or G. Gul's (1991) disappointment aversion model also belongs to the betweenness family.

Betweenness: $F \succeq G$ implies $F \succeq \alpha F + (1-\alpha) G \succeq G$ for $\alpha \in [0,1]$.

The axiom is incompatible with preference for randomization, and it follows that betweenness models cannot generate choice stochasticity in $\{F, G\}$ unless $F \sim G$. As such, all these models are incompatible with either MSB in choice list or switching behavior in repeated choice.

Models without Betweenness

Machina (1985) examines stochastic choice arising from deterministic preferences, and notes that preference for randomization can occur if the utility model is quasiconcave in probabilities. In relation to this, aforementioned betweenness models are linear in probabilities, and hence imply no randomization preference. In the non-betweenness class, several models can exhibit quasiconcavity and in the sequel we will discuss three of them, including rank-dependent utility, quadratic utility, and cautious expected utility.[5] All three models turn out to be compatible with preference for randomization under certain conditions. In the analyses, we shall focus on rank-dependent utility in deriving the explicit predictions of choice behavior under different settings, and briefly discuss the other two models compared with rank-dependent utility.

Rank-Dependent Utility. Consider the rank-dependent utility (RDU—Quiggin, 1982):

$$\mathbf{U}_{RDU}(F) = \int_{x \in X} u(x)\, df(F(x)),$$

where f is an increasing probability weighting function and onto. Rank-dependent utility can be quasiconcave in probability if f is concave, and hence is able to exhibit preference for randomization.

Next, we exemplify how rank-dependent utility can generate choice stochasticity in a simple binary choice problem $\{(H, L; p), \delta_c\}$, where $(H, L; p)$ is a binary lottery delivering two outcomes H and L $(H > L)$ with probabilities p and $1-p$, and δ_c a degenerate lottery that delivers an intermediate outcome c with certainty. An α-mixture of the two lotteries $\alpha(H, L; p) + (1-\alpha)\delta_c$ delivers $(H, c, L; p\alpha, 1-\alpha)$, with its rank-dependent utility is as follows:

$$\mathbf{U}_{RDU}(\alpha) = f(p\alpha)(u(H) - u(c)) + f(p\alpha + 1 - \alpha)(u(c) - u(L)) + u(L).$$

[5] Some other behavioral models that incorporate reference dependence, such as the choice-acclimatizing personal equilibrium in Koszegi and Rabin (2007), can also exhibit quasiconcavity. As shown in Masatlioglu and Raymond (2016), this model can be identified as the intersection of rank-dependent utility and quadratic utility.

Evaluating the derivative of $\mathbf{U}_{RDU}(\alpha)$ w.r.t. α at 0 and 1 delivers:

$$\begin{aligned}
\frac{d}{d\alpha}\mathbf{U}_{RDU}(\alpha)\,|_{\alpha=0} &= pf'(0)\,(u(H)-u(c)) - (1-p)\,f'(1)\,(u(c)-u(L))\,, \text{ and} \\
\frac{d}{d\alpha}\mathbf{U}_{RDU}(\alpha)\,|_{\alpha=1} &= pf'(p)\,(u(H)-u(c)) - (1-p)\,f'(p)\,(u(c)-u(L))\,.
\end{aligned}$$

It is possible to have $\frac{d}{d\alpha}\mathbf{U}_{RDU}(\alpha)\,|_{\alpha=0} > 0 > \frac{d}{d\alpha}\mathbf{U}_{RDU}(\alpha)\,|_{\alpha=1}$ (e.g., given f concave), which implies the decision maker strictly prefers an interior α-mixture of the two lotteries to either of the two lotteries. One can further obtain the randomization interval $(\underline{c}, \overline{c})$, such that the optimal mixture $\alpha^* \in (0,1)$ for $c \in (\underline{c}, \overline{c})$. Intuitively, $\underline{c}$ and $\overline{c}$ are the values satisfying the following:

$$\frac{d}{d\alpha}\mathbf{U}_{RDU}(\alpha)\,|_{\alpha=1,c=\underline{c}} = \frac{d}{d\alpha}\mathbf{U}_{RDU}(\alpha)\,|_{\alpha=0,c=\overline{c}} = 0,$$

which delivers a well-defined 'randomization interval' given f concave:

$$\left(u^{-1}\left(pu(H)+(1-p)\,u(L)\right), u^{-1}\left(\frac{pf'(0)\,u(H)+(1-p)\,f'(1)\,u(L)}{pf'(0)+(1-p)\,f'(1)}\right)\right).$$

It follows that a rank-dependent utility decision maker prefers to randomize between $(H, L; p)$ and δ_c for a range of values c, and hence can exhibit MSB in certainty choice list where the sure amount c varies, as well as switching behavior in certainty repeated choice where the sure amount c is fixed.[6]

Quadratic Utility. Quadratic utility (QU—Chew, Epstein and Segal, 1991) admits the following general form:

$$\mathbf{U}_{QU}(F) = \int_{y\in X}\int_{x\in X} \phi(x,y)\,dF(x)\,dF(y)\,,$$

where $\phi(x,y)$ is a symmetric function increasing in its first argument. Similar to rank-dependent utility, quadratic utility can also exhibit quasiconcavity and thus be compatible with MSB in choice list as well as switching behavior in repeated choice.[7]

Cautious Expected Utility. Cautious expected utility (CEU—Cerreia-Vioglio, Dillenberger,

[6]Here, we focus on binary choice problems where one of the options is a degenerate lottery. One can show that rank-dependent utility is also compatible with both MSB and switching behavior in choice environments where both lotteries are non-degenerate such as Holt and Laury (2002). In Appendix B, we show how rank-dependent utility with gain-loss differentiation can account for the 'hump' pattern identified in our subsequent results analyses: the MSB frequency in choice lists involving mixed lotteries is significantly higher than that in choice lists with lotteries that involve only gains (losses).

[7]Consider for example the choice problem $\{(H, L; p), \delta_c\}$, suppress the notation and use ϕ_{xy} to denote $\phi(x,y)$, the quadratic utility for the α-mixture of the two lotteries is given by

$$\mathbf{U}_{QU}(\alpha) = \mathbf{p}\boldsymbol{\Phi}\mathbf{p}^T,$$

and Ortoleva, 2015) also belongs to the non-betweenness class:

$$\mathbf{U}_{CEU}(F) = \min_{u \in \mathcal{U}} u^{-1}\left(\int u(x)\,dF(x)\right),$$

where $\mathcal{U}$ is a set of vNM utility indices. Intuitively, the minimization operator implies that cautious expected utility admits quasiconcavity and hence is compatible with preference for randomization. Compared with rank-dependent utility or quadratic utility, one difference of cautious expected utility is that it cannot generate choice stochasticity in choice problems involving degenerate lotteries, which stems from the following weaker version of independence in its axiomatization.

Negative Certainty Independence: $F \succeq \delta_c$ implies $\alpha F + (1-\alpha) G \succeq \alpha\delta_c + (1-\alpha) G$ for every $\alpha \in (0,1)$.

Replace G with either F or δ_c, apply Negative Certainty Independence twice and we have

$$F \succeq \alpha F + (1-\alpha)\,\delta_c \succeq \delta_c,$$

which implies that cautious expected utility is incompatible with preference for randomization in choice problem $\{F, \delta_c\}$ where $F \succeq \delta_c$. Moreover, observe that the above relation entails linear indifference curves passing degenerate lotteries: $F \sim \alpha F + (1-\alpha)\,\delta_c \sim \delta_c$ given $F \sim \delta_c$. Under this observation, for the case where $\delta_c \succ F$, consider a lottery G such that $G \sim \delta_c$ and G first-order stochastic dominates F, denoted by $G \succ_{FOSD} F$. It follows that:

$$\delta_c \sim \alpha G + (1-\alpha)\,\delta_c \succ_{FOSD} \alpha F + (1-\alpha)\,\delta_c.$$

As cautious expected utility respects first-order stochastic dominance, the above relation implies that cautious expected utility is also incompatible with preference for randomization in choice problem $\{F, \delta_c\}$ where $\delta_c \succ F$.[8] Regarding general choice problems $\{F, G\}$ between

where $\mathbf{p} = (\alpha p, 1-\alpha, \alpha(1-p))$, and $\mathbf{\Phi}$ is a symmetric matrix $\begin{pmatrix} \phi_{HH} & \phi_{Hc} & \phi_{HL} \\ \phi_{cH} & \phi_{cc} & \phi_{cL} \\ \phi_{LH} & \phi_{Lc} & \phi_{LL} \end{pmatrix}$. Denote by $\mathbf{p}_\alpha = (p, -1, 1-p)$, $\mathbf{p}_0 = (0,1,0)$ and $\mathbf{p}_1 = (p, 0, 1-p)$, and we have

$$\frac{1}{2}\left(\frac{d}{d\alpha}\mathbf{U}_{QU}(\alpha)\,|_{\alpha=0} - \frac{d}{d\alpha}\mathbf{U}_{QU}(\alpha)\,|_{\alpha=1}\right) = \mathbf{p}_\alpha \mathbf{\Phi} \mathbf{p}_0 - \mathbf{p}_\alpha \mathbf{\Phi} \mathbf{p}_1 = -\mathbf{p}_\alpha \mathbf{\Phi} \mathbf{p}_\alpha^T.$$

As a result, it is possible to have $\frac{d}{d\alpha}\mathbf{U}_{QU}(\alpha)\,|_{\alpha=0} > 0 > \frac{d}{d\alpha}\mathbf{U}_{QU}(\alpha)\,|_{\alpha=1}$ given $\mathbf{\Phi}$ negative semidefinite, and hence generating preference for randomization.

[8] Cerreia-Vioglio et al. (2019) axiomatically characterize a cautious stochastic choice function which stems from maximizing certain cautious expected utility. One of the key axioms, Weak Stochastic Certainty Effect, precludes preference for randomization in binary choice problems involving degenerate lotteries.

two non-degenerate lotteries, Agranov and Ortoleva (2017) show that cautious expected utility is strictly quasiconcave and thus compatible with switching behavior in lottery repeated choice as well as MSB in lottery choice list.

Stochastic Dominance, Reduction, and Random Incentive

As shown above, non-betweenness models can exhibit quasiconcavity and thus generate conscious stochastic choice in binary choice under certain conditions. We would like to first point out that all models considered in this subsection respect first-order stochastic dominance. As a result, these models cannot generate stochastic choice in binary choice if one lottery in the choice set first-order stochastic dominates the other.

One critical assumption in our preceding analyses is RCLA, as we assume a probabilistic (stochastic) choice generates the mixture lottery $\alpha F + (1-\alpha) G$, which is reduced from the compound lottery $\{F, G; \alpha\}$ that delivers F with probability α and G with $1-\alpha$. Should RCLA fail, such a compound lottery can be evaluated differently from the reduced simple lottery, by adopting a recursive specification, e.g., recursive expected utility (Kreps and Porteus, 1978) or recursive rank-dependent utility (Segal, 1987). Both models first obtain the certainty equivalents, c_F and c_G, of stage-2 lotteries F and G with either expected utility or rank-dependent utility, and then evaluate the compound lottery as a stage-1 simple lottery $\{c_F, c_G; \alpha\}$ with again, (a possibly distinct) expected utility or rank-dependent utility. It follows that all recursive models respecting first-order stochastic dominance at stage-1 are incompatible with preference for randomization. Hence, a *necessary* condition for MSB to be generated by deterministic preference is that the decision maker should be consistent with RCLA.

