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Multiple-switching behavior in choice-list elicitation of risk preference ☆

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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 find 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 concurrently exhibit non-expected utility behavior and reduce compound lottery, and to deliberately randomize in repeated choice. 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.

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1. Introduction

Choice list is a common method to elicit risk preference in experimental economics and applied research. In an influential paper, Holt and Laury (2002) popularize one specific form of choice list in which subjects need to make a number of choices between two binary lotteries. In their list, the two lotteries arranged in two columns have fixed outcomes (H, L) and $\left(H', L'\right)$ with $H' > H > L > L'$. As the subjects move from the top to the bottom of the list, the probability p of receiving H and H' in the two lotteries increases simultaneously from 0 to 1, so that 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 (when p is low) and switch to options on the right (when p is high) 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 proxy 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). In a recent study, Filippin and Crosetto (2016) find an average MSB frequency of 14.3 percent across 41 studies.

On the surface, MSB seems puzzling since it involves choosing a right-hand option earlier in a list and switching to the left-hand option subsequently as the right-hand option becomes more attractive. Yet, MSB is commonly observed in the experimental as well as applied literature adopting choice-list elicitation. Reflecting the prevalent view of MSB as choice error, Charness et al. (2013) write, "*such inconsistent behavior is difficult to rationalize under standard assumptions on preferences*", and suggest that MSB can be a manifestation of violation of first-order stochastic dominance or transitivity. This view is reflected in several practices in the experimental and applied literature to deal with MSB, e.g., deleting observations with MSB, training subjects to reduce the frequency of MSB, and forbidding MSB through the response mode.

Despite its prevalence, little has been done to arrive at a more comprehensive understanding of MSB. Founded in theory, this paper experimentally investigates MSB from two perspectives on stochastic choice, and suggests a method to improve diagnosis of decision making quality. One perspective views choice as inherently harboring a stochastic component, as the underlying attention and perception involve a continual and unconscious process to optimize the brain's metabolic load. "Random utility" represents one direction in this literature. In Luce (1959), the probabilities of choosing different options are proportional to their relative appeal. 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.[1]

Another perspective views choice stochasticity as being *deliberate* 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. When randomization is not explicitly given as an option in the choice set, Machina (1985) argues that decision maker may consider the convex hull of all the options as the implicit choice set and choose the optimal probabilistic mixture among the options. In this regard, the decision maker would exhibit choice stochasticity

[1] Additional models include Marschak (1960), McFadden (2001), Gul and Pesendorfer (2006), Ahn and Sarver (2013), Manzini and Mariotti (2014), Fudenberg et al. (2015), Gul et al. (2014), among others.

when preference is deterministic and convex. Such preferences depart from expected utility and satisfy implicitly the reduction of compound lottery axiom (RCLA)—being indifferent between a compound lottery and its reduction to a simple lottery. Deliberate randomization may also be driven by the need to minimize regret (Machina, 1985; Dwenger et al., 2018), achieve multiple goals (Marley, 1997), and hedge across uncertain tastes (Fudenberg et al., 2015). Cerreia-Vioglio et al. (2019) refer to stochastic choice generated by convex preference as deliberate randomization, and discuss properties of the stochastic choice functions generated from different channels, including random utility and convex preference.[2]

In this paper, we begin with the theoretical observation that subjects can exhibit MSB in a choice list by deliberately randomizing between pairs of choices. In this connection, we propose a behavioral classification of MSB into 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. As the right option always becomes increasingly attractive compared to the left option in a choice list, we hypothesize that regular MSB is more likely to be caused by deliberate randomization compared with irregular MSB. By contrast, irregular MSB may arise from inherent stochastic choice and is more in line with the choice error interpretation in the literature. We examine whether MSB is a manifestation of inherent stochastic choice versus deliberate randomization in two experiments.

Our Experiment 1 is based on the observation that for deliberate randomization to generate MSB, it necessitates non-expected utility (NEU) behavior and conformance to RCLA. In the experiment, we adopt five choice lists to elicit the certainty equivalents for five lotteries that vary in probabilities and outcomes, and examine the corresponding frequencies of MSB. At the same time, we include choice tasks in the setting of a probability triangle and examine whether subjects exhibit NEU behavior and two compound lotteries along with their reduced lottery to examine whether they conform to RCLA.

We observe an interesting hump pattern in the observed frequencies of MSB when moving from the gain domain to the mixed domain, and then to the loss domain: the MSB frequency for the mixed lottery over gains and losses is 23.2 percent, more than three times higher than the MSB frequencies other lotteries with pure gains or pure losses. We find that subjects with more regular MSB are more likely to satisfy RCLA and exhibit NEU behavior concurrently. In contrast, we do not observe such a link for irregular MSB. The overall message from these findings suggests that regular MSB, compared to irregular MSB, is more likely to be a manifestation of deliberate randomization involving convex preference.

To examine in detail whether and how MSB may be linked to deliberate randomization versus inherent choice stochasticity, our Experiment 2 utilizes 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 repeated thrice in a row and only one of the three pairs will be implemented.

[2] 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 et al., 1991), maxmin expected utility (Cerreia-Vioglio, 2009) and cautious expected utility (Cerreia-Vioglio et al., 2015) can exhibit convexity.

Agranov and Ortoleva (2017) argue that the observed switching behavior is not likely to arise from random utility or choice error and that it supports the notion of deliberate randomization. We extend Agranov and Ortoleva's (2017) argument and show that deliberate randomization 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 2 to examine the potential link between MSB in choice list and switching behavior in repeated choice.

Experiment 2 includes 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.[3] With regard to certainty choice list, its appearance can be traced to Cohen et al. (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.

We observe that the frequency of MSB is 6.2 percent in certainty choice list, and 7.8 percent in lottery choice list. The frequencies for switching behavior are 26.1 percent in lottery repeated choice and 29.7 percent in certainty repeated choice. 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 the repeated choice setting. By comparison, irregular MSB in certainty choice list (lottery choice list) is not significantly correlated with switching behavior in certainty repeated choice (lottery repeated choice), but it is significantly correlated with dominance violations in the repeated choice setting. Overall, these results corroborate our findings in Experiment 1—regular MSB is linked to deliberate randomization along with switching behavior in repeated choice, and further suggest that irregular MSB is more likely to result from choice error.

