Sleepiness, Choice Consistency, and Risk Preferences

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Abstract:

We investigate the consistency and stability of individual risk preferences by manipulating sleepiness as a type of cognitive resource challenge. Validated morning-type and evening-type diurnal preference individuals are randomly assigned to an experiment session at a preferred (circadian matched) or non-preferred (circadian mismatched) time of day relative to their diurnal preferences. These subjects are administered an incentivized task where they must choose allocations between two risky assets. Consistency of behavior of circadian matched and mismatched subjects is statistically the same. However, mismatched subjects tend to take more risks. We conclude that, consistent with several theories, preferences are rational yet can change depending on state-level cognitive resource affects.

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1. Introduction

There is growing evidence that individual risk attitudes, as measured by economic experiments, vary across circumstances as well as across individuals. For example, risk attitudes vary across individuals for reasons such as genetic makeup (1) cognitive ability (2-4), and prenatal testosterone exposure (5). The way in which a decision is framed or the individual primed may also affect attitude towards risk (6), as can the way ones views and brackets the choice (7). But there are also appears to be evidence that risk attitude may vary temporally due to life-cycle changes (8), traumatic personal or family experiences (9-10).

We examined risky choice in the presence of a temporary cognitive challenge that is of significant concern in modern society: sleepiness. We manipulate sleepiness by randomly assigning subjects to a more- or less-preferred time of day for their experiment session. Non-preferred times of day (henceforth, circadian mismatch) have been associated with changes in decision making consistent with impairments in higher-level cognitive function (11-14).[*] Yet, none of these existing studies attempted to evaluate whether circadian mismatch increases irrationality of choice. A common assumption in standard economic models is that changes in preferences can occur without the loss of rationality. This is true, for example, with Arrow-Debreu state-dependent preferences models (15), as well as in behavioral models (16-18). Our experimental design provides empirical evidence to investigate this assumption.

Circadian timing of decisions, which produce variation in sleepiness during decision making, is a natural environment to test the stability and consistency of preferences. First, sleepiness has been widely studied in the sciences, and its effects on performance in many domains are well documented and understood.[†] Secondly, sleepiness is a highly relevant temporary physical state commonly experienced by many. Because of this, circadian mismatch, compared to other ways to temporarily impact cognition, is a manipulation that is less likely to

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[*] To be more specific, depletion of cognitive resources would disproportionately affect executive function. The behavioral effects of circadian mismatch reported in the aforementioned studies either involved an increased reliance on heuristics (i.e., stereotyping and transference effect) or decreased ability to engage in strategic reasoning (i.e., the guessing game), both of which are consistent with reduced engagement of deliberate thought regions of the brain that rely on fully intact cognition.

[†] Total sleep deprivation studies are a more common approach to studying how sleepiness affects performance and decisions. However, circadian mismatch is a milder, and arguably more externally valid, way to study sleepiness of the sort commonly experienced by real-world decision makers.

generate inconsistencies in behavior due to learning or adaptation to the circadian mismatch. This is important because such learning would confound an examination of preference consistency across cognitive states. Thirdly, results from this type of environment should be relevant to policy given that sleepiness is of particular concern in occupations where public safety is affected by risky choice (e.g., long-haul trucking, air traffic control, surgeons, to name just a few). Understanding whether risky choice while sleepy is rational or not, and whether or not preferences change when sleepy, could help inform the design of institutions and policies.

Existing results (2,3,8,19) all show that higher levels of permanent cognitive ability are correlated with an increased propensity to take monetary risk. In contrast, sleepy deprived subjects, who in some sense have temporarily depleted cognitive resources, have been found to take additional risk for monetary gambles of gains (20). Relatedly, we find that circadian mismatched subjects have higher calculated certainty equivalents for the monetary gambles they face. This indicates an increased preference for monetary risk when sleepy. Our experiment was not designed to identify the mechanism causing these effects. However, our results do show that the relationship between sleepiness and preferences is causal.