One related issue concerns the random incentive mechanism. In an experiment involving multiple pairs of options $\{\{F, G\}, \{F', G'\}, ...,\}$ and adopting random incentive to compensate subjects based on one randomly selected choice, it is possible for the subjects to utilize such mechanism to randomize across different problems. Should RCLA hold, such randomization can contaminate inferences drawn from the experiment. For example, a non-betweenness utility maximizer may separately prefer optimal mixture $\alpha^\star$ and $\alpha^{\star\prime}$ in choice problems $\{F, G\}$ and $\{F', G'\}$. Nevertheless, the two mixture probabilities may no longer be optimal when considering the two choice problems jointly under random incentive mechanism, i.e., $\frac{1}{2}\left(\alpha^\star F + (1-\alpha^\star) G\right) + \frac{1}{2}\left(\alpha^{\star\prime} F' + (1-\alpha^{\star\prime}) G'\right)$ is not the optimal lottery in terms of delivering the highest overall utility.[9] Notably, although RCLA together with random

[9] Random incentive is commonly used in experimental economics in order to collect more data from each subject and to make within-subject analysis. There has been a number of studies discussing the validity of random incentive mechanism. Starmer and Sugden (1991) study random incentive mechanism by directly comparing the choice behaviors in pay-1-in-1 treatment and pay-1-in-2 treatment. They do not find significant difference between the choice patterns in the two treatments, but do find violations of RCLA

incentive can distort the optimal mixture probability, it will not change the qualitative prediction in terms of stochastic choice, i.e., only non-betweenness utility models is compatible with preference for randomization.

2.2 Incorporating Randomness/Errors

In this subsection, we consider models incorporating random components into utility or errors in decision process. Both classes of models are shown to be compatible with 'non-conscious' stochastic choice, and we detail their predictions in the sequel.

Models Incorporating Randomness

Random Utility. The widely-used random utility model directly associates the utility of a lottery with a noise term:

$$\mathbf{U}_{RUM}(F) = U(F) + \epsilon_F, \text{ and } \mathbf{U}_{RUM}(G) = U(G) + \epsilon_G,$$

where U can admit arbitrary utility form. At the individual level, the noise term is often assumed to be caused by random shocks in preferences.[10]

Random Expected Utility. Eliashberg and Hauser (1985) propose that the randomness is associated with preference parameters, and consider the following random expected utility where the CRRA utility index admits a random relative risk aversion parameter:

$$\mathbf{U}_{REU}(F) = \int x^{\rho+\epsilon} dF(x), \text{ and } \mathbf{U}_{REU}(G) = \int x^{\rho+\epsilon} dG(x).$$

Loomes and Sugden (1995) suggest a more general random preference model. Given a probability distribution μ on a set of preference orderings $\mathcal{P}$, the probability of choosing F in $\{F, G\}$ equals:

$$\mu\{\succeq_p \in \mathcal{P} : F \succeq_p G\}.$$[11]

and independence. Recently, Freeman, Halevy, and Kneeland (2018) compare choice-list and simple binary choice, and show that random lottery incentive could bias the elicitation of risk preference. The necessary and sufficient condition for the incentive compatibility of random incentive mechanism is compound independence axiom introduced in Segal (1990).

[10] A well-known example is the logit model, where ϵ_i is assumed to be i.i.d. with double exponential distribution, giving rise to the logit probability of choosing F in $\{F, G\}$:

$$\frac{e^{U(F)}}{e^{U(F)} + e^{U(G)}}.$$

[11] Recent developments of random expected utility include Gul and Pesendorfer (2006), and Apesteguia and Ballester (2018). Gul and Pesendorfer (2006) axiomatize random expected utility in that the set $\mathcal{P}$ consists of all expected utility preferences. Apesteguia and Ballester (2018) compare random expected utility with

When considering the predictions of the two models in relation to MSB or switching behavior, we follow Agranov and Ortoleva (2017) and assume that the random component is fixed in the repeated-choice setting as the decision maker is aware of that she is making three identical choices consecutively. In the choice-list setting, we allow the random component to vary within one list since (at least) one of the options keeps changing. Under such assumption, random utility model and random expected utility both can generate choice stochasticity in choice list but not in repeated choice. It follows that both models are compatible with MSB in choice list but incompatible with switching behavior in repeated choice.[12] A difference between the two models arises where stochastic dominance is concerned. Random expected utility respects first-oder stochastic dominance and cannot generate stochastic choice when a binary choice problem involves a dominated lottery. In contrast, random utility model can generate non-zero probability of choosing the dominated lottery if the distribution of the noise term has full support.

Errors/Bounded Rationality

This class of models assume that a decision maker, even with deterministic preference, may be unable to choose the optimal option due to bounded rationality, and hence exhibit choice stochasticity. Bounded rationality can arise from complexity, inattention, or information cost, etc. In our experimental setting, the predictions of boundly rational models can resemble those of random utility model. We illustrate such similarity with a specific boundly rational model, the drift diffusion model (Ratcliff, 1978; Ratcliff and McKoon, 2008).

Drift diffusion model explicitly specifies the following decision-making process along the time horizon: when choosing between F and G, a decision maker continuously collects information in favor of one option, which is modeled as a Brownian motion with a drift rate equal to the difference in utilities of the two options $U(F)$ and $U(G)$ as follows:

$$Z_t = (U(F) - U(G))\, t + B_t,$$

where B_t is a standard Brownian motion. The decision maker will stop and choose F (G) once the information accumulated—Z_t, hits an exogenous upper (lower) bound.[13] It follows that the level of choice stochasticity in drift diffusion model depends on the drift rate and boundaries. In a choice-list setting where the lotteries keep changing, drift diffusion model is compatible with MSB. For repeated choice, the prediction depends on whether the decision

the general random utility model and discuss the monotonicity property of stochastic choice functions.

[12]To some extent, random utility model is a more general model and can (partially) encompass random expected utility in which the randomness in the utility index can be regarded as preference shocks. See Cerreia-Vioglio et al. (2019) for a related discussion.

[13]For recent developments to endogenous bounds, see e.g., Guo (2016) and Fudenberg, Strack and Strzalecki (2018).

maker could re-collect information in such an environment. We follow Agranov and Ortoleva (2017) and assume that there is no new information collection when the decision maker is making identical choices consecutively. Accordingly, drift diffusion model is incompatible with switching behavior in repeated choice. Finally, when one lottery first-oder stochastic dominates the other, drift diffusion model generates a positive probability of choosing the dominated lottery.

2.3 Summary

Recently, Cerreia-Vioglio et al. (2019) discuss the properties of stochastic choice arising from different channels. They classify the literature into three main classes of stochastic choice functions: one class is generated by deterministic preferences; the other by random expected utility; and the last class is characterized by *Regularity*, a 'stochastic version' of the independence of irrelevant alternatives. Random utility model belongs to the last class. The increasingly used drift diffusion model considered here does not fit well into the above classifications as it only applies to binary choice problems.[14] In the following, we summarize the predictions of various models (see Table 1). Recall that choice stochasticity can generate MSB in choice list and switching behavior in repeated choice.

Deterministic models in the betweenness family, e.g., expected utility, weighted utility, and disappointment aversion utility, are incompatible with preference for randomization and thus cannot generate MSB (switching behavior) in choice list (repeated choice). In contrast, non-betweenness models including rank-dependent utility and quadratic utility, can exhibit global quasiconcavity and thus be compatible with both MSB and switching behavior. Notably, cautious expected utility can generate the two types of behavior only when both options are non-degenerate lotteries. Finally, a common feature of these deterministic models is that all of them respect first-order stochastic dominance, and hence predict null probability of choosing the dominated lottery.

When randomness in utility/preference is considered, it may be argued that the random component is fixed in repeated choice but not so in choice list. It follows that both the random utility model and random expected utility model are compatible with MSB but not switching behavior. Moreover, given generic distributions of the noise term, random utility model can generate positive probability of choosing a dominated lottery while random expected utility cannot. The drift diffusion model considers a dynamic decision process that may involve errors, and shares the same predictions with random utility model should there

[14] There are other stochastic choice functions satisfying Regularity, e.g., additive perturbed utility (Fudenberg, Iijima and Strzalecki, 2015). In binary choice problems, random utility model and additive perturbed utility coincide under an additional Positivity condition.

be no re-collection of information in repeated choice.

Finally, consider a further differentiation of MSB into those being regular—initially choosing options on the left and eventually switching to the options on the right, and those being irregular—either starting and ending choosing options on the same side, or starting with options on the right and ending with options on the left. Observe that non-betweenness models, e.g., rank-dependent utility, often deliver a 'randomization interval' in certainty choice list—the decision maker strictly prefers to randomize between the two options if the sure amount falls into that interval. Similarly, random expected utility model can also deliver a randomization interval in certainty choice list—the maximum (minimum) of the expected utility of the lottery according to all preference parameters coincides with the utility of the upper (lower) bound sure amount of the interval. As such, should the randomization interval being a strict subset of the range of the sure amounts in certainty choice list, non-betweenness models and random expected utility can generate only regular MSB but not irregular MSB. In contrast, random utility model cannot deliver a randomization interval if the distribution of the noise term has full support, and hence is generically compatible with both regular MSB and irregular MSB.

Table 1: Summary of Theoretical Predictions.

		Regular MSB	Irregular MSB	Switching Behavior	Dominance Violation
Betweenness	EU, Weighted, Disappointment Aversion	N	N	N	N
Non-Betweenness	Cautious Expected Utility	Y†	N*	Y†	N
	Rank-dependent Utility, Quadratic Utility	Y	N*	Y	N
Random & Errors	Random Expected Utility	Y	N*	N	N
	Random Utility, Drift Diffusion	Y	Y	N	Y

*Under the assumption of strict sub-interval.

†Partially compatible with the corresponding behavior.

Notes: This table summarizes the qualitative predictions of different theories in terms of whether they are compatible with MSB in choice list, switching behavior in repeated choice, and violations of first-order stochastic dominance. 'Y' ('N') for a specific family of models means it is compatible (incompatible) with the corresponding behavior.

3 Experimental Design

This section presents our experimental design. In Experiment 1, we examine the relationship between choice list and repeated choice using a within-subject design. In Experiment 2, we make use of a comprehensive study on economic decision making, and investigate the links among a number of behavior patterns, including MSB, NEU behavior, and RCLA.

3.1 Experiment 1

We implement two types of choice list: certainty choice list and lottery choice list, in Experiment 1. For certainty choice list, subjects make a series of binary choices between a fixed lottery and a range of sure amounts (Cohen, Jaffray and Said, 1987). For lottery choice list, subjects make a series of binary choices between pairs of lotteries (Holt and Laury, 2002). Table 2 summarizes the parameters for the choice list in Experiment 1.

Table 2: Parameters for Choice List in Experiment 1

6 Certainty Choice Lists			6 Lottery Choice Lists			
Even-chance lottery		Sure option	Option 1		Option 2	
H	L		H_1	L_1	H_2	L_2
40	0	20±10	24	16	40	0
36	4	20±10	32	8	40	0
32	8	20±10	24	16	32	8
80	0	40±20	48	32	80	0
72	8	40±20	64	16	80	0
64	16	40±20	48	32	64	16

Notes: This table presents the parameters for 6 certainty choice list and 6 lottery choice list in experiment 1. For certainty choice list, each lottery has even chance of receiving a high outcome (H) and a low outcome (L) with expected value either 20 (3 choice lists) or 40 (3 choice lists). Correspondingly, the sure amount vary within the range of 10 (20) at a step size of 1 (2) for low (high) expected value lists. For lottery choice list, Option 1 is a safer option with the lower spreads, compared to Option 2. The probability p increases from 0 to 1 at a step of 0.05. The expected value is 20 (40) for low (high) EV lists for the option located in the middle (11th) of the list which has an even chance for both options.