Our findings shed light on different perspectives of stochastic choice underpinning MSB. The observed correlation between RCLA and NEU behavior with regular MSB but not with irregular MSB in Experiment 1 lends support to regular MSB as a result of deliberate randomization arising from convex preference. This is further supported by the observed association between regular MSB and switching behavior in repeated choice in Experiment 2, given that inherent stochastic choice, which encompasses random utility or choice error, are in general incompatible with switching behavior in repeated choice as pointed out in Agranov and Ortoleva (2017). Moreover, given its association with dominance violation, irregular MSB seems more in line with the popular view of MSB as reflecting choice error.

These observations from our two experiments are correlational and do not directly separate genuine preference from choice error. To address this question further, we make use of an existing data set from Yu et al. (2021), which propose a simple nudge treatment by asking subjects to reconsider their choices in the choice-list elicitation of risk preference. In a between-subject design, they find that MSB is substantially reduced by 21 percent from 31 percent in the standard

[3] 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 et al. (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.

protocol to 10 percent in the nudge protocol. After classifying MSB in their experimental data in terms of "regular" versus "irregular", we find among the observed 21 percent reduction in MSB, 14.4 percent are from irregular MSB and 6.5 percent are from regular MSB. This result of re-analyzing the nudge effect in Yu et al. (2021) provides further support for our interpretation of regular MSB as being linked to deliberate randomization while irregular MSB more likely reflects choice error.

Our findings contribute to the experimental literature and have direct implications in relation to the common practice of grouping MSB data together with dominance violation as choice error. Given the correlation between regular MSB with both NEU behavior and RCLA, it seems sensible to treat regular MSB as part of the elicited choice data reflecting underlying convex preference. With the correlation between irregular MSB and dominance violation, grouping them together gives rise 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.

Our study sheds light on stochastic choice models. First, our general findings provide support for the empirical relevance of deliberate randomization and reveal significant incidence of deliberate randomization in the setting of choice-list elicitation of risk preference (Machina, 1985; Cerreia-Vioglio, 2009; Cerreia-Vioglio et al., 2019). In particular, while alternative approaches including preference incompleteness and false diversification can help explain regular MSB, they are silent on our observed link between regular MSB with NEU behavior and RCLA in Experiment 1. Second, our findings have further implications on existing models of convex preference. Given that we continue to observe MSB and switching behavior in repeated choice when one option in a binary choice is deterministic, we can reject cautious expected utility model (Cerreia-Vioglio et al., 2015) in favor of globally convex models, including rank-dependent utility (Quiggin, 1982) and quadratic utility (Chew et al., 1991). In addition, we demonstrate in an appendix how one convex preference model, based on 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.

2. Theoretical background

This section provides the theoretical background of our experiments. We are concerned with a pair of lotteries, denoted by F and G, which are distributions on the set of monetary outcomes X. In the sequel, we first discuss different classes of models that can generate stochastic choice in a binary choice problem denoted by $\{F, G\}$, and show whether and how different types of stochastic choice connect with MSB in choice list and switching behavior in repeated choice. Finally, we discuss briefly the random incentive system.

In deterministic models, choice stochasticity arises if a decision maker prefers randomizing between the two lotteries to choosing each one of the lotteries for sure. Notice that randomization between F and G delivers a probability mixture of the two lotteries: $\alpha F + (1 - \alpha) G$, where α is the probability of choosing F. Under expected utility, if F is strictly preferred to G, it is also preferred to any probability mixture $\alpha F + (1 - \alpha) G$—a direct implication of Independence axiom. In fact, expected utility belongs to a broader class of models of decision making under risk, named *betweenness* models. Models in this family (Chew, 1983, 1989; Dekel, 1986; Gul, 1991) all satisfy the betweenness axiom that requires any probability mixture of lotteries F and G

to be intermediate in preference between the two respective lotteries. It follows that betweenness models cannot generate deliberate randomization in $\{F, G\}$ unless $F \sim G$.

Convex preference models A number of non-betweenness utility models, e.g., rank-dependent utility (Quiggin, 1982), quadratic utility (Chew et al., 1991) and cautious expected utility (Cerreia-Vioglio et al., 2015) can display convexity and hence be compatible with deliberate randomization in $\{F, G\}$ even if F is preferred to G.[4] For example, rank-dependent utility can exhibit global convexity if its probability weighting function is not pessimistic (Chew et al., 1987). Under cautious expected utility, preferences are in general convex except for degenerate lotteries.[5] It follows that cautious expected utility is incompatible with deliberate randomization in $\{F, G\}$ when F or G is degenerate unless $F \sim G$.

In the above analyses, reduction of compound lottery axiom (RCLA) is an implicit assumption. Specifically, randomizing between F and G produces a compound lottery $(F, G; \alpha)$ that delivers F with probability α and G with $1-\alpha$, which is assumed to reduce to a simple lottery $\alpha F + (1-\alpha) G$. In this regard, randomization has an instrumental value in delivering the desired simple lottery, rather than a procedural value per se.[6] A final remark is that the deterministic models considered here all respect dominance.

Models incorporating randomness When one incorporates random components into a utility model, choice stochasticity may also arise. For example, the widely used random utility model directly associates the utility of a lottery with an additive noise term: $U(F)+\epsilon_F$ and $U(G)+\epsilon_G$. In contrast, the random preference model proposes that the randomness is associated with preference parameters. Eliashberg and Hauser (1985) consider a random expected utility model where that the randomness is associated with the CRRA parameters: $\int x^{\rho+\epsilon} dF(x)$ and $\int x^{\rho+\epsilon} dG(x)$.[7] Both types of models are able to generate choice stochasticity given different realizations of the respective random component in their specifications. Choice stochasticity may also arise from perceptual noise in the decision process through randomness in the perceived probabilities or valuations of outcomes (e.g., Enke and Graeber, 2019; Khaw et al., 2021).[8]

[4] See Cerreia-Vioglio (2009) for a general class of convex preference models. The Kőszegi and Rabin (2007) model, shown by Masatlioglu and Raymond (2016), is the intersection of rank-dependent utility and quadratic utility and hence can also exhibit convexity. In Appendix B.1, we exemplify how convex preference models, including rank-dependent utility and quadratic utility, can generate choice stochasticity when choosing between a binary lottery and a degenerate lottery. In Appendix B.2, we further 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).

[5] This is a direct implication of the negative certainty independence axiom that characterizes cautious expected utility (see Cerreia-Vioglio et al., 2015).