To our knowledge, ours is the first paper to show that changes in preferences can occur without loss of rationality. Another recent study found increased violations of stochastic dominance among young teens and elderly, who also made more risk averse choices (8). In other words, those with lower cognitive function were more risk averse and more irrational. Not only do we find that temporarily sleepier subjects were more risk loving, but we also find that these sleepier subjects were equally as rational as the less sleepy subjects who made choices at more optimal times of the day. Thus, it is clear that temporary challenges to cognition do not produce similar changes in risky choice as compared those found due to a decline in permanent cognitive function.

2. Experimental Procedures

2.1 The Risky Choice Experiment Environment

We administer an established risky choice design (21) for our study that generates a rich set of individual-level data.[‡] In each decision round, subjects are asked to allocate tokens between two different accounts: X and Y. Tokens in account X only generate a payoff for the subject if account X is randomly chosen by the computer at the end of that decision round. Similarly, tokens in account Y only pay if account Y is randomly selected. We implement the "symmetric" treatment design (21) with a common knowledge 50% probability that either account X or Y will be chosen. Figure 1 shows a sample stimulus where the subject makes an allocation choice on a computer interface by using a mouse-driven pointer to drag point C along the line AB to their desired choice location (including the endpoint locations, if desired). An allocation such as point A or point B is a risky choice with all tokens placed in one account. Thus, the subject would only receive a payoff if the computer randomly selects the account where all the tokens are allocated. An intermediate allocation of tokens, such as point C in Figure 1, places some tokens in each account, which guarantees the subject a smaller, but sure, payoff in both states of the world. A choice along the X=Y line in Figure 1 is a perfectly safe portfolio that guarantees the same payoff no matter which state of the world applies.

The experiment consists of 50 decision rounds (i.e., 50 different stimuli) where the slope and intercept of the AB line are randomly determined for each stimulus.[§] After all 50 rounds, one round is randomly selected for payment, and each round has an equal probability of being chosen. The randomly selected payoff-round, the computer's random selection of account X or Y, and the subject's allocation decision for that round determine the subject's payoffs.

2.2 The Cognitive Resource Manipulation

We use a circadian match/mismatch protocol to randomly manipulate sleepiness of subjects, thereby randomly assigning temporary state of mildly altered cognition.[**] While there

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[‡] We are grateful to Sachar Kariv for providing us with the code for the experiment task.

[§] For the first eight sessions, the X and Y intercepts were constrained to lie in the [50,100] interval. For the latter eight sessions, in order to generate more extreme relative prices, the budgets were chosen among the set of lines that intersect at least one axis at or above the 50-token level, but below 100, and intersect both axes at or below the 100-token level. The initial starting point for the mouse-pointer along each budget line was also randomly determined. See Choi et al., (21) for full details.

[**] We use the same self-reported sleepiness measure as is used in the sleep literature (i.e., the "Karolinska Sleepiness Scale" (KSS) as one way to document the impact of a sleep manipulation. Because not all research

may be other ways to alter or even temporarily deplete resources, our method has broad applicability to circumstances encountered in daily life, has been previously used and validated in the literature, and is relatively easy to administer. Previous research has shown that single-vehicle accidents increase at times of the day where the typical circadian rhythm dictates sleepiness due to natural release of melatonin (22).

To implement the circadian mismatch protocol for our current study, we first administer a large-scale online survey at two academic institutions. The survey generates a database of morning-type and evening-type individuals using a validated diurnal preference instrument (23). From this database, we randomly assign morning-types and evening-types to either a morning (7:30 a.m.) or an evening (10:00 p.m.) experiment session. We then contact them for recruitment to the risky choice experiment at their randomly assigned time. This resulted in 57% of our sample being circadian matched for the risky choice experiment.

Because subjects could not select themselves into one time slot or the other, our data imply a more causal interpretation of our sleepiness manipulation outcomes. Importantly, we find no evidence of selection in show-up rates across the matched and mismatched subjects. The proportion of subjects who actually showed up for their session (114 circadian matched, 88 circadian mismatched) relative to those who signed up (137 matched, 110 mismatched) is not significantly different across our matched and mismatched subjects (the p-value of a Chi-square test of difference is 0.516). In total, the 202 subjects who participated in this study earned an average of $22.56 (s.d. $9.61), which included a $5 show up fee (see Tables S1 and S2 for additional subject details). As a validation of the circadian mismatch protocol, self-reported sleepiness ratings were significantly higher for circadian mismatched subjects ($p<.0001$, two-sample t-test. See Table S2 for further details comparing summary statistics of matched and mismatched subjects).