We elicit the certainty equivalents of six lotteries with expected values of either 20 or 40. For each lottery with expected value 20—$(40, 0; 0.5)$, $(36, 4; 0.5)$ and $(32, 8; 0.5)$, the 21 levels of sure amounts range within the corresponding expected value±10 at a step size of 1. For lotteries with expected value 40—$(80, 0; 0.5)$, $(72, 8; 0.5)$ and $(64, 16; 0.5)$, the corresponding sure amounts are doubled. To reduce potential bias towards risk seeking or risk aversion being driven by the list itself, the expected value of the lottery is positioned in the middle of the sure amounts. In addition, either the lowest or the highest sure amount in each certainty choice list is changed to an amount in such a way that the lottery either dominates or is dominated by the sure amount in the sense of first-order stochastic dominance.

We include six lottery choice lists in which subjects choose between "safer" options $(H_1, L_1; p)$ versus "riskier" options $(H_2, L_2; p)$ with $H_2 > H_1 > L_1 > L_2$. As the case of certainty choice list, we have three lists where the expected value of the lotteries is low compared to that in the remaining three lists (see Table 2 for details). The probability p is set to increases from 0 to 1 at a step of 0.05, again resulting in a 21-level list. Note that the two lotteries in the middle (11th) choice in each list have the same expected value. In addition, the first and last comparison in each choice list always involves degenerate lotteries with one dominating the other.

For repeated choice setting, we follow the design of Agranov and Ortoleva (2017), in which subjects are instructed to choose between the same pairs of uniform four-outcome lotteries repeated thrice in a row. As with the design of choice list, we include two types of repeated choice. In certainty repeated choice, subjects choose between a uniform four-outcome lottery and a sure amount. In lottery repeated choice, subjects choose between two uniform four-outcome lotteries. Here, we also consider repeated choice in which one lottery dominates the other. We include four sets of certainty repeated choice and four sets of lottery repeated choice, together with two sets in which one option dominates the other, as summarized in Table 3.

Table 3: Parameters for Repeated Choice in Experiment 1

	Option 1				Option 2			
	25%	25%	25%	25%	25%	25%	25%	25%
Dominance	49	49	49	49	51	51	51	51
	34	34	16	16	34	34	34	34
Certainty Repeated Choice	23	23	30	30	27	27	27	27
	50	50	50	50	16	16	76	76
	12	15	28	33	23	23	23	23
	56	56	56	56	20	28	80	90
Lottery Repeated Choice	19	19	19	39	8	8	47	47
	90	10	90	90	32	44	44	56
	2	21	26	50	13	15	29	34
	12	30	50	80	18	32	38	86

Notes: This table lists the parameters for the 10 repeated choices in experiment 1. For certainty repeated choice, one option is a uniform four-outcome lottery and other is a sure amount. For lottery repeated choice, both options are uniform four-outcome lotteries. Additionally, there are two sets of choices in which one option dominates the other.

In sum, the experiment consists of three main parts: certainty choice list, lottery choice list, and repeated choice. We implement the experiment in a within-subject manner. The order of the three parts and the choice lists within each part are counterbalanced across sessions. Payoffs are displayed in experimental tokens with 2 tokens being worth CNY1 (about USD0.15). After performing the choice tasks, subjects complete a demographic questionnaire and participate in the three-question version of the cognitive reflection test, which measures how reflective participants in the study are with regard to their own mental states

(Frederick, 2005). This test has been found to be correlated with measures of intelligence, risk preference and time preference. At 2.54 (s.e. = 0.053), the overall score in our experiment is on the high end. The compensation is based on one randomly selected choice for each subject.

The experiment was conducted using pen and paper at a lab at Zhejiang University of Technology from November 2017 to January 2018. It consisted of 14 sessions varying from 4 to 22 subjects per session. 184 undergraduates (116 males and mean age 20.6, s.e. = 0.136) were recruited via on-campus advertisement. After arriving at the experimental venue, subjects were given the consent form approved by institutional review board of National University of Singapore and Zhejiang University of Technology. Subsequently, general instructions were read out loud to subjects (see Appendix C for experimental instructions). The experiment lasted about 40 minutes, and subjects on average received CNY34.

3.2 Experiment 2

Experiment 2 is based on a sizable study of the biological basis of decision making conducted between 2010 and 2012. In the experiment, we make use of certainty choice list as in Experiment 1 with the following five lotteries:

- Moderate prospect $(60, 0; 0.5)$ with sure amounts ranging from 15 to 35.
- Moderate hazard $(0, -15; 0.5)$ with sure amount ranging from -8 to -6.4.
- Longshot prospect $(200, 0; 0.01)$ with sure amounts ranging from 0.5 to 9.
- Longshot hazard $(0, -30; 0.98)$ with sure amount ranging from -0.1 to -2.
- Mixed lottery $(30, -16; 0.5)$ with sure amount ranging from -3 to 10.

We further included two certainty choice lists to elicit the certainty equivalents of two compound lotteries:

- Uniform compound lottery: 1/21 chance of receiving 21 simple lotteries $\{(60, 0; p), p = 0, 0.05, 0.1, \dots, 1\}$.
- p-q compound lottery: 5/8 chance of receiving simple lottery $(60, 0; 0.8)$; 3/8 chance of receiving 0.

Note that both compound lotteries reduce to the same simple lottery $(60, 0; 0.5)$. Therefore, comparing the elicited certainty equivalents of the three lotteries enables us to infer for each subject whether RCLA is satisfied for both compound lotteries, for one of the two compound lotteries, or for neither compound lotteries. To allow for choice errors, if the difference in the numbers of choosing the lottery over the sure amount is not more than one between the moderate prospect $(60, 0; 0.5)$ and the compound lottery, we state that RCLA is satisfied.

Finally, we use three lottery choice lists to infer NEU behavior inside a probability triangle with three outcomes of 0, 30 and 60. In the first choice list, subjects choose between a fixed lottery $(60, 30; 0.5)$ and a list of 10 lotteries of the form $(60, 0; p_1)$ with p_1 ranging from 74 percent to 83 percent. In the second choice list, subjects choose between a fixed degenerate lottery δ_{30} and a list of 10 lotteries of the form $(60, 0; p_2)$ with p_2 ranging from 48 percent to 66 percent. In the third choice list, subjects choose between a fixed lottery $(30, 0; 0.5)$ and a list of 10 lotteries of the form $(60, 0; p_3)$ with p_3 ranging from 24 percent to 33 percent. These three choice lists are intended to elicit the 'probability equivalent' of the fixed lottery from which we can infer the slopes of indifference curves passing each of the three fixed lotteries. By examining whether the indifference curves are parallel in the upper (lower) triangle based on the first (latter) two elicited probability equivalents, we measure NEU behavior in terms of the number of instances of violating parallelism in either upper or lower triangle.

We have recruited a cohort of 2066 ethnic Han Chinese undergraduates from Singapore (53 percent female; mean age: 21.4) and an additional cohort of 1181 Han Chinese students was recruited from several universities in Beijing (48.4 percent female; mean age: 21.5). The instructions and procedures were the same (see Appendix C for experimental instructions), except that the both oral and written instructions were in English for Singapore subjects, and in Chinese for Beijing subjects. Moreover, we present the parameters in terms of SGD. The parameter for Beijing subjects are in terms of CNY using a multiple of 4. Subjects participated in 2-hour sessions each comprising a number of decision-making tasks without any feedback followed by performing an IQ test using Raven's Progressive Matrices. All subjects gave written informed consent approved by the Institutional Review Board at the National University of Singapore.

4 Results

4.1 Experiment 1

The subsection provides a summary for observed behavior for choice list and repeated choice at both lottery and individual level. We then examine the relationship between MSB in choice list and switching behavior in repeated choice.

4.1.1 Choice List

For risk attitude in certainty choice list, we count the number of times that the lottery is chosen as a proxy for risk attitude. As the expected value of the lottery corresponds to the median of the 21 sure amounts in the list, choosing lottery 11 times is proximally risk neutral (see Table A1 for summary statistics, and also Figure A1 and A2). In our sample, the average number of lotteries chosen is 7.98, which suggests that subjects are on average risk averse. For lottery choice list, we count the number of times that the "riskier" option is chosen as a proxy for risk attitude. The expected payoff is the same for the two options in the 11th choice of 21 choices. The average number of "risky" options chosen is 7.90, which indicates that subjects are on average risk averse as well.

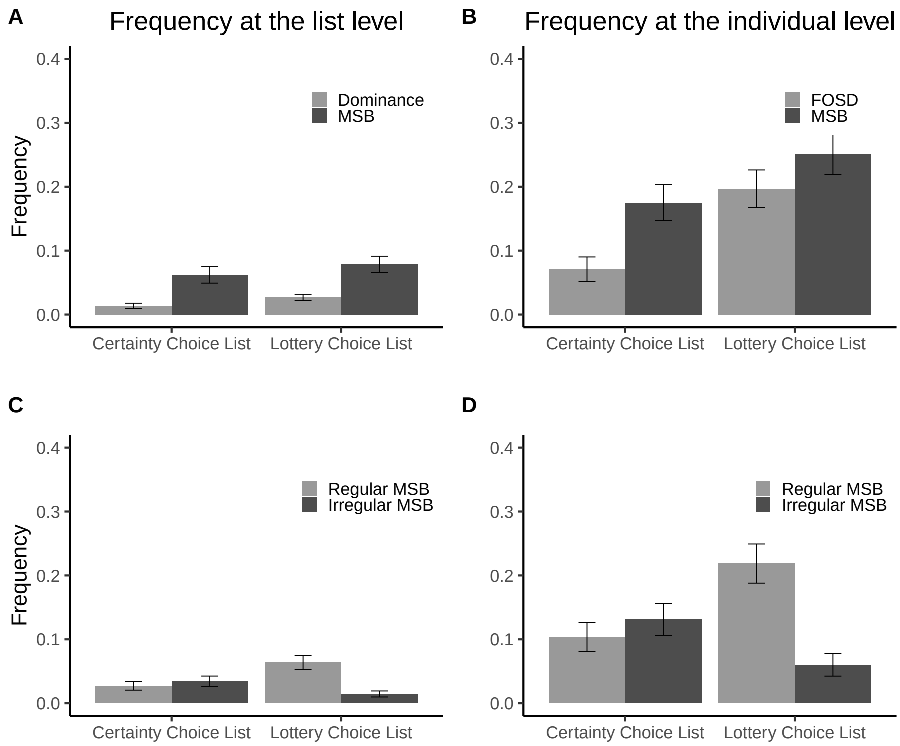
In addition, some of the choices in the choice lists involve dominance. For example, if the lowest (highest) sure amount is lower (higher) than the lower (higher) outcome of the lottery, choosing the sure amount (the lottery) does not respect first-order stochastic dominance. Before we proceed to the results of MSB, we first examine dominance violations in the first or the last of the choice in the choice list. The average frequency of dominance violation is 1.37 percent in certainty choice list and 2.69 percent in lottery choice list at the list level. In the subsequent analysis of MSB, we do not include choices which violate dominance.

Figure 2 presents the frequency of MSB. At the list level, the frequency of MSB is 6.19 percent for certainty choice list and 7.83 percent for lottery choice list (logit regression, z = 1.85, p = 0.06). There is no difference between lotteries with high and low expected value (logit regression, $z = 0.59$, p = 0.554 for certainty choice list; $z = 0.68$, p = 0.496 for lottery choice list). At the individual level, we count the number of the subjects exhibiting MSB at least once or more, and the frequency of MSB is 17.5 percent for certainty choice list and 25.1 percent for lottery choice list. Logit regression shows that the frequency of MSB in lottery choice list is higher than that of certainty choice list at the individual level ($z = 2.42$, p = 0.016).