[6] Should RCLA fail, the compound lottery would be evaluated differently from the reduced simple lottery, by adopting a recursive specification (e.g., Kreps and Porteus, 1978; Segal, 1987). When evaluating a compound lottery $(F, G; \alpha)$ in a recursive model, the certainty equivalents, c_F and c_G, of the stage-2 lotteries F and G, are first evaluated followed by the compound lottery being evaluated as a stage-1 simple lottery $(c_F, c_G; \alpha)$. It follows that randomization generates a first-order stochastic dominated lottery at stage-1 under recursive models.

[7] Block and Marschak (1960) and Loomes and Sugden (1995) consider a general model with a distribution μ on a set of preference orderings $\mathcal{P}$, and the probability of choosing F in $\{F, G\}$ equals $\mu\left\{\succeq_p \in \mathcal{P} : F \succeq_p G\right\}$. Recent developments of random expected utility include Gul and Pesendorfer (2006), and Apesteguia and Ballester (2018), among others.

[8] Another source of randomness in decision making arises from the inherently stochastic nature of limited attention. This has been modeled in an emerging literature involving random consideration sets (Manzini and Mariotti, 2014;

For models incorporating randomness/errors, a differentiation may arise from considering dominance violation. Random utility model can generate a non-zero probability of choosing the dominated lottery. Similarly, for those models involving perceptual noise, it is also possible for the decision maker to choose a dominated lottery with positive probability given the noise in perceived probability or valuation (e.g., Enke and Graeber, 2019; Khaw et al., 2021) are of full support. In contrast, random expected utility respects dominance and does not generate incidence of choosing a dominated lottery.[9]

We proceed to derive the predicted behavioral patterns of different theories in the choice-list setting and the repeated-choice setting. Naturally, if a subject exhibits choice stochasticity in binary choice $\{F, G\}$, it is possible for her to exhibit (1) MSB in a choice-list setting in which one (or both) of the options keeps changing and, (2) switching behavior in the repeated-choice setting in which she needs to make a binary choice between F and G three times consecutively. Moreover, Agranov and Ortoleva (2017) observe that it is unlikely for the decision maker to experience multiple utility shocks as she moves from one choice to another identical choice in the repeated-choice setting. Therefore, only convex preference models, rather than models incorporating randomness/errors, can account for the observed switching behavior in a repeated-choice setting. In contrast, as the decision maker makes successive distinct choices in a choice-list setting, fresh shocks may occur. As such, both convex preference models and models involving randomness/choice error can generate MSB in the choice-list setting. In sum, we arrive at the following two main predictions regarding the nature of MSB.

Prediction 1. *Decision maker with convex preference can exhibit MSB in choice list and switching behavior in repeated choice. At the same time, the decision maker would exhibit non-expected utility behavior and conform to RCLA, but not violate dominance.*

Prediction 2. *Decision maker with random utility can exhibit MSB in choice list and dominance violation concurrently, but not switching behavior in repeated choice.*

In testing Predictions 1 and 2, while we can not tell exactly which proportion of MSB arises from convex preference, we can examine the correlation between the observed MSB and NEU $\times$ RCLA, as well as the switching behavior in repeated choice. The finding of a positive correlation would provide evidence for (some of) the observed MSB arising from convex preference. Nevertheless, it remains a challenge as to how one could discern MSB generated by convex preference from MSB generated by choice errors or preference randomness. Besides Predictions 1 and 2, we have two auxiliary predictions. First, under cautious expected utility, preferences are in general convex except for degenerate lotteries. It follows that cautious expected utility is incompatible with MSB in choice list or switching behavior in repeated choice where one option is degenerate. Second, compared with choice lists where both lotteries are non-degenerate, it is less likely for the decision maker to experience fresh information shock as she moves along a certainty choice list where the lottery option is fixed and the certain amounts vary. Hence, models incorporating randomness/errors predict lower MSB frequency in certainty choice list.

Brady and Rehbeck, 2016; Cattaneo et al., 2020; Barseghyan et al., 2021). In our setting of choice-list elicitation of risk preference, the effect of randomness in consideration sets is observationally indistinguishable from random utility.

[9] To some extent, random utility model is a more general model and can (partially) encompass random expected utility. See Cerreia-Vioglio et al. (2019) for a related discussion.

One experimental design that may partially separate MSB stemming from randomness/errors would be a choice list that is sufficiently long so that the right-hand option dominates/is dominated by the left-hand option. As such, if a subject multiple switches while choosing the dominated option, it would be against the prediction of convex preference models. In experiment 2, we include dominated options in our choice-list design for such a purpose. While a complete separation is difficult, we would propose a behavioral differentiation of MSB and let the data "speak". Specifically, we classify MSB into those which are *regular*—initially choosing options on the left and eventually switching to the options on the right—and *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. Recall that the right-hand option becomes increasingly attractive compared to the left-hand option in a choice list. Our hypothesis is that irregular MSB, compared with regular MSB, is more likely to arise from choice error. It follows that irregular MSB, compared with regular MSB, should be less likely to correlate with NEU $\times$ RCLA or switching behavior, and more likely to correlate with dominance violation. In the subsequent analyses, we remain agnostic and let the data inform our behavioral differentiation.

Random incentive In the preceding analyses, we are silent on how the decision maker could implement randomization. In experiments (including the current study) adopting the random incentive mechanism in which subjects make a number of choices and are paid based on one randomly selected choice, it is possible for the subjects to utilize such a mechanism to randomize. Consider a repeated choice of $3 \times \{F, G\}$, the random incentive mechanism delivers $\frac{\alpha}{3}F + \left(1 - \frac{\alpha}{3}\right)G$ given a subject chooses α times of F. Therefore, if a subject prefers $\frac{1}{3}F + \frac{2}{3}G$ to any other probability mixtures between F and G, she can either randomize in each choice separately or simply choose F once and G twice, knowing that the incentive mechanism will eventually deliver her the preferred mixture lottery.

In the choice-list setting, random incentive as randomization device could be problematic. Consider for example two adjacent binary choices $\{F, G\}$ and $\left\{F, G'\right\}$ in a choice list, where F is a fixed lottery and G' first-order stochastic dominates G. A subject who randomizes "globally" will not choose G in the first choice and F in the second, since the resulting lottery $\frac{1}{2}G + \frac{1}{2}F$ is strictly dominated by $\frac{1}{2}F + \frac{1}{2}G'$. The incidence of MSB in choice list would necessarily violate dominance.

A related issue concerns the incentive compatibility of a random incentive mechanism (see Wakker (2007) and Azrieli et al. (2018) for detailed discussions). In our setting, we adopt the assumption of isolation (Kahneman and Tversky, 1979) whereby subjects consider each choice as being distinct from the others, and would then not make use this mechanism to randomize across different decisions.