3. Results

3.1 Consistency of Behavior

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indicates a performance deficit, depending on the task, resulting from sleep loss (e.g., Tucker et al (24)), we are careful to note that what we manipulate is sleepiness with our circadian mismatch protocol.

We look first at rationality and then choices in the risk task. We test for consistency of choices with rationality for matched and mismatched subjects using several measures of rational behavior. Specifically, we test if subjects satisfy the Generalized Axiom of Revealed Preferences (GARP) (25,26) and payoff dominance. GARP is a fundamental axiom used in economics to described consistency of preferences with some underlying and "well-behaved" utility function. In general, our approach to examining rationality in the data is a way of testing whether there is an increase in the choice data noise when sleepy. Noisier choice data would result in increased violations of GARP and payoff dominance.

Figure 2 presents the distribution of the Critical Cost to Efficiency Index, CCEI (25), for matched and mismatched subjects. This index measures how much budget constraints would need to be adjusted to eliminate all violations of GARP. As a point of reference, we also generate a distribution of CCEI that would result from random choices for the budget constraints used in the experiment. This random choice distribution is shown in light bars, and the distribution for actual subject choices is shown in blue bars. The two distributions are significantly different (Chi-square test of difference in distribution p-value=0.000) and show that subject choices in the experiment are not random.[††]

Looking at the CCEI's of subjects, Figure 2 shows that 13 percent of matched and mismatched subjects satisfied GARP without having to modify any budget (CCEI = 1). An additional 21 percent of the matched subjects and 22 percent of the mismatched subjects require a small change in the budgets to satisfy GARP (CCEI above 0.999). All told, 78 percent of the matched subjects and 83 percent of the mismatch subjects have indices strictly above 0.9. Importantly, the circadian matched and mismatched CCEI distributions are not significantly different (rank sum test of difference in distributions p-value= 0.7805). That is, the increase in sleepiness resulting from circadian mismatch does not cause an increase in choice inconsistency, as measured by a fundamental economic axiom of revealed preference.

More basically, we also examine whether subjects choose asset bundles that are payoff dominated, which would imply an irrational choice. Namely, if one considers Fig. 1, we can see that for any set of relative asset prices other than 1, a subject should never choose along the

[††] We only consider positive prices in all the analyses in the paper. Out of the 10,100 choices made in the experiment (50 choices per subject x 202 subjects), 10,094 were with strictly positive prices.

segment of the budget line on the short side of the safe bundle line. In other words, any choice off the X=Y line represents increased risk, but moving away from X=Y onto the longer segment of the budget line increases expected payoff compared to choosing the short side of the budget line, which increases risk but decreases expected payoff. Thus, all choices on the short side (e.g., above the X=Y line in Fig. 1) of the budget line violate payoff dominance. Our data set provides ample observations to examine violations of payoff dominance in our two experimental groups.

Table 1 presents the contingency table of violations of payoff dominance for the steep versus flat budget constraints (the rows), and it does so for the case of the entire data set as well as subsets of the data for which relative prices are quite close (the columns further to the right). The importance of investigating relatively close price ratios is because violations of dominance in those cases are less costly in terms of expected payoff loss. Observing significant differences across matched and mismatched participants for close price ratios would be a strong test for noisy decision making. Fisher's exact tests are performed for each column represented in Table 1

Two things are clear from Table 1. First, there are a significant number of violations of payoff dominance. It is violated roughly 1/3 of the time for the set of all budget constraints and, not surprisingly, violations are more frequently when a violation is less costly (i.e., the $\left|\boldsymbol{ln}\left(\frac{P_x}{P_Y}\right)\right| < \mathbf{0.10}$ and $\left|\boldsymbol{ln}\left(\frac{P_x}{P_Y}\right)\right| < \mathbf{0.05}$ subsamples). Secondly, there is no significant difference in propensity to violate dominance between circadian matched and mismatched participants (p-values at bottom of Table 1). These results complement our examination of GARP consistency, which together present a unified theme regarding subject rationality in our experiments.