For the latter part of the analysis, we further classify MSB into two types. For regular MSB, subjects initially choose options on the left and eventually switch to options on the right. The rest, classified as irregular MSB, includes two cases in which subjects start and end with an option on the same side—left or right—and the remaining case of MSB which starts from the right and ends on the left. Note that this latter case includes the possibility of a single switch. Figure 2 presents the frequency of MSB separately for regular and irregular MSB. With respect to certainty choice list, the frequency is 2.73 percent for regular MSB and 3.46 percent for irregular MSB including one instance of irregular single switch at 0.09 percent.[15] For lottery choice list, the frequency is 6.38 percent for regular MSB and 1.46 percent for the irregular MSB with one instance of irregular single switch also at 0.09 percent. For both certainty choice list and lottery choice list, the conditional frequencies of regular

[15]The relative frequencies of these three types of irregular MSB are pooled for simplicity of analysis in tables A3 and A4 for Experiment 1 and Experiment 2 given that each type has relatively small sample size.

Figure 2: MSB in Choice List in Experiment 1



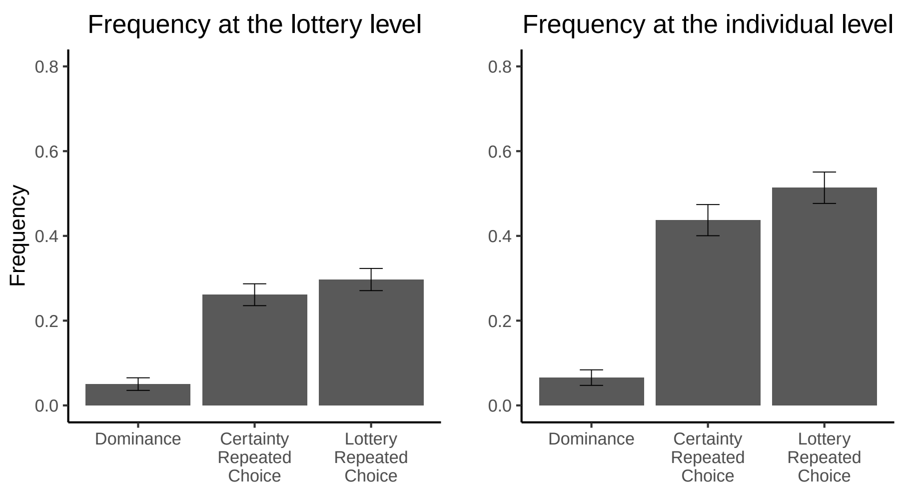
Notes: This figure summarizes the behavior in certainty choice list and lottery choice list in experiment 1. The top panels present the frequency of dominance violation and Multiple Switching Behavior (MSB) at the lottery level (left) and individual level (right) respectively. The bottom panels present the frequency of regular and irregular MSB at the lottery level (left) and individual level (right) respectively. Standard errors of the frequencies are inserted for each bar.

MSB given respectively by 44.1 percent and 81.4 percent each significantly exceeds 1/4 (t-test, certainty choice list: t = 3.2, df = 67, p < 0.002; lottery choice list: t = 13.0, df = 85, p < 0.001). At the individual level, for certainty choice list, the frequency is 10.4 percent for the regular MSB and 13.1 percent for irregular MSB for certainty choice list, and is 21.9 percent for the regular MSB and 6.0 percent for the irregular MSB for lottery choice list. The corresponding conditional frequencies of 44.2 percent and 78.4 percent each exceeds 1/4 significantly (t-test, certainty choice list: t = 2.5, df = 42, p = 0.02; lottery choice list: t = 0.2, df = 50, p < 0.001).

4.1.2 Repeated Choice

Figure 3 presents the frequency of switching behavior and dominance violation in repeated choice. At the lottery level, the average frequency of switching behavior is 26.1 percent for certainty repeated choice, 29.7 percent for lottery repeated choice, and 5.03 percent for dominance violation. The frequency of switching behavior in either case is significantly higher than that of dominance violation (logit regression, z = 6.31, p < 0.001 for certainty repeated choice; z = 7.06, p < 0.001 for lottery repeated choice), and the frequency is not significantly different between certainty repeated choice and lottery repeated choice (logit regression, z = 1.64, p = 0.102). We further check whether the expected value difference between the two options will influence switching behavior and dominance violation, and find no significant correlations in both certainty repeated choice lotteries (logit regression, z = 0.17, p = 0.863) and lottery repeated choice (logit regression, z = 0.81, p = 0.420), and a significant negative relationship between the expected value difference and the frequency of dominance violation (logit regression, z = -2.44, p = 0.015). At the individual level, the switching frequency is 43.7 percent for certainty repeated choice and 51.4 percent for lottery repeated choice, and the frequency is 6.56 percent for dominance violation. Our results show that the observed switching behavior in Agranov and Ortoleva (2017) is robust to different expected values and generalizable to certainty repeated choice in which one of the two options is a sure amount.

Figure 3: Switching Behavior in Repeated Choice in Experiment 1



Notes: This figure presents the frequency of dominance violation and switching behavior in certainty repeated choice and lottery repeated choice at the lottery level (left) and individual level (right) respectively. Standard errors of the frequencies are inserted for each bar.

4.1.3 Linking Choice List and Repeated Choice

Table 4 presents the results from regression analyses linking behaviors in choice list and behaviors in repeated choice at the individual level (see also Figure A3). The dependent variables are the frequencies of MSB, regular MSB, irregular MSB and dominance violation in certainty choice list and lottery choice list, respectively. The independent variables are the frequencies of switching behavior in certainty repeated choice and lottery repeated choice together with dominance violation in the corresponding repeated choice. As each subject responds to 6 choice lists, the number of instants of MSB ranges from 0 to 6. The results in the table are reported using ordered probit regression analysis, and are robust to the usage of linear regression analysis. In the meantime, we include gender, age, scores in the cognitive reflection task as well as the number of lottery chosen to proxy risk attitude as covariates.

Table 4: Linking Choice List and Repeated Choice in Experiment 1

Variables	(1) Pooled MSB in CCL	(2) Pooled MSB in LCL	(3) Regular MSB in CCL	(4) Regular MSB in LCL	(5) Irregular MSB in CCL	(6) Irregular MSB in LCL	(7) FOSD in CCL	(8) FOSD in LCL
Switching Behavior	0.255***	0.219***	0.278***	0.231***	0.134	0.0927	0.0402	−0.0384
	(0.0843)	(0.0739)	(0.0988)	(0.0753)	(0.0938)	(0.120)	(0.126)	(0.0826)
FOSD	0.442*	0.202	0.221	0.0131	0.703***	0.669**	-3.825	0.189
	(0.247)	(0.247)	(0.274)	(0.259)	(0.263)	(0.328)	(332.2)	(0.288)
Gender	-0.491**	-0.329	-0.279	-0.318	-0.681**	-0.411	0.515	0.279
	(0.236)	(0.213)	(0.269)	(0.219)	(0.266)	(0.345)	(0.359)	(0.233)
Age	-0.0951	0.00602	0.0113	-0.0523	-0.162*	0.0946	0.0782	0.0458
	(0.0728)	(0.0569)	(0.0780)	(0.0625)	(0.0874)	(0.0828)	(0.0833)	(0.0548)
CRT	-0.238*	-0.219	-0.0530	-0.148	-0.354**	-0.291	-0.127	0.0250
	(0.144)	(0.134)	(0.178)	(0.138)	(0.154)	(0.216)	(0.191)	(0.158)
Risk attitude	-0.0251	-0.0375	-0.00624	-0.0456	-0.0358	0.00484	0.0122	0.0229
	(0.0434)	(0.0434)	(0.0514)	(0.0452)	(0.0475)	(0.0695)	(0.0501)	(0.0433)
Observations	179	179	179	179	179	179	179	179

Notes: This table presents linear regression results for the behavior in choice-list and the behavior in repeated-choice at the individual level in Experiment 1. Dependent variables are frequencies of the pooled, regular MSB, irregular MSB, and dominance violation in the choice list. The odd columns are for the dependent variables from the certainty choice list (CCL) and the even columns are from the lottery choice list (LCL). Independent variables comprise of the frequencies of switching behavior and dominance violation in repeated choice. The odd columns are the switching behavior from the certainty choice list (CRC) and the even columns are the switching behavior from the lottery choice list (LCL). Control variables are risk attitude and the demographic variables gender, age and scores in cognitive reflection test (CRT). The table reports the regression coefficients with robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

We observe a positive relationship between MSB in certainty choice list (lottery choice list) and switching behavior in certainty repeated choice (lottery choice list) reported in Column 1 (Column 2). In further analysis separating regular MSB and irregular MSB, we observe a positive relationship between regular MSB and switching behavior in repeated choice, but not for dominance violation in repeated choice (Column 3, Column 4). If a subject were to increase the frequency of switching behavior by one point, his/her ordered log-odds of having one more regular MSB would increase by 0.278 in certainty repeated choice and 0.271 in lottery choice list. By contrast, for irregular MSB, we observe an opposite pattern: a positive relationship with dominance violation in repeated choice, but not with switching behavior (Column 5, Column 6). If a subject were to increase the frequency of dominance violation by one point, his/her ordered log-odds of having one more irregular MSB would increase by 0.703 in certainty repeated choice and 0.669 in lottery choice list. Possibly due to the low frequency of dominance violation in choice list, we do not observe significant correlation between dominance violation in choice list and dominance violation in repeated choice (Column 7, Column 8). We further show that the scores in the cognitive reflection task is negatively correlated with irregular MSB in certainty choice list, but not with regular MSB in certainty choice list or either types of MSB in lottery choice list. Taken together, regardless of whether one option is a sure amount or both options are lotteries, regular MSB is linked to switching behavior in repeated choice, while irregular MSB is linked to dominance violation in the repeated choice.

4.2 Experiment 2

This subsection summarizes the frequency of MSB, NEU behavior, and RCLA, and examine their possible links (see Table A2 for summary statistics). For the 5 certainty choice lists, we use the number of lotteries chosen to be a proxy of risk attitude, and find that the percentage of risk aversion is 78.5 percent for moderate prospect, 52.2 percent for longshot hazard, and 81.6 percent for mixed lottery, and the percentage of risk seeking is 67.9 percent for moderate hazard and 63.6 percent of longshot prospect (see Figure A2). This is consistent with the observations in Kahneman and Tversky (1979).