3. Experimental design

This section presents our experimental design. In Experiment 1, we make use of a comprehensive study on economic decision making, and investigate the links among a number of behavioral patterns, including MSB in a certainty choice list, NEU behavior, and RCLA. In Experiment 2, we examine the relationship between MSB in two kinds of choice list—certainty and lottery—and switching behavior in repeated choice.

3.1. Experiment 1

In Experiment 1, we make use of certainty choice list in which subjects make a series of binary choices between a fixed lottery and a range of sure amounts. Denote by $(H, L; p)$ a binary lottery that delivers outcome H with probability p and outcome L with probability $1 - p$. The five lotteries and the respective sure amounts are as follows.

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 $\{(60, 0; p), p = 0, 0.05, 0.1, \ldots, 1\}$.
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 $(60, 0; 0.5)$. Moreover, the sure amounts in these two choice lists are the same as those in the choice list for $(60, 0; 0.5)$ and range from 15 to 35. Therefore, comparing the elicited certainty equivalents of the three lotteries can identify 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 a compound lottery, we state that RCLA is satisfied for that compound lottery.

Finally, we use three lottery choice lists to infer NEU behavior inside a probability triangle with three possible outcomes 0, 30, and 60. In the first choice list, subjects choose between receiving 30 for sure, and a list of 10 lotteries of the form $(60, 0; p_1)$ with p_1 ranging from 48 percent to 66 percent. In the second choice list, subjects choose between a fixed lottery $(30, 0; 0.5)$ and a list of 10 lotteries of the form $(60, 0; p_2)$ with p_2 ranging from 24 percent to 33 percent. In the third choice list, subjects choose between a fixed lottery $(60, 30; 0.5)$ and a list of 10 lotteries of the form $(60, 0; p_3)$ with p_3 ranging from 74 percent to 83 percent. Given the 10 levels of different p_1 in the first choice list, we set $p_2 = 0.5p_1$ ($p_3 = 0.5p_1 + 0.5$) for each of the 10 choices in the second (third) choice list. This design enables us to directly infer whether individuals exhibit NEU behavior in terms of violating independence axiom in the upper and lower triangles. For example, if 30 is chosen over $(60, 0; p_1)$ for the first n choices and $(30, 0; 0.5)$ is also chosen over $(60, 0; p_2)$ for the first n choices, independence axiom is satisfied, otherwise NEU behavior is observed. We further allow for choice errors for testing independence axiom with above or below one switching point in the list.[10]

[10] Our results are robust if we do not allow choice errors.

Table 1
Parameters for choice list in Experiment 2.

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 varies 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.

This experiment is based on a study of the biological basis of decision making conducted in between 2010 and 2012 with a cohort of 2066 student subjects from Singapore (53 percent female) and an additional cohort of 1181 student subjects from several universities in Beijing (48.4 percent female). The instructions and procedures were the same (see Appendix C), except that 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 parameters 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. To incentivize participation, in addition to a SGD 35 (about USD 26) show-up fee, we adopt the random incentive mechanism, paying each subject based on one of her randomly selected decisions in the experiment. Finally, all subjects gave written informed consent approved by the Institutional Review Board at the National University of Singapore.

3.2. *Experiment 2*

We implement two types of choice list in Experiment 2: *certainty choice list* and *lottery choice list*. For certainty choice list, subjects again make a series of binary choices between a fixed lottery and a range of sure amounts. For lottery choice list, subjects make a series of binary choices between pairs of lotteries. Table 1 summarizes the parameters for the choice lists.

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. This yields a discontinuity in the sure amounts that enables us to test for violation of dominance.

Table 2
Parameters for repeated choice in Experiment 2.

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

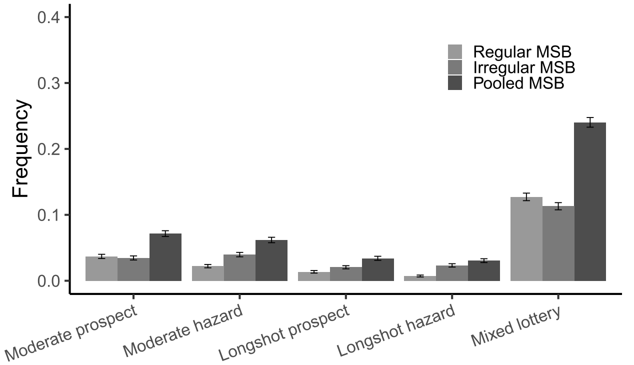
Notes: This table lists the parameters for the 10 repeated choices in experiment 1. For certainty repeated choice, one option is a uniform four-outcome lottery and other is a sure amount. For lottery repeated choice, both options are uniform four-outcome lotteries. Additionally, there are two sets of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

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 in the case of certainty choice list, we have three choice lists where the expected value of the lotteries is lower compared to that in the remaining three lists (see Table 2 for details). The probability p is set to increases from 0 to 1 in steps of 0.05, resulting again 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 the 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 choice-list design, 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 2.

In sum, Experiment 2, which is implemented in a within-subject manner, consists of three main parts: certainty choice list, lottery choice list, and repeated choice. 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 CNY 1 (about USD 0.15). After performing the choice tasks, subjects complete a demographic questionnaire and participate in the three-question version of the cognitive reflection test (Frederick, 2005). 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 students (37 percent female) 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



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 1. Standard errors of the frequencies are inserted for each bar.

Fig. 1. MSB in Experiment 1.

for experimental instructions). The experiment lasted about 40 minutes, and subjects on average received CNY 34.

4. Results

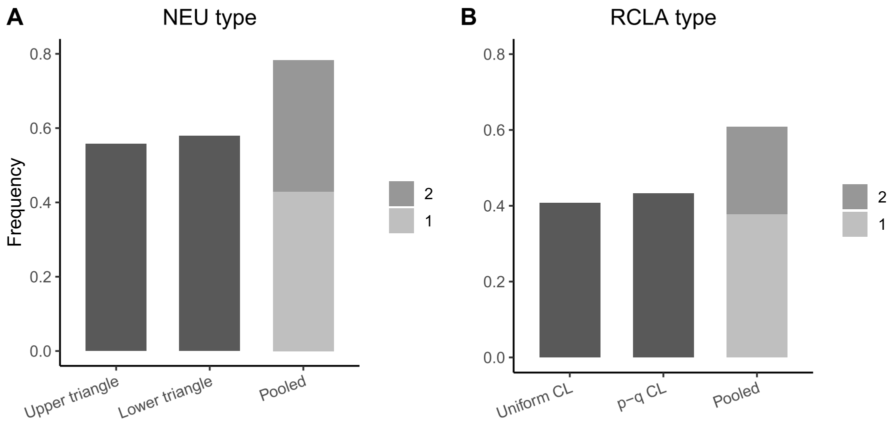
4.1. Experiment 1

This subsection summarizes the frequency of MSB, NEU behavior, and RCLA, and examines their possible links (see Table A.1 in Appendix A 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 Fig. A1 in Appendix A).