RESULT 1: Increased sleepiness due to circadian mismatch does *not* affect choice consistency

In summary, we find that distance to rational behavior across circadian matched and mismatched subjects is similar regardless of the test of rational behavior we conduct. When testing the data's consistency with GARP, for which there are some CCEI benchmarks in the literature, both our circadian matched and mismatched groups would be deemed "rational."

We now examine if consistency in behavior, whether cognitively challenged or not, also implies that choices in the risk task are the same.

3.2 Choices in the Risk Task

Here, we look at the distribution of asset investments, from which we calculate certainty equivalents for subjects. These certainty equivalents constitute a theoretically valid measure of risk preference. Because deviations from expected utility theory might manifest through nonlinear responses to prices we take these factors into consideration in the analysis that follows. In particular, subjects might choose a distribution of assets that favors constant payoffs, and so small variations in relative prices will have a different impact on asset allocations than large changes in relative prices. It will be important to examine behavior in these extremes as a result.

Figure 3 shows the distribution of the proportion of the budget share in asset Y for all relative prices for matched and mismatched subjects. Matched subjects tend to more frequently choose asset allocations that secure equal payoffs across states of nature. Thus, matched subjects choose the safe bundle more frequently, which is an indication of increased risk aversion relative to circadian mismatched subjects.[‡‡] The significance of this result is tested and shown in Table 2. This table shows the results of an interquantile regression of budget share on a dummy variable for being a mismatched subject. The estimation shows that the interquantile range of a subject's budget share in the Y asset is 8.5 percentage points larger if circadian mismatched, which indicates they are significantly more likely to make riskier investments.

To more rigorously assess differences in risk aversion, we also calculate non-parametric certainty equivalents for the matched and mismatched subject groups. The certainty equivalent for a particular risky lottery is estimated as the highest payoff "safe bundle" (i.e., equal payoffs across states) that would be less preferred to risky bundle and still be consistent

[‡‡] Given the mouse-driven graphical choice interface, one might think that sleepy subjects would be less likely to choose safe asset bundles due to motor skill deficits resulting from fatigue. We note that this is not likely the case in our data, however, because that argument would imply these same sleepy subjects are more likely to choose extreme border asset bundles. This is not the case in our data.

with GARP. That is, we look for all sets of relative prices that would support the “risky” lottery without violating GARP and pick the set of relative prices that include the highest possible “safe bundle.” This highest income “safe bundle” is our certainty equivalent measure. So, the more risk averse an individual is the lower payoff the “safe bundle” would be to make them switch away from the lottery. In other words, more risk averse individuals will have lower certainty equivalents. Finally, calculating certainty equivalents requires subject choices to be consistent. So, since many subjects have some violations of GARP, we adjust the revealed preference relationship according to the subject’s CCEI. In particular, all the calculations define a bundle x at prices p to be revealed preferred to y if $CCEI(i)*p*x \geq p*y$, where CCEI(i) is subject i’s CCEI.[§§]

The results from calculating these certainty equivalents are shown in Figure 4. The average certainty equivalent (CE) for matched and mismatched subjects are calculated for each asset bundle, and Figure 4 shows the difference of these CEs between matched and mismatched subjects relative to the expected value of the lottery—this normalizes the CE for comparability. The height of each bar in Fig. 4 shows how much larger the CE is for mismatched compared to matched subjects in percentage points. The general path of where these bars lie is due to the range of actual available lotteries seen in the experiment. What is clear from these data is that mismatched individuals have higher calculated certainty equivalents than matched individuals, especially for extreme lotteries that are far from the sure payoff lotteries on the diagonal (i.e., the valley between the two masses of CE difference bars). In other words, sleepier circadian mismatched subjects are more risk loving than matched subjects.

We test for the significance of these differences in Table 3. This table shows results for Tobit regressions of the CE on a dummy variable for being mismatched for various sets of relative prices.[***] The first column includes all the data and shows that mismatched subjects have a 4.4 percentage point larger CE than matched subjects. The second column confirms this result when the data are restricted to include relative prices strictly different from one.