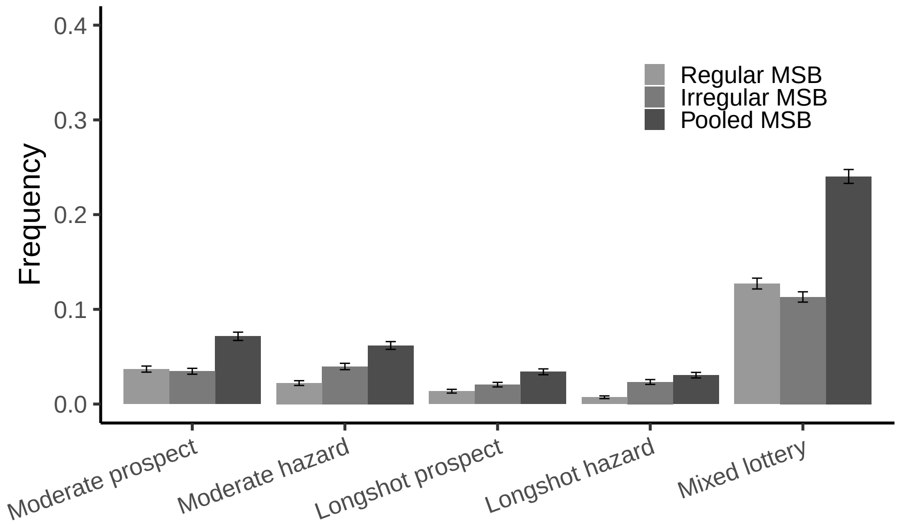
Figure 4 plots the percentage of MSB. For moderate prospect, moderate hazard, longshot prospect, longshot hazard, and mixed lottery, the frequencies of MSB are 7.1 percent (regular: 3.6 %, irregular: 3.4 %), 6.0 percent (regular: 2.1 %, irregular: 3.9 %), 3.4 percent (regular: 1.3%, irregular: 2.0%), 3.0 percent (regular: 0.7%, irregular: 2.3%), and 23.2 percent (regular: 12.3%, irregular: 10.9%), Overall, there is a hump pattern – the MSB frequency for the mixed lottery is more than three times the frequency of MSB for any of the other four lotteries (proportion test, $p < 0.001$). Moreover, the conditional frequency of regular MSB in each case significantly exceeds 1/4 except for that of longshot hazard.[16]

Figure 5 plots the percentage of NEU behavior and RCLA. The frequency of NEU behavior is 73.3 percent in the upper triangle and 71.5 percent in the lower triangle. At the individual level, 56.0 percent percent of the subjects display NEU behavior in terms of exhibiting non-parallel indifference curves in both upper and lower triangles, and 32.7 percent of the subjects exhibit NEU in either upper or lower triangle, and the rest 11.2 percent of the subjects conform with parallelism.[17] The frequency of RCLA is 40.8 percent for uniform

[16]The conditional frequency of regular MSB significantly exceeds 1/4 in moderate prospect (t = 3.3, df = 210, $p < 0.001$), in moderate hazard (t = 3.3, df = 120, p = 0.001), in mixed lottery (t = 16, df = 820, $p < 0.001$), in longshot prospect (t = 3.3, df = 120, p = 0.001), but not in longshot hazard (t = -0.34, df = 100, p = 0.700).

[17]Note that these tests are sufficient but not necessary for identifying NEU behavior as we only obtain

Figure 4: MSB in Experiment 2



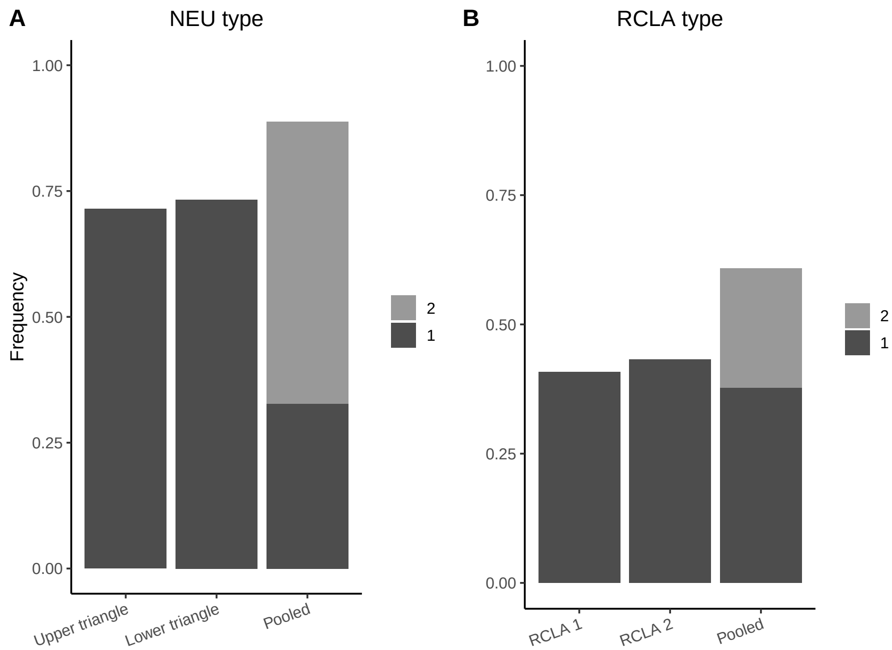
Notes: This figure summarizes the frequency of regular MSB, irregular MSB, overall MSB in five choice lists including moderate prospect, moderate hazard, longshot prospect, longshot hazard and mixed lottery in Experiment 2. Standard errors of the frequencies are inserted for each bar.

compound lottery, and 43.2 percent for *p*-*q* compound lottery. At the individual level, 23.0 percent of the subjects satisfy RCLA for both lotteries, 37.8 percent of the subjects violate RCLA for one of the two lotteries with the rest 39.2 percent violating RCLA for both lotteries.

Table 5 reports the results from ordered probit regression analysis with the frequencies of MSB, regular MSB, irregular MSB in the 5 certainty choice lists as the dependent variables and the frequencies of NEU behavior, RCLA and their interaction term as independent variables (see also Figure A4). The covariates include demographic information of age, squared age, gender, city, parents' education and number of siblings as well as risk attitudes measured in each of the choice lists. We find that the frequency of MSB is positively correlated with NEU behavior (Column 1), but not with RCLA (Column 2) or the interaction term between NEU behavior and RCLA (column 3). We examine regular and irregular MSB separately, and find that the frequency of regular MSB remains positively correlated with NEU behavior (Column 4) and RCLA (Column 5). If a subject were to increase NEU (RCLA) frequency by one point, his ordered log-odds of having more regular MSB would increase by 0.186 (0.066). Moreover, we observe a significant effect of the interaction term between NEU behavior and

two points on the same indifference curve in the probability triangle, and the indifference curve passing the two points may not be a straight line.

Figure 5: NEU behavior and reduction of compound lottery in Experiment 2



Notes: This figure illustrates the individual type of NEU behavior and RCLA. In the left panel, the first two bars represent the frequencies of violating the parallelism of the indifference curve in the upper and lower probability triangle respectively. The third bar presents presents the number of instances of NEU behavior at the individual level. In the right panel, the first two bars represent the frequencies of individual behavior that satisfies RCLA for uniform compound lottery and p-q compound lottery respectively. The third bar presents the number of instances of RCLA satisfaction at the individual level.

RCLA (Column 6). By contrast, the frequency of irregular MSB is marginally correlated with NEU behavior (Column 7), but not with RCLA (Column 8) or the interaction term between NEU behavior and RCLA (Column 9). This suggests that subjects exhibiting NEU and RCLA at the same time are more likely to have regular MSB, but not for irregular MSB. Relevant to the question of whether MSB reflects cognitive ability, we observe that the negative regression coefficient for IQ score is almost double when irregular MSB is compared with regular MSB. This further supports the observation in Experiment 1 that irregular MSB is more likely to be related to choice errors.

Table 5: Linking MSB with NEU and RCLA in Experiment 2

Variables	(1) Pooled MSB	(2) Pooled MSB	(3) Pooled MSB	(4) Regular MSB	(5) Regular MSB	(6) Regular MSB	(7) Irregular MSB	(8) Irregular MSB	(9) Irregular MSB
NEU	0.148***		0.108*	0.186***		0.072	0.077*		0.094
	(0.039)		(0.060)	(0.044)		(0.07)	(0.046)		(0.074)
RCLA		0.0395	-0.014		0.066*	-0.09		0.023	0.041
		(0.03)	(0.08)		(0.037)	(0.08)		(0.039)	(0.093)
NEU × RCLA			0.046			0.126**			-0.018
			(0.050)			(0.05)			(0.06)
IQ	-0.06***	-0.06***	-0.06***	-0.04***	-0.04***	-0.04***	-0.07***	-0.07***	-0.07***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	2,768	2,804	2,749	2,768	2,804	2,749	2,768	2,804	2,749

Notes: This table presents the regression analysis linking MSB with NEU and RCLA in Experiment 2. Dependent variables are the frequency of pooled, regular and irregular MSB. Independent variables are the frequency of NEU, RCLA and their interaction terms. Control variables are scores in IQ, risk attitudes, and demographic information including age, squared age, gender, city, parents' education and number of siblings. The table reports the regression coefficients with robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5 Discussion

This paper adds to the growing literature on stochastic choice in various settings,[18] and contributes to a deeper understanding of the widely reported phenomenon of MSB in the choice-list elicitation risk preference. In both experimental and applied research, MSB is commonly viewed as choice errors signaling low quality decision making. This is corroborated in Jacobson and Petrie's (2009) finding in a rural area of Rwanda that subjects with more MSB are more likely to exhibit sub-optimal financial decisions. Some studies attempt to reduce the frequency of MSB. Tanaka et al. (2010) ask subjects to indicate the row in which they would like to switch from the risky option to the safe option. Bruner (2011) finds that MSB frequency is lower when subjects are provided with verbal instructions emphasizing that only one decision will be randomly picked to determine earnings, compared to those who are only provided with written instructions. Zhang, Yu and Zuo (2018) utilize a novel "nudge" treatment in which MSB subjects are asked to reconsider their choices and find a reduction in MSB frequency with this nudge treatment. In this paper, we stratify the observed MSB patterns into regular and irregular types and find association between irregular MSB and violation of dominance. While this is in line with the view of MSB as choice error, it is also

[18]Experimental evidence on stochastic choice include the early work of Tversky (1969) and subsequent studies including Camerer (1989), Starmer and Sugden (1989), Hey and Orme (1994), Ballinger and Wilcox (1997), Hey (2001), Regenwetter et al. (2011), Regenwetter and Davis-Stober (2012). Some experimental studies directly test the betweenness axiom (See Camerer and Ho, 1994, Feldman and Rehbeck, 2018, and references therein).

compatible with decision makers possessing a random utility.

In contrast, besides not being associated with violation of dominance, regular MSB is positively correlated with switching behavior in repeated choice in Experiment 1 along the line of Agranov and Ortoleva's (2017) observation that 29 percent of their subjects are willing to flip a costly coin to make a randomized decision. We further observe that regular MSB is positively related to subjects' NEU behavior as well as consistency with RCLA in Experiment 2. This suggests that regular MSB may be evidential for deliberate randomization rather than choice error. Additional papers corroborating deliberate randomization include Feldman and Rehbeck (2019) which reports direct evidence of convex preference in the probability triangle, Dwenger, Kübler, and Weizsäcker (2018) which reports choice patterns consistent with preference for randomization in a large dataset for university admissions in Germany, and Levitt (2016) which reports coin flipping by subjects in deciding whether to maintain the status quo in a sizable randomized field experiment.

Besides models with convex preference, the observed behavior in these studies are also compatible with hypotheses relying on the need to minimize regret (Machina, 1985), to achieve multiple goals (Marley 1997), or to hedge across uncertain tastes (Fudenberg, Iijima and Strzalecki, 2015). One additional potential source of deliberate randomization has to do with preference incompleteness. In their axiomatization of expected utility with incomplete preference (Dubra, Maccheroni and Ok, 2004; Galaabaatar and Karni, 2013), two lotteries are non-comparable, i.e., preference is incomplete, if the expected utility of one lottery is not always greater than that of the other lottery according to a set of utility functions.[19] Karni and Safra (2016) further suggest that preference incompleteness may serve as a source of stochastic choice. In a revised choice list, in which subjects are giving an additional randomization option, Cettolin and Riedl (2019) observe that a substantial proportion of subjects choose the randomization option more than once and further that about half of these participants are unwilling to pay a small cost to randomize (consistent with incomplete preferences) and about one third are willing to pay a small cost to do so (consistent with a preference for randomization). Qiu and Di (2019) propose a multiple-self model in which randomization probability reveals the degree of indecisiveness in choices, and provide experimental support of subjects randomizing between two income streams.