Fig. 1 plots the percentage of MSB, which is further classified into regular MSB and irregular MSB.[11] 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, when moving from the gain domain to the mixed domain and finally the loss domain, we can observe a significant 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, $p < 0.001$).

Fig. 2 plots the percentage of NEU behavior and RCLA at the individual level. The frequency of NEU behavior is 55.7 percent in the upper triangle and 57.9 percent in the lower triangle. When pooled together, 35.4 percent of the subjects display NEU behavior twice in terms of violation of independence axiom in both upper and lower triangles, and 43.0 percent of the subjects exhibit NEU once—in either upper or lower triangle, and the rest 21.6 percent of the subjects conform

[11] The frequency of more specific types of irregular MSB is presented in Tables A.3 and A.4 for Experiment 1 and Experiment 2 in Appendix A.



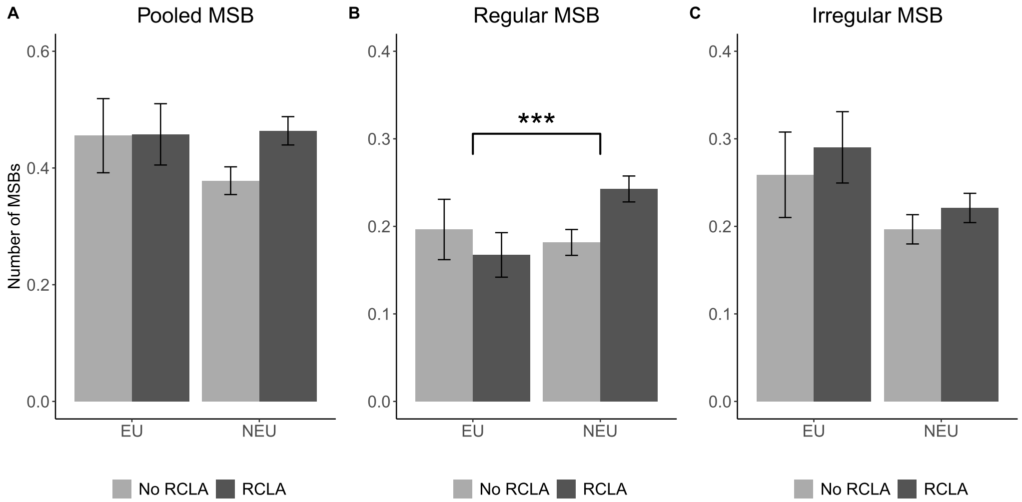
Notes: This figure illustrates the individual type of NEU behavior and RCLA. In the left panel, the first two bars represent the frequencies of independence violation in the upper and lower probability triangle respectively. The third bar presents the number of instances of NEU behavior at the individual level: "1" means that independence is violated either in the upper triangle or in the lower triangle, and "2" means that independence is violated in both upper and lower triangles. 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: "1" means RCLA is satisfied for either the uniform compound lottery or the p-q compound lottery, and "2" means RCLA is satisfied for both compound lotteries.

Fig. 2. NEU behavior and reduction of compound lottery in Experiment 1.

with independence axiom. Regarding conformity with RCLA, the frequency is 40.8 percent for uniform compound lottery, and 43.2 percent for p-q compound lottery. When pooled together, 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.

Fig. 3 plots the relationship between NEU behavior/RCLA and MSB. From the figure, we observe an interaction effect of NEU behavior and RCLA on regular MSB. More specifically, the frequency of regular MSB is 24.3 percent for subjects with both NEU behavior and RCLA, 18.2 percent for those with only NEU, 16.7 percent for those with only RCLA, and 19.6 percent for those with neither NEU behavior nor RCLA. The interaction term between NEU behavior and RCLA using regression analysis is statistically significant for regular MSB ($p = 0.007$), but not for pooled MSB ($p = 0.23$), or irregular MSB ($p = 0.39$).

Table 3 reports the results from regression analysis on the relationship between NEU behavior/RCLA and MSB. We use ordered probit regression analysis with robust standard errors clustered at the individual level. The dependent variables are the frequencies of MSB, regular MSB, irregular MSB in the 5 certainty choice lists, and the independent variables are the frequencies of NEU behavior, RCLA and their interaction term. The covariates include risk attitudes measured in each of the choice lists, age, gender and IQ. We find that the frequency of regular MSB is 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 0.075 (0.068). Moreover, we observe a significant effect of the interaction term between NEU behavior and RCLA (Column 6). Overall, it 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



Notes: This figure plots the frequency of pooled MSB, regular MSB, irregular MSB for four groups of subjects: with EU but not RCLA, EU and RCLA, NEU but not RCLA, NEU and RCLA. Interaction effect is observed for regular MSB ($p = 0.007$), but not for pooled MSB and irregular MSB.

Fig. 3. Linking NEU/RCLA with MSB.

Table 3
Linking MSB with NEU and RCLA in Experiment 1.

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	0.032		0.010	0.075**		-0.015	-0.031		0.026
	(0.033)		(0.051)	(0.037)		(0.058)	(0.038)		(0.061)
RCLA		0.054*	0.021		0.068*	-0.039		0.049	0.101
		(0.032)	(0.061)		(0.036)	(0.065)		(0.038)	(0.070)
NEU × RCLA			0.030			0.105**			-0.057
			(0.044)			(0.048)			(0.051)
IQ	-0.071***	-0.072***	-0.071***	-0.041***	-0.041***	-0.042***	-0.082***	-0.081***	-0.081***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.009)
Gender	0.071	0.077	0.077	0.119**	0.120**	0.126**	-0.005	0.004	-0.003
	(0.052)	(0.052)	(0.053)	(0.060)	(0.059)	(0.060)	(0.061)	(0.061)	(0.062)
Age	-0.000	-0.002	-0.003	-0.038**	-0.038**	-0.037**	0.033*	0.032*	0.029*
	(0.015)	(0.015)	(0.015)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Risk attitudes	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	2,908	2,971	2,890	2,908	2,971	2,890	2,908	2,971	2,890

Notes: This table presents the regression analysis linking MSB with NEU and RCLA in Experiment 1. 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, age, and gender. The table reports the regression coefficients with robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

observe that the negative regression coefficient for IQ score is double when irregular MSB is compared with regular MSB. To sum, we have the following observation.