[§§] As a robustness check, we evaluate our results on the differences in certainty equivalents between matched and mismatched subjects by also constraining the sample to subjects whose CCEI is close to one. Our main result, that matched subjects are more risk averse, still holds. The result is no longer statistically significant though, and that is a reflection of the smaller number of observations in the constrained sample.

[***] The Tobit regression takes the calculated certainty equivalent for an individual for a given lottery and regresses it on a dummy variable for being mismatched. There are 361 possible generated lotteries for each individual and 202 individuals, yielding 72,922 observations, and the regressions cluster at the individual level.

Columns 3-6 further restrict the data to include only progressively more extreme relative prices, in which case mismatched subjects have higher CE than matched subjects that is only significant in a one-sided test. This leads to our second result:

RESULT 2: Cognitive resource depletion via circadian mismatch leads to higher certainty equivalents (i.e., increased preference for risk).

As a further robustness check of our result, we examine how price responsiveness varies across groups. Table 4 shows regressions of price elasticity on relative prices, a dummy for being mismatched and an interaction term of relative prices on being mismatched. Mismatched subjects are less responsive to relative asset price changes than matched subjects.

While mismatched subjects are more risk taking, a relevant question is whether this difference in behavior impacts payoffs of the subjects? In our experiments, subjects are paid based on one randomly chosen trial, so a more proper examination of payoffs would examine expected payoff differences given a subject's 50 trails of risky choices. In doing so, we find that expected payoffs are higher for circadian mismatched subjects, but the result is not statistically significant.[†††] We therefore find no evidence that the increased tendency of circadian mismatched subjects to take additional monetary risk either benefits or harms their payoffs.

In sum, while the emerging literature has found that individuals with lower levels of permanent cognitive abilities are more risk averse, we find that our random manipulation that increases sleepiness leads to less risk aversion, as measured by certainty equivalents. This result is consistent with other studies that have examined the impact of extreme forms of temporary cognitive impairment on incentivized risky choice tasks, such as total sleep deprivation (20) or intoxication (27). Importantly, despite the shift in risk attitudes, we do not find any significant difference in decision-making rationality or choice consistency resulting from circadian mismatch.

[†††] We test this by running quantile regressions of expected payoff on a dummy variable for being mismatched. While expected payoffs are higher for mismatched subjects, there is no significant difference for the 25%, 50% or 75% quantile. Errors are bootstrapped 1000 times.

4. Conclusions

In this paper we investigate how a particular sleepiness impacts choice consistency and outcomes in a risky choice task. The circadian mismatch protocol we implement to manipulate sleepiness and cognition is not only effective but externally valid and similar to what decision makers face in field environments. While much of the recent literature has focused on how permanent cognitive ability levels may correlate with risk preferences, we address how temporary fluctuations in cognitive functioning typically associated with fatigue may affect choice, independent of permanent abilities.

Our results are significant and reveal evidence that sleepier subjects are more risk loving yet equally rational than less sleepy subjects. Specifically, we have shown that circadian mismatched subject choices are no more or less consistent with GARP or payoff dominance theories. And yet, these mismatched subjects are more willing to accept risky asset bundles and are less sensitive to relative asset price changes than circadian matched subjects.

This is an important result with practical and policy implications, especially if one considers that many real-world decision makers face even more serious bouts of sleepiness than the relatively mild manipulation we implement. In the realm of monetary risk choice, sleep deprivation is estimated to affect over 25% of workers in the financial and insurance industries (28). In such industries, any increased tendency to take risk may have significant monetary consequences. In other occupations, risky choice may not involve explicit monetary risk (e.g., air traffic controllers, long-haul trucking, medical practice, or emergency service workers), but sleepiness is commonplace and of great concern to policymakers establishing regulations that may involve prescribed rest or time-off to avoid sleep deprivation or limit shift work.

If one considers the other various forms of temporary cognitive challenges we often face (e.g., multi-tasking, stress, time pressure), this research may have even more wide reaching implications. We leave it to future research to establish the relationship, if any, between various distinct forms of cognitive resource manipulations, or whether any effects are specific to certain choice domains. Nonetheless, it is clear that this area of research is fertile ground for studying choice in the real world where cognitive functioning may experience temporary but predictable variations.