Another source of deliberate randomization stems from a "false" sense of diversification. Rubinstein (2002) reports a series of experiments on "false diversification", in which subjects report "diversified" answers leading to violation of dominance. For example, in

[19]Cerreia-Vioglio, Dillenberger, and Ortoleva, 2015 show that cautious expected utility can be derived from a "cautious" completion of an incomplete preference by applying the rule that the decision maker always opts for the certainty if the original (incomplete) relation is unable to compare a lottery with a sure amount.

the well-documented ‘probability-matching’ phenomenon, instead of maximizing the winning probability, subjects choose mixtures of actions in proportion to the probabilities of winning. Relatedly, Eliaz and Fréchette (2008) show that subjects prefer lotteries that pay in multiple states to those paying only in one state, despite the overall distribution being the same. While false diversification and preference incompleteness can both accommodate regular and irregular MSB in choice list and switching behavior in repeated choice, they are silent about the observed link between regular MSB with NEU behavior and RCLA in Experiment 2.

Our finding of the differential roles of regular versus irregular MSB have important implications for research as well as applications relying on the choice-list elicitation of risk preference. While irregular MSB tends to be linked to choice errors or random utility, regular MSB may be informative about the underlying risk preference in terms of deliberate randomization. This suggests that the loss of data in deleting MSB may be partially salvageable by recovering regular MSB using a common practice in the literature—counting the number of lotteries chosen on one side of a choice list as proxy for risk attitude. As exposited in Section 2, this practice may be theoretically grounded and leads naturally to the proportion of irregular MSB and violation of first-order stochastic dominance (if available) as a diagnostic measure of the quality of decision making. Beyond this, it remains an interesting follow-up question how to separate random utility from choice error in irregular MSB in the choice-list elicitation of risk preference.

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Appendix A: Supplementary Tables and Figures

Table A.1: Summary Statistics for Experiment 1

Variables	Mean	SD
Risk attitude (Certainty Choice List)	7.98	2.88
Risk attitude (Lottery Choice List)	7.90	2.47
MSB (Certainty Choice List)	0.062	0.173
MSB (Lottery Choice List)	0.078	0.175
Dominance Violation (Certainty Choice List)	0.014	0.05
Dominance Violation (Lottery Choice List)	0.027	0.07
Switching Behavior (Certainty Repeated Choice)	0.261	0.350
Switching Behavior (Lottery Repeated Choice)	0.297	0.350
Dominance Violation (Repeated Choice)	0.050	0.199
Age	20.6	1.82
Gender (Male = 1)	36%	-
Cognitive Reflection Test	2.54	0.711

Notes: This table summarizes the mean and standard deviation for the key variables of choice-list setting and repeated-choice setting in Experiment 1 and the corresponding demographic information, including sample size, age, gender and score in the cognitive reflection task.

Table A.2: Summary Statistics for Experiment 2

Variables	Mean	SD
Risk attitude (Moderate prospect)	5.11	2.42
Risk attitude (Moderate hazard)	6.42	3.03
Risk attitude (Longshot prospect)	5.63	3.11
Risk attitude (Longshot hazard)	5.52	3.72
Risk attitude (Mixed lottery)	4.80	2.89
MSB (Moderate prospect)	0.072	0.26
MSB (Moderate hazard)	0.062	0.24
MSB (Longshot prospect)	0.034	0.18
MSB (Longshot hazard)	0.031	0.17
MSB (Mixed lottery)	0.24	0.42
NEU	0.888	0.316
RCLA	0.608	0.488
Age	21.3	2.42
Gender (Male = 1)	48.5%	-
IQ	56.3	3.03

Notes: This table summarizes the mean and standard deviation for the key variables for the five certainty choice lists and the corresponding NEU and RCLA behavior in Experiment 2 as well as demographic information, including age, gender and the score measured by Raven's Progressive Matrices.

Table A.3: Frequencies of Irregular MSB in Experiment 1

Condition	Certainty Choice List	Lottery Choice List
Type 1	15.8%	56.2%
Type 2	71.1%	25.0%
Type 3	13.2%	18.8%

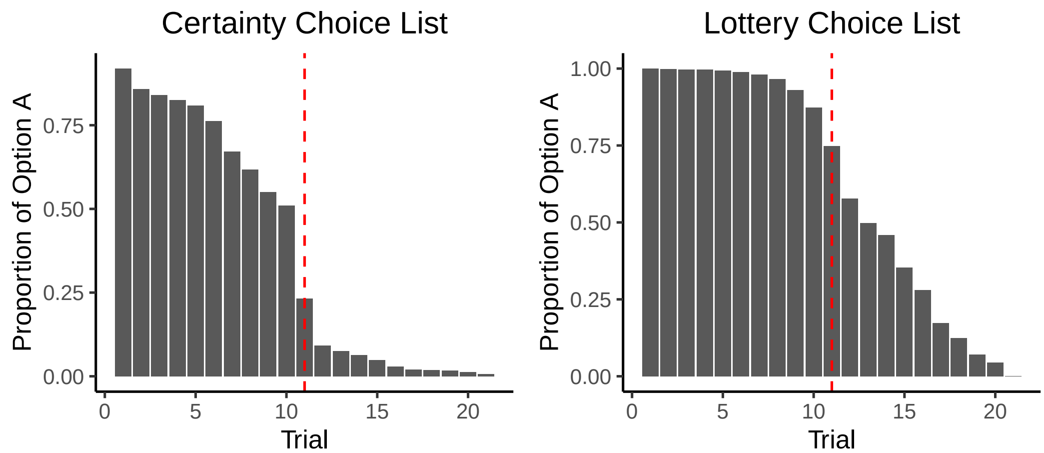
Notes: This table present the frequency of the 3 types of irregular switches in certainty choice list and lottery choice list. Type 1: subjects initially choose the left option, and eventually switch back to the left option; Type 2: subjects initially choose the right option, and eventually switch back to the right option; Type 3: subjects initially choose the right option, and eventually switch to the left option.

Table A.4: Frequencies of Irregular MSB in Experiment 2

Condition	Moderate Prospect	Moderate hazard	Longshot prospect	Longshot hazard	Mixed lottery
Type 1	60.8%	53.7%	53.5%	44.4%	26.3%
Type 2	19.2%	12.5%	21.1%	24.7%	58.9%
Type 3	20.0%	33.8%	25.4%	30.9%	14.8%

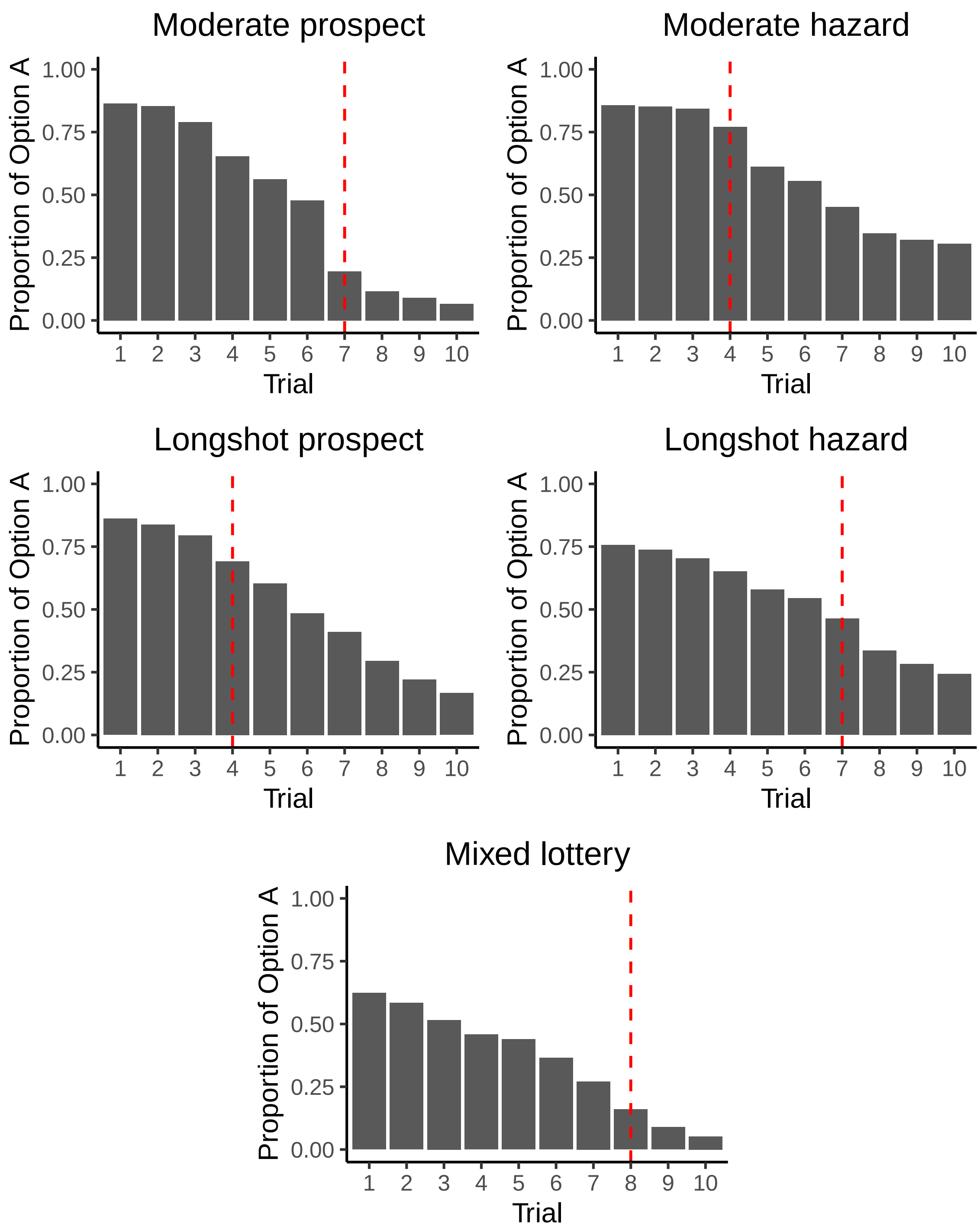
Notes: This table presents the frequencies of the 3 types of irregular MSB in Experiment 2 for the five choice lists. Type 1: subjects initially choose the left option, and eventually switch back to the left option; Type 2: subjects initially choose the right option, and eventually switch back to the right option; Type 3: subjects initially choose the right option, and eventually switch to the left option. For Type 3 irregular MSB, we include the conditional frequencies of single-switch patterns: 10.0 percent (moderate prospect), 9.9 percent (moderate hazard), 17.7 percent (longshot prospect), 17.2 percent (longshot hazard), and 9.1 percent (mixed lottery).