Observation 1. *Regular MSB is linked to the interaction between NEU behavior and RCLA, while irregular MSB is not.*

In the above classification of NEU behavior and RCLA, when MSB occurs in the related choice lists, we count the number of left-option choices to approximate the certainty equivalent of a lottery, or to infer the probability equivalent of a specific lottery in the probability triangle. To check if the correlations identified in Table 3 are robust, we remove those subjects exhibiting MSB in the related choice lists and conduct similar correlation analyses with the remaining sample. The relevant choice lists include the list of moderate prospect, two lists of compound lotteries, and three lists of lottery choice tasks inside the probability triangle. Table A.5 in Appendix A shows that Observation 1 remains robust.

4.2. Experiment 2

This subsection provides a summary of the 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.

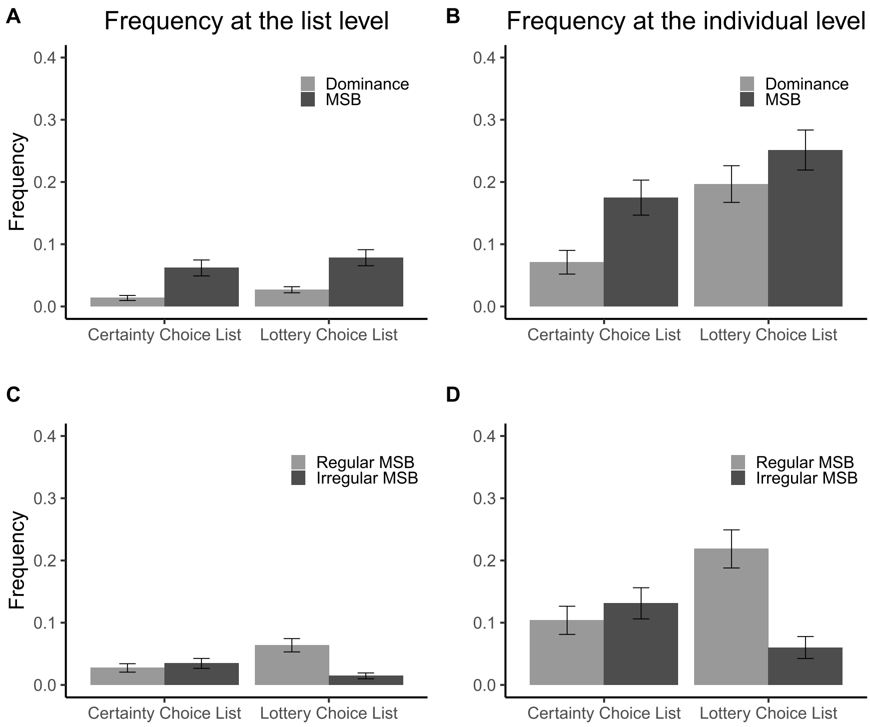
4.2.1. Choice list

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 A.2 for summary statistics, and also Fig. A2). 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. In our sample, subjects are on average risk averse in both types of choice list.

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 dominance. 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. Given that dominance violation is more likely to be a choice error than MSB, we do not include choices which violate dominance in the subsequent analysis of MSB.

Fig. 4 presents the frequency of MSB, regular MSB and irregular 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, $z = 1.85$, $p = 0.06$). Comparing lotteries with high versus low expected values, there is no significant difference in MSB frequency (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. The MSB frequency 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 ($z = 2.42$, $p = 0.016$).

Differentiating between regular and irregular MSB, the frequencies are 2.73 percent and 3.46 percent respectively in certainty choice list and 6.38 percent and 1.46 percent respectively for lottery choice list. At the individual level, the regular versus irregular MSB frequencies are 10.4 percent and 13.1 percent respectively for certainty choice list and 21.9 percent and 6.0 percent respectively for lottery choice list.

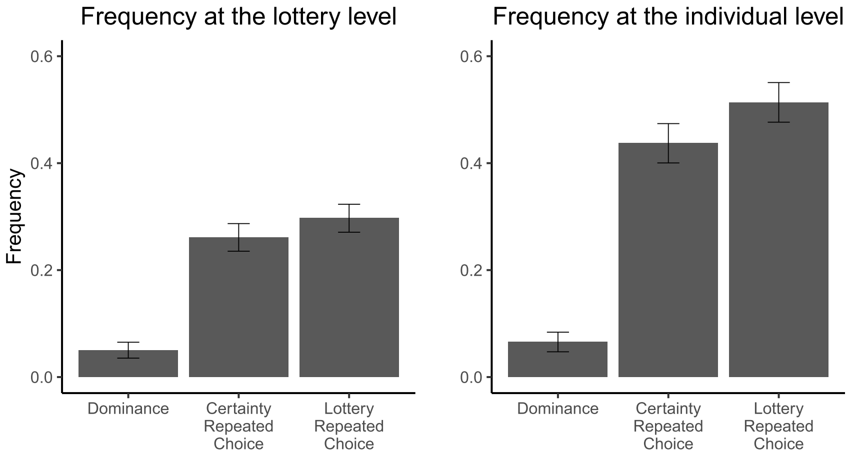


Notes: This figure summarizes the behavior in certainty choice list and lottery choice list in experiment 2. The top panels present the frequency of dominance violation and Multiple Switching Behavior (MSB) at the lottery level (left) and individual level (right) respectively. The bottom panels present 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.

Fig. 4. MSB in choice list in Experiment 2.

4.2.2. Repeated choice

Fig. 5 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. There is no significant difference in the frequencies of switching behavior between certainty repeated choice and lottery repeated choice (logit regression, $z = 1.64$, $p = 0.102$). Moreover, the switching frequency does not differ significantly across different expected values for both certainty repeated choice lotteries (logit regression, $z = 0.17$, $p = 0.863$) and lottery repeated choice (logit regression, $z = 0.81$, $p = 0.420$). At the individual level, the switching frequency is 43.7 percent for certainty repeated choice and 51.4 percent for lottery repeated choice. Our results show that the observed switching behavior in repeated choice in Agranov and Ortoleva (2017) is robust to variations in expected value and generalizable to certainty repeated choice in which one of the two options is a sure amount. The frequency for dominance violation is 5 percent at the choice level and 6.6 at the individual level, and it is lower for lotteries with lower expected value (logit regression, $z = -2.44$, $p = 0.015$).