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Figure 1: Sample Stimuli

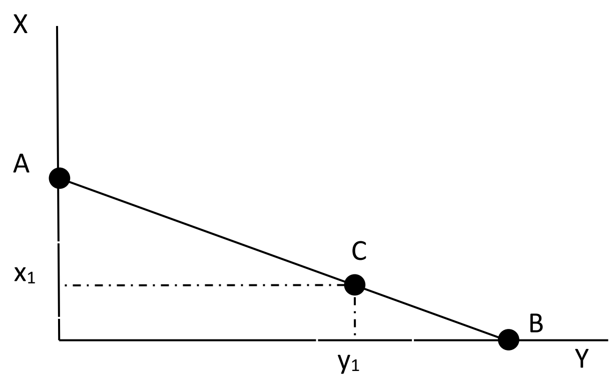

Figure 2: Distribution of Critical Cost to Efficiency Index (CCEI) for Matched and Mismatched subjects (blue bars) and for random choices (yellow bars)

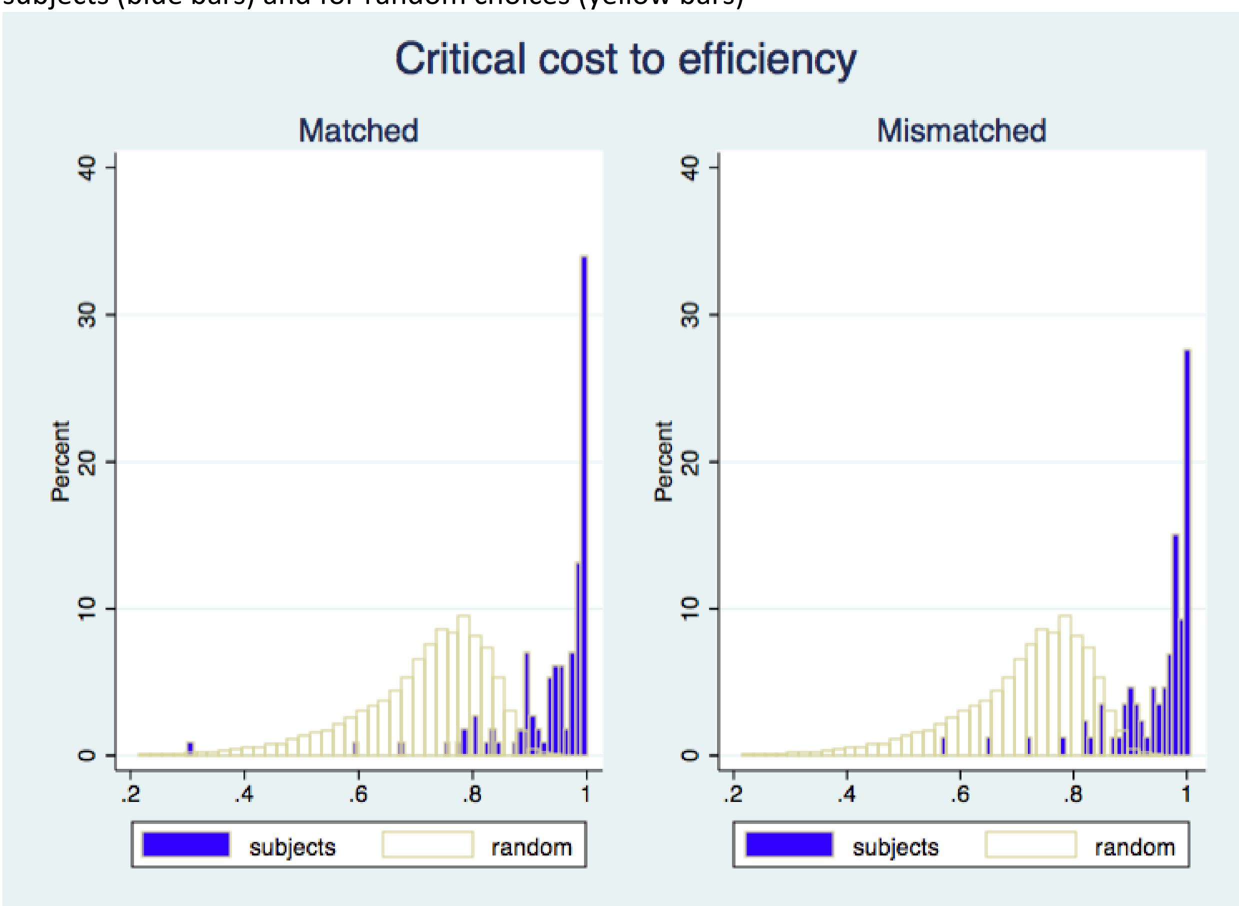