Figure A.1: Risk Attitude in Experiment 1



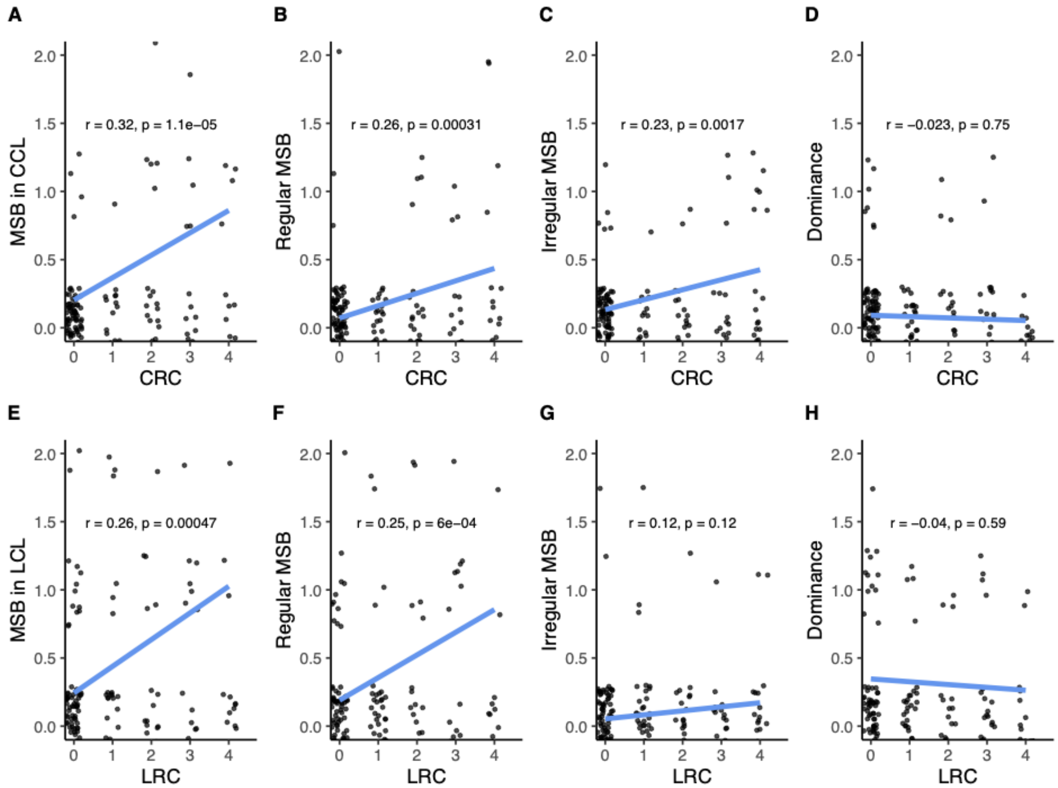
Notes: This figure plots risk attitude in certain choice list and lottery choice list. The x variable is the number of the trials ranging from 1 to 21 in each choice list, the y variable is the proportion of subjects choosing option A in each specific trial pooled across lists and individuals. For the left panel, as the amount of the certainty option B increases, the proportion of subjects choosing the lottery option A decreases accordingly in certainty choice list. For the right panel, as the probability of receiving the larger outcome increases from 0 to 1 at increment 0.05, the proportion of subjects choosing option A (safer option) decreases in lottery choice list. The red dashed line indicates the trial with equal expected value between option A and option B for both choice lists.

Figure A.2: Risk Attitude in Experiment 2



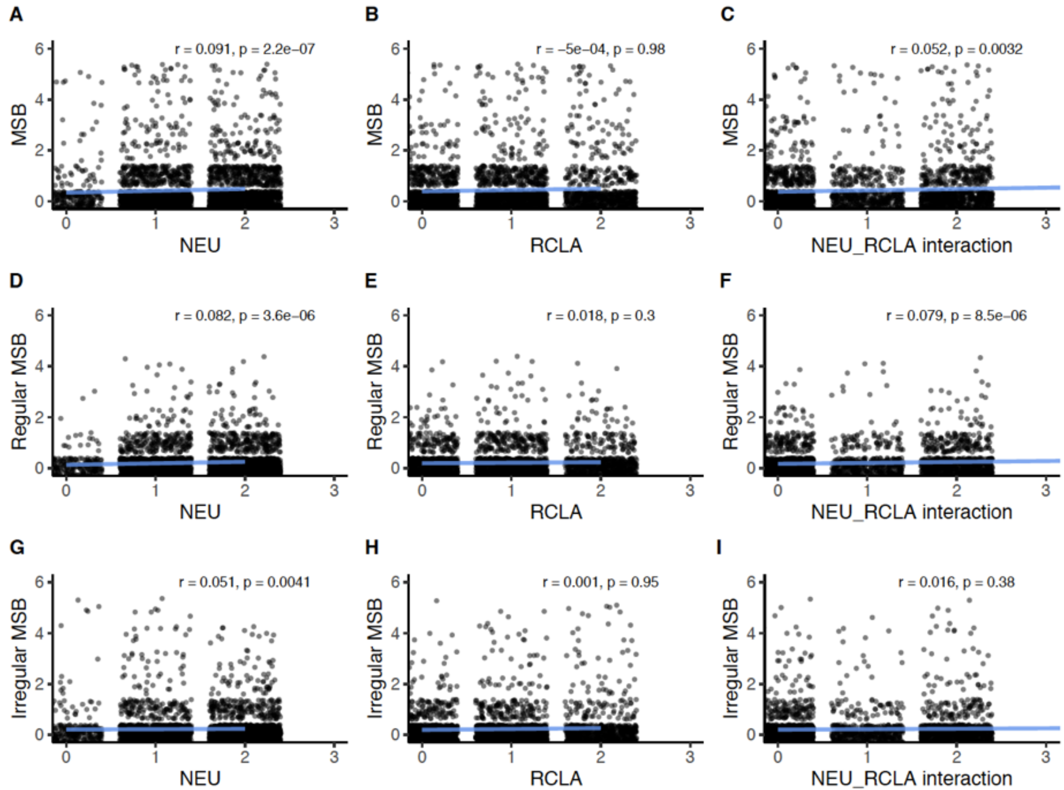
Notes: This figure presents the elicited risk attitude in five certainty choice lists. In a similar spirit with Figure A.1, the x variable is the number of the trials in each choice list, the y variable is the proportion of subjects choosing option A in each specific trial pooled across individuals. In general, as the amount of right option increases, the proportion of subjects choosing option A decreases. For each choice list, the red dashed line indicates the trial with equal expected value between option A and option B.

Figure A.3: Correlation between Behavior in Choice List and Repeated Choice in Experiment 1



Notes: The figure presents the correlation analysis between behavior in choice list and the switching behavior in repeated choice in Experiment 1. Top panel indicates the correlation between certainty repeated choice (CRC) and the pooled, regular, irregular MSB and dominance violation in certainty choice list (CCL). Bottom panel indicates the correlation between lottery repeated choice (LRC) and the pooled, regular, irregular MSB and dominance violation in lottery choice list (LCL).

Figure A.4: Correlation between NEU, RCLA and MSB in Experiment 2



Notes: This figure illustrates correlation between NEU, RCLA and MSB in choice list in Experiment 2. The x variables refer respectively to the degree of NEU, RCLA and the interaction between NEU and RCLA for left, middle and right panel. The y variables refer respectively to the pooled, regular and irregular MSB for the top, middle and bottom panel.

Appendix B: Preference for Randomization for Gains and Losses

Here, we offer a rank-dependent utility model with a concave probability weighting function and a loss-averse utility function to account for the MSB hump pattern: higher frequency of MSB for mixed lottery than that for gain/loss lotteries.

For analytical simplicity, we consider the case of a piecewise linear loss-averse value function with unity slope for the positive portion and $\lambda > 1$ as the slope of the negative portion. Consider a binary choice problem $\left\{\left(H, L; \frac{1}{2}\right), \delta_c\right\}$, where $\left(H, L; \frac{1}{2}\right)$ is an even-chance lottery that can involve only gains, losses, or mixed outcomes. For gain and loss cases, the utility of an α-mixture between the two lotteries is given by:

$$\text{Gain } (H > c > L \geq 0)\text{: } f(\frac{\alpha}{2})H + [f(1-\frac{\alpha}{2}) - f(\frac{\alpha}{2})]c + [1 - f(1-\frac{\alpha}{2})]L,$$
$$\text{Loss } (0 \geq H > c > L)\text{: } \lambda\{f(\frac{\alpha}{2})H + [f(1-\frac{\alpha}{2}) - f(\frac{\alpha}{2})]c + [1 - f(1-\frac{\alpha}{2})]L)\},$$

Similar analysis as that in subsection 2.1 shows that the randomization interval for both the gain and the loss cases is given by:

$$\left(\frac{H+L}{2}, \frac{f'(0)H + f'(1)L}{f'(0) + f'(1)}\right).$$

Let $\frac{f'(1)}{f'(0)} = \delta$, the range of the above interval is translated into:

$$\frac{H+\delta L}{1+\delta} - \frac{H+L}{2} = \frac{1-\delta}{2\left(1+\delta\right)}\left(H-L\right). \tag{B.1}$$

In the mixed case $\{(H', L'; 0.5), \delta_c\}$ where $H' > 0 > L'$, the utilities of α-mixture are given by:

$$\text{Mixed } (H' > 0 \geq c > L')\text{: } f(\frac{\alpha}{2})H' + [f(1-\frac{\alpha}{2}) - f(\frac{\alpha}{2})]\lambda c' + [1 - f(1-\frac{\alpha}{2})]\lambda L',$$
$$\text{Mixed } (H' > c \geq 0 > L')\text{: } f(\frac{\alpha}{2})H' + [f(1-\frac{\alpha}{2}) - f(\frac{\alpha}{2})]c' + [1 - f(1-\frac{\alpha}{2})]\lambda L'.$$

We identify four possible extreme values for the randomization interval as displayed below:

$$\text{Possible upper bounds} \;:\; \frac{f'(0)H' + f'(1)\lambda L'}{f'(0) + f'(1)} \text{ and } \frac{f'(0)H' + f'(1)\lambda L'}{\lambda\,(f'(0) + f'(1))}$$
$$\text{Possible lower bounds} \;:\; \frac{H' + \lambda L'}{2} \text{ and } \frac{H' + \lambda L'}{2\lambda}.$$

This gives rise to three possible randomization intervals as follows:

$$\left(\frac{H' + \lambda L'}{2}, \frac{f'(0)H' + f'(1)\lambda L'}{f'(0) + f'(1)}\right) \text{ if } H + \lambda L > 0, \tag{B.2a}$$
$$\left(\frac{H' + \lambda L'}{2\lambda}, \frac{f'(0)H' + f'(1)\lambda L'}{\lambda\,(f'(0) + f'(1))}\right) \text{ if } f'(0)H + f'(1)\lambda L < 0, \tag{B.2b}$$
$$\left(\frac{H' + \lambda L'}{2\lambda}, \frac{f'(0)H' + f'(1)\lambda L'}{f'(0) + f'(1)}\right) \text{ contains } \{0\}. \tag{B.2c}$$

To compare the randomization intervals across different cases, we further introduce a translation parameter τ to link the gain lottery $(H, L; \frac{1}{2})$ with the mixed lottery $(H', L'; \frac{1}{2})$ where $H' = H - \tau$, and $L' = L - \tau$ and $\tau \in (L, H)$. The ranges of the randomization intervals in the mixed case are given by:

$$\frac{H - \tau + \delta\lambda\,(L - \tau)}{1 + \delta} - \frac{H - \tau + \lambda\,(L - \tau)}{2} = \frac{1 - \delta}{2\,(1 + \delta)}\,(H - \tau - \lambda(L - \tau)) \tag{B.3a}$$
$$\frac{H - \tau + \delta\lambda\,(L - \tau)}{\lambda\,(1 + \delta)} - \frac{H - \tau + \lambda\,(L - \tau)}{2\lambda} = \frac{1 - \delta}{2\lambda\,(1 + \delta)}\,(H - \tau - \lambda(L - \tau)) \tag{B.3b}$$

Since $H > \tau > L$, we have that (B.3a) > (B.1) > (B.3b). Notice that for the randomization interval to admit the form of (B.2b), the parameter τ needs to satisfy $H - \tau + \delta\lambda\,(L - \tau) < 0$. This delivers a lower bound of $\frac{H + \delta\lambda L}{1 + \delta\lambda}$ for τ. Comparing the ranges of the intervals in (B.2c) and (B.1), their difference is given by:

$$\begin{aligned}
&\frac{1 - \delta}{2\,(1 + \delta)}\,(\lambda - 1)\,(\tau - L) - \left(\frac{1}{\lambda} - 1\right)\frac{H - \tau + \lambda\,(L - \tau)}{2} \\
&= \left(\frac{1 - \delta}{2\,(1 + \delta)} - \frac{1}{2}\right)(\lambda - 1)\,(\tau - L) - \left(\frac{1}{\lambda} - 1\right)\frac{H - \tau}{2}.
\end{aligned}$$

This difference is positive if $H - \tau > \frac{2\delta\lambda}{1+\delta}\,(\tau - L)$. Recall that for the randomization interval to admit the form of (B.2c), we need to have:

$$\lambda\,(t - L) > H - \tau > \delta\lambda\,(\tau - L)\,.$$

Since $\delta < 1$, the range of (B.2c) exceeds that of (1) if the following holds

$$\lambda\left(\tau - L\right) > H - \tau > \frac{2\delta\lambda}{1+\delta}\left(\tau - L\right).$$

In summary, we have the randomization interval for a mixed lottery $(H - \tau, L - \tau; \frac{1}{2})$ being greater than that for a gain lottery $(H, L; \frac{1}{2})$ or a loss lottery $(-H, -L; \frac{1}{2})$ if:

$$\tau \in \left(L, (H + \frac{2\delta\lambda}{1+\delta}L)/(1 + \frac{2\delta\lambda}{1+\delta})\right). \tag{B.4}$$

Observe that for δ small, the above constitutes a large proportion of the interval (L, H) and converges to the full interval in the limit as $\delta \to 0$. This implies that there are parameter values such that a quasiconcave rank-dependent utility with a piecewise linear loss-averse value function would exhibit a hump pattern in MSB for the mixed lotteries compared to the gain and the loss lotteries in Study 1.