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.

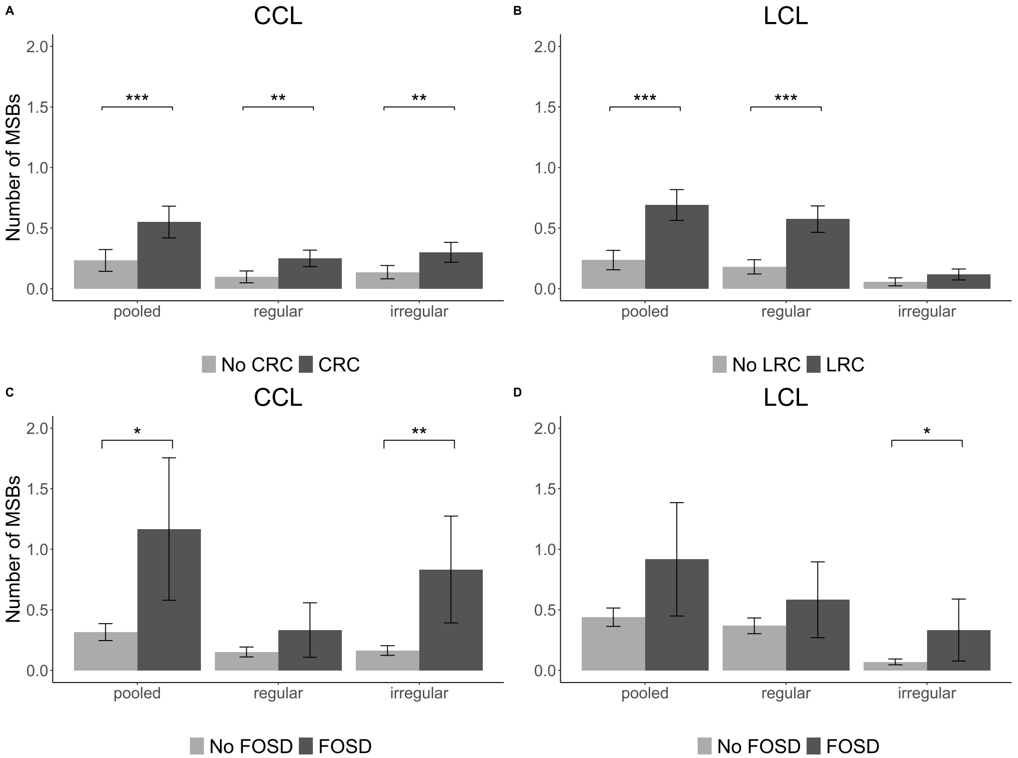
Fig. 5. Switching behavior in repeated choice in Experiment 2.

4.2.3. Linking choice list and repeated choice

Fig. 6 plots the relationship between behavior in repeated choices with MSB in choice lists at the individual level. From the figure, we observe a general tendency for subjects with a higher frequency of MSB to exhibit a higher frequency of switching behavior and dominance violation in repeated choice. When we separate regular MSB and irregular MSB, we observe a higher frequency of regular MSB for subjects with a higher frequency of switching behavior in repeated choice, but not for dominance violation. By contrast, a higher frequency of irregular MSB is observed for subjects with a higher frequency of dominance violation in repeated choice.

Table 4 presents the results from regression analysis. The dependent variables are the frequencies of MSB, regular MSB, irregular MSB and dominance violation in certainty choice list and in lottery choice list. The independent variables are the frequencies of switching behavior in repeated choice in certainty repeated choice and in lottery repeated choice together with dominance violation in the corresponding repeated choice. In the meantime, we control for the number of lottery chosen as proxy for risk attitude, age, gender and scores in the cognitive reflection tasks. We use ordered probit regression analysis with robust standard errors clustered at the individual level.

We observe a positive relation between MSB in certainty choice list (lottery choice list) and switching behavior in certainty repeated choice (lottery repeated choice) 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 0.231 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



Notes: This figure plots the frequency of MSB, regular MSB, irregular MSB in the certainty choice list for subjects with and without switching behavior in certainty repeated choice (panel A), for subjects with and without FOSD in certainty repeated choice (panel C), as well as the frequency of MSB, regular MSB, irregular MSB in the lottery choice list for subjects with and without switching behavior in lottery repeated choice (panel B), for subjects with and without FOSD in lottery repeated choice (panel D). Significant difference is indicated, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Fig. 6. Linking repeated choices with MSB in choice lists.

list, we do not observe significant correlation between dominance violation in choice list and dominance violation in repeated choice (Column 7, Column 8). Taken together, we arrive at the following observation.

Observation 2. *Regular MSB is linked to switching behavior in repeated choice, while irregular MSB is linked to dominance violation in the repeated choice.*

We further test if the observed link is robust by classifying the individuals into three mutually exclusive types. Specifically, for those who ever violate FOSD in the choice lists, we classify them as the FOSD type and only their FOSD violation choices will be counted in the regression analyses (they are coded as 0 in variables irregular MSB and regular MSB, and similarly for other types). In a similar vein, for subjects in the remaining sample who ever exhibit irregular MSB, we classify them as the irregular MSB type, with only their irregular MSB choices counted. Finally, for subjects with neither FOSD violation nor irregular MSB who ever exhibit regular MSB, we classify them as the regular MSB type. In the repeated choice setting, we follow the same

Table 4
Linking choice list and repeated choice in Experiment 2.