Proposition. *Under rank-dependent utility with f concave and piecewise linear utility with loss aversion parameter $\lambda > 1$, the size of its randomization interval exhibits a hump pattern if* the translation parameter τ satisfies condition (B.4).

Appendix C: Experimental Instructions

Experiment 1

STAGE 1 GENERAL INSTRUCTIONS

Thank you for participating in our decision making experiment. The descriptions of the study contained in this experimental instrument will be implemented fully and faithfully. All information will be kept confidential. The information provided by you in this experiment including your personal information, decisions and earnings will be used for research purpose only. At the 1st stage of the experiment, you need to complete a series of decision-making tasks under risk. The illustrative decision tasks are shown as in the table below:

	Option A	Option B	Decision
1	A1	B1	A ☐ B ☐
2	A2	B2	A ☐ B ☐
3	A3	B3	A ☐ B ☐
4	A4	B4	A ☐ B ☐
5	A5	B5	A ☐ B ☐
6	A6	B6	A ☐ B ☐
7	A7	B7	A ☐ B ☐
8	A8	B8	A ☐ B ☐
9	A9	B9	A ☐ B ☐
10	A10	B10	A ☐ B ☐
11	A11	B11	A ☐ B ☐
12	A12	B12	A ☐ B ☐
13	A13	B13	A ☐ B ☐
14	A14	B14	A ☐ B ☐
15	A15	B15	A ☐ B ☐
16	A16	B16	A ☐ B ☐
17	A17	B17	A ☐ B ☐

18	A18	B18	A □ B □
19	A19	B19	A □ B □
20	A20	B20	A □ B □
21	A21	B21	A □ B □

In this case, you need to make 10 decisions (between A1 and B1, A2 and B2…between A10 and B10). Each decision has two options to choose from (option A, option B), and you can check either option A on the left or option B on the right with a tick **(√).**

Your income consists of the following parts: you will first receive 15 RMB as the show-up fee. There are 12 decision tables in this experiment, and each table has 10 choices. After completing the whole experiment, we will randomly select a decision option from all the choices you have made to calculate your final benefits. One half of the amount of each experimental coin in the table corresponds to the actual amount of RMB. That is, if you end up getting X from the choices, you end up with 15+ (X/2). Determine your final return based on the return of the selected option and your choice.

Please begin now: During the experiment, if you have any questions, please raise your hand and the experimenter will answer your questions individually.

Sample Decision Sheet

	Option A	Option B	Decision
1	50% chance of receiving 40 and 0	100% chance of receiving 10	A □ B □
2	50% chance of receiving 40 and 0	100% chance of receiving 11	A □ B □
3	50% chance of receiving 40 and 0	100% chance of receiving 12	A □ B □
4	50% chance of receiving 40 and 0	100% chance of receiving 13	A □ B □
5	50% chance of receiving 40 and 0	100% chance of receiving 14	A □ B □
6	50% chance of receiving 40 and 0	100% chance of receiving 15	A □ B □
7	50% chance of receiving 40 and 0	100% chance of receiving 16	A □ B □
8	50% chance of receiving 40 and 0	100% chance of receiving 17	A □ B □
9	50% chance of receiving 40 and 0	100% chance of receiving 18	A □ B □
10	50% chance of receiving 40 and 0	100% chance of receiving 19	A □ B □
11	50% chance of receiving 40 and 0	100% chance of receiving 20	A □ B □
12	50% chance of receiving 40 and 0	100% chance of receiving 21	A □ B □
13	50% chance of receiving 40 and 0	100% chance of receiving 22	A □ B □
14	50% chance of receiving 40 and 0	100% chance of receiving 23	A □ B □
15	50% chance of receiving 40 and 0	100% chance of receiving 24	A □ B □
16	50% chance of receiving 40 and 0	100% chance of receiving 25	A □ B □
17	50% chance of receiving 40 and 0	100% chance of receiving 26	A □ B □
18	50% chance of receiving 40 and 0	100% chance of receiving 27	A □ B □
19	50% chance of receiving 40 and 0	100% chance of receiving 28	A □ B □
20	50% chance of receiving 40 and 0	100% chance of receiving 29	A □ B □
21	50% chance of receiving 40 and 0	100% chance of receiving 40	A □ B □

STAGE2 GENERAL INSTRUCTIONS

Welcome to our study on risk decision making. In this part of the experiment, you have to choose between a series of two options. For each choice, two options are located on the left and right sides of the same row, each option contains four equal or unequal amounts, and each amount has the same probability, a quarter. For each of the left and right options selected, you can select by checking the box with a tick (√). Here's an example of an option that looks like this:

Option one ( )	5	30	80	95	Option two ( )	1	15	87	98

In option one, you have 25% chance of receiving 5, 25% chance of receiving 30, 25% chance of receiving 80, 25% chance of receiving 95. In option two, you have 25% chance of receiving 1, 25% chance of receiving 15, 25% chance of receiving 87, 25% chance of receiving 98. You can select an option by putting a tick in the bracket () of the option. There are 10 decision problems in this section. Each page contains three options for the same decision question, and you need to make a choice for each one.

As mentioned above, after completing the whole experiment, we will randomly select a decision option from all the choices you have made to calculate your final benefits. One half of the amount of each experimental coin in the table corresponds to the actual amount of RMB. That is, if you end up getting X from the choices, you end up with 15+ (X/2). Determine your final return based on the return of the selected option and your choice.

Please begin now: During the experiment, if you have any questions, please raise your hand and the experimenter will answer your questions individually.

Sample Decision Sheet

Question 1

Option one ( )	49	49	49	49	Option two ( )	51	51	51	51

Experiment 2

GENERAL INSTRUCTIONS

Welcome to our study on decision making. The descriptions of the study contained in this experimental instrument will be implemented fully and faithfully.

You will go through 3 stages in this study. Stage 1 (i.e., today) is a 2-hour study consisting of 3 sets of tasks. The first set comprises 19 individual decision making tasks. The second set is made up of 11 decision making tasks involving other participants in another study. The third set consists of a questionnaire.

Stage 2 is an online study involving both decision making tasks and questionnaires. After completing stage 2, you will be emailed a link where you can sign up for a 30-minute time slot for Stage 3 that will be held a week later. You will receive your overall compensation during Stage 3.

Each participant will receive on average $80 for participation in the study. Your actual compensation includes a $35 show up fee in addition to earnings and losses based on how you and others make decisions.

All information provided will be kept CONFIDENTIAL. Information in the study including your personal information as well as your decisions will be used for research purposes only.

1. The set of decision making tasks and the instructions for each task are **the same** for all participants. Please refrain from discussing with anyone any aspect of the specific tasks during or after the study.
2. **This experimental instrument is printed double-sided. Please go through the instructions carefully** to understand the tasks fully and make informed decisions.
3. **At any time**, if you have questions, please raise your hand**.**
4. **Please do not communicate** with other participants during the experiment.
5. Cell phones and other electronic devices (except for calculator functions) are **not allowed**.
6. Today's session, i.e., Stage 1, will last about two hours.

This concludes the general instructions. Please go through the subsequent instructions by yourself and make your decisions carefully. Please raise your hand if you have questions.

GENERAL INSTRUCTIONS

This set comprises 19 decision sheets. The first 16 sheets are of the form illustrated in the table below.

	Option A	Option B	Decision
1	A	B1	A ☐ B ☐
2	A	B2	A ☐ B ☐
3	A	B3	A ☐ B ☐
4	A	B4	A ☐ B ☐
5	A	B5	A ☐ B ☐
6	A	B6	A ☐ B ☐
7	A	B7	A ☐ B ☐
8	A	B8	A ☐ B ☐
9	A	B9	A ☐ B ☐
10	A	B10	A ☐ B ☐

Each such table lists 10 choices to be made between a fixed Option A and 10 different Option B's arranged in an ascending manner in terms of value either in the amount of money (Decision Sheets A1 – A13) or in the probability of receiving a higher money outcome (Decision Sheets A14 – A16). For each row, you are asked to indicate your choice in the final "Decision" column – A or B – with a tick **(√).**

Decision Sheets A17 and A18 each involves one choice. The last Decision Sheet (A19) involves 20 choices.

Selection of decision sheet to be implemented: One out of the first 18 Decision Sheets (selected randomly by you) will be implemented. Should the chosen sheet be from the first 16 decision sheets, one of your 10 choices will be further selected randomly and implemented.

For Decision Sheet A19, to determine whether to implement your decision, you can either guess a number from 00 to 99 or use the last 2-digits of your NRIC/FIN. If your number is the same as the result of tossing a 10-sided die twice consecutively, then one of your 20 choices will be randomly selected and implemented. You may now begin.

At any time during the study, should you have questions, please raise your hand. An experimenter will come to you and answer your questions individually.

Sample Decision Sheet

This situation involves your guessing the color – red or black – of a card drawn randomly from a deck of 20 cards, comprising 10 black cards and 10 red cards.

Option A: You guess the color – black or red – and then draw a card from the deck of 20 cards. If you make a correct guess, you receive $60; otherwise, you receive nothing. That is: **50% chance of receiving $60 and 50% chance of receiving $0.**

The Option B column lists 10 amounts (displayed in an ascending manner) each corresponding to what you will receive for sure if you choose this option.

DECISION: For each of the 10 rows, please indicate your decision in the final column with a tick (√).

	Option A	Option B	Decision
1	50% of receiving $60, 50% of receiving $0	Receiving $15 for sure	A □ B □
2	50% of receiving $60, 50% of receiving $0	Receiving $19 for sure	A □ B □
3	50% of receiving $60, 50% of receiving $0	Receiving $23 for sure	A □ B □
4	50% of receiving $60, 50% of receiving $0	Receiving $25 for sure	A □ B □
5	50% of receiving $60, 50% of receiving $0	Receiving $27 for sure	A □ B □
6	50% of receiving $60, 50% of receiving $0	Receiving $29 for sure	A □ B □
7	50% of receiving $60, 50% of receiving $0	Receiving $30 for sure	A □ B □
8	50% of receiving $60, 50% of receiving $0	Receiving $31 for sure	A □ B □
9	50% of receiving $60, 50% of receiving $0	Receiving $33 for sure	A □ B □
10	50% of receiving $60, 50% of receiving $0	Receiving $35 for sure	A □ B □