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	0.255***	0.219***	0.278***	0.231***	0.134	0.093	0.040	-0.038
Behavior	(0.085)	(0.076)	(0.101)	(0.075)	(0.092)	(0.109)	(0.110)	(0.073)
Dominance	0.442	0.202	0.221	0.013	0.703***	0.669**	-3.825***	0.189
Violation	(0.278)	(0.263)	(0.293)	(0.293)	(0.271)	(0.281)	(0.251)	(0.363)
Gender	-0.491**	-0.329	-0.279	-0.318	-0.681**	-0.411	0.515	0.279
	(0.237)	(0.207)	(0.264)	(0.212)	(0.265)	(0.300)	(0.361)	(0.220)
Age	-0.095	0.006	0.011	-0.052	-0.162	0.095	0.078	0.046
	(0.093)	(0.054)	(0.078)	(0.056)	(0.132)	(0.079)	(0.065)	(0.057)
CRT	-0.238**	-0.219*	-0.053	-0.148	-0.354***	-0.291*	-0.127	0.025
	(0.118)	(0.121)	(0.133)	(0.123)	(0.128)	(0.163)	(0.188)	(0.129)
Risk attitude	-0.025	-0.037	-0.006	-0.046	-0.036	0.005	0.012	0.023
	(0.045)	(0.040)	(0.044)	(0.041)	(0.053)	(0.057)	(0.074)	(0.043)
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 2. 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 (CCL) 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. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

protocol and classify first the FOSD type and then the switching type. Table A.6 in Appendix A shows that Observation 2 remains robust with this alternative classification.[12]

5. Discussion

In both experimental and applied research, MSB is commonly viewed as choice error signaling a low quality in decision making (Bruner, 2011; Charness et al., 2013). In this paper, we posit that some of the observed MSB may arise from deliberate randomization and experimentally test our hypothesis. We further stratify the MSB into two types—regular and irregular—and find an association between irregular MSB and violation of dominance. In contrast, besides not

[12] Following a recent paper by Agranov and Ortoleva (2020), we also investigate the "range" of MSB in choice lists. We first "truncate" the choice lists by removing the boundary choices (either the first and last one, or the first and last two), and classify regular MSB from the truncated list with the remaining MSB classified as being irregular (FOSD violations are identified prior to the truncation). Table A.7 in Appendix A shows that the correlation between regular MSB in choice list and switching behavior in repeated choice remains significant. We also measure the exact range of regular MSB by the number of choices within the first and last switches, and find that the range of regular MSB is uncorrelated with switching behavior in repeated choice. When we further separate the regular MSB by the above and below median range, subjects with different ranges of regular MSB do not differ significantly in terms of switching behavior in the repeated choice. More specifically, the frequency of subjects with below-median ranges exhibiting switching behavior is 50 percent in certainty repeated choice and 47.5 percent in lottery repeated choice. The corresponding percentages for above-median subjects are 61.1 in certainty repeated choice and 41.2 in lottery repeated choice. Both differences are not statistically significant (certainty repeated choice: $p = 0.5$; lottery repeated choice: $p = 0.6$).

being associated with violation of dominance, regular MSB (but not irregular MSB) is positively correlated with NEU behavior and RCLA in Experiment 1, and switching behavior in repeated choice in Experiment 2. Overall, these findings suggest that MSB, regular MSB in particular, is evidential of deliberate randomization.

Our findings contribute to a deeper understanding of the widely reported phenomenon of MSB in the choice-list elicitation of risk preference, and add to the growing literature on stochastic choice in various settings.[13] In particular, our behavioral dichotomy of MSB has practical implications on the choice-list elicitation of risk preference. The observed differential role of regular versus irregular MSB suggests that the loss of data in deleting MSB may be partially salvageable by recovering regular MSB. In this spirit, a common practice in the literature—counting the number of lotteries chosen on one side of a choice list as proxy for risk attitude, may merit further investigation. Our findings also lead naturally to the use of the proportion of irregular MSB and dominance violation (if available) as a diagnostic measure of the decision making quality. Beyond this, it remains an interesting follow-up question how to separate random utility from choice error in irregular MSB when eliciting risk preference using choice lists.

While our results suggest that deliberate randomization may underpin regular MSB, we acknowledge that the full separation between *deliberate* MSB and *non-deliberate* MSB remains a challenge.[14] This is in part because deliberation randomization is not directly observable using the standard choice list. One possibility is to examine the effect of nudges intended to reduce choice errors and see how they may affect different types of MSB. As mentioned in the introduction, our re-analysis of the data in Yu et al. (2021) show that their nudge, involving reconsideration of one's choices, reduces the incidence of irregular MSB disproportionately compared to regular MSB, in support of our proposed classification. An alternative possibility is to adopt a within-subject design to compare the standard choice list and the approach proposed in Agranov and Ortoleva (2020), whereby subjects are allowed to explicitly state their randomization preferences in each row of a choice list. If MSB in the standard choice list is within the "range" where the subjects exhibit preference for randomization, deliberate randomization may seem more plausible. Conversely, if MSB in the standard choice list is outside the "range", it would presumably be more likely to be choice error.

Besides the range of models exposited in the Introduction, we would like to discuss some other potential sources of deliberate randomization here. One has to do with preference incompleteness. In their axiomatization of expected utility with incomplete preference (Dubra et al., 2004; Galaabaatar and Karni, 2013), preference is incomplete if the expected utility of one lot-

13 Experimental evidence on stochastic choice includes the early work of Tversky (1969) and subsequent studies including Camerer (1989), Starmer and Sugden (1991), Hey and Orme (1994), Hey and Carbone (1995), Ballinger and Wilcox (1997), Hey (2001), Regenwetter et al. (2011), Regenwetter and Davis-Stober (2012). Some experimental studies directly test the betweenness axiom (e.g., Camerer and Ho, 1994). Besides Agranov and Ortoleva (2017), a number of recent studies further corroborate deliberate randomization (e.g., Dwenger et al., 2018; Agranov and Ortoleva, 2020; Feldman and Rehbeck, 2022; Levitt, 2021).

14 A related point is that the observed link between regular MSB and NEU behavior and RCLA may share alternative underpinnings other than convex preference, such as violation of transitivity (see Dembo et al. (2021)) for a recent study in the revealed preference setting). Strictly speaking, we cannot falsify such a hypothesis in a choice-list setting. While MSB and NEU behavior appear "irrational" and may both link to violations of some fundamental properties of a preference order, conformance with RCLA seems highly "rational". In this regard, we view the observed association between MSB and NEU $\times$ RCLA as suggestive evidence of deliberate randomization.

tery is not always greater than that of the other lottery according to a set of utility functions.[15] 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 given 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) while about one third are willing to pay a small cost to do so (consistent with deliberate randomization).

Going beyond revealed preference, 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 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. Recently, Agranov et al. (2021) find that probability matching behavior correlates with randomization in repeated choices in various domains including individual risky choice and games.

As discussed above and in the Introduction, there are alternative models which can deliver "deliberate" randomization and account for the observed link between regular MSB and switching behavior in Experiment 2. However, they are silent on the corresponding link between regular MSB with NEU behavior and RCLA in Experiment 1. In sum, models of deliberate randomization based on convex preference are better supported by the experimental findings in this paper.

Appendices A–C. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jet.2022.105510.

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[15] Cerreia-Vioglio et al. (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.

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