Figure 3: Share of Assets in Y for all relative prices—Matched (N=114) and Mismatched (N=88) subjects

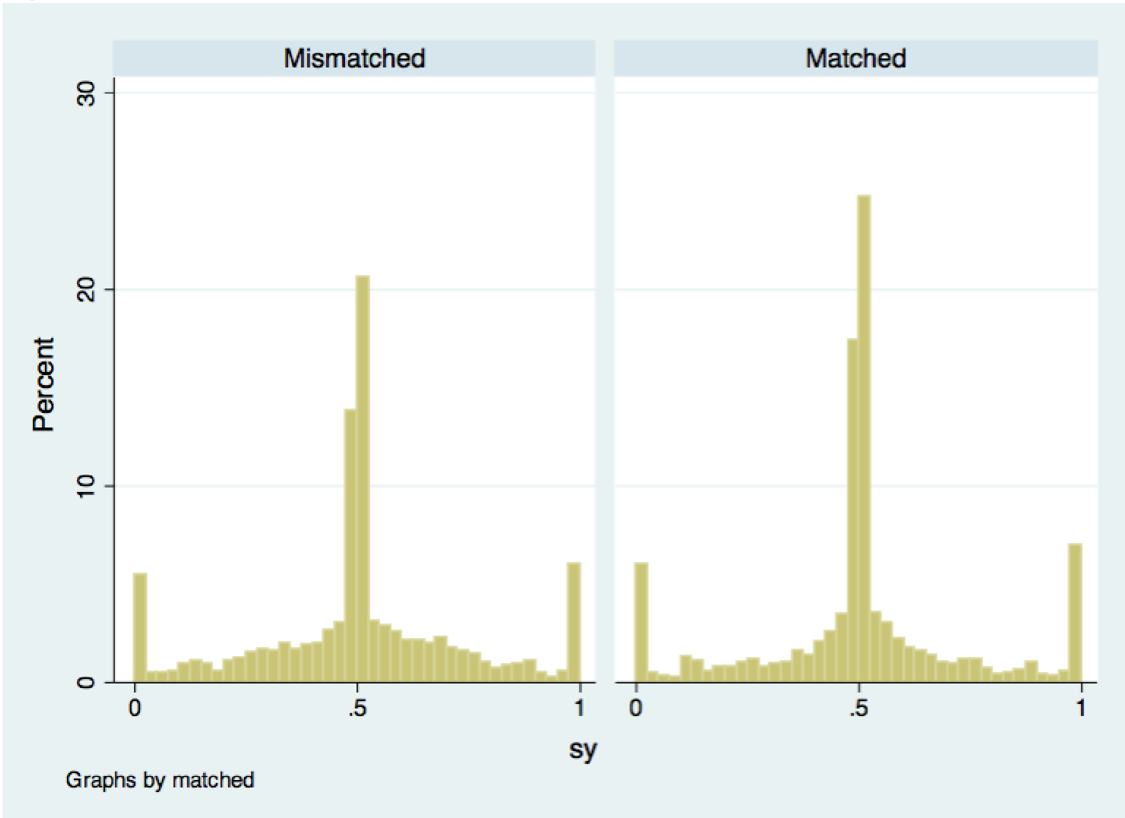

Figure 4: Certainty equivalent for mismatched minus certainty equivalent for matched subjects for different asset bundles, as a proportion of the expected value of the lottery. Bars with positive height indicate mismatched subjects preferring more risk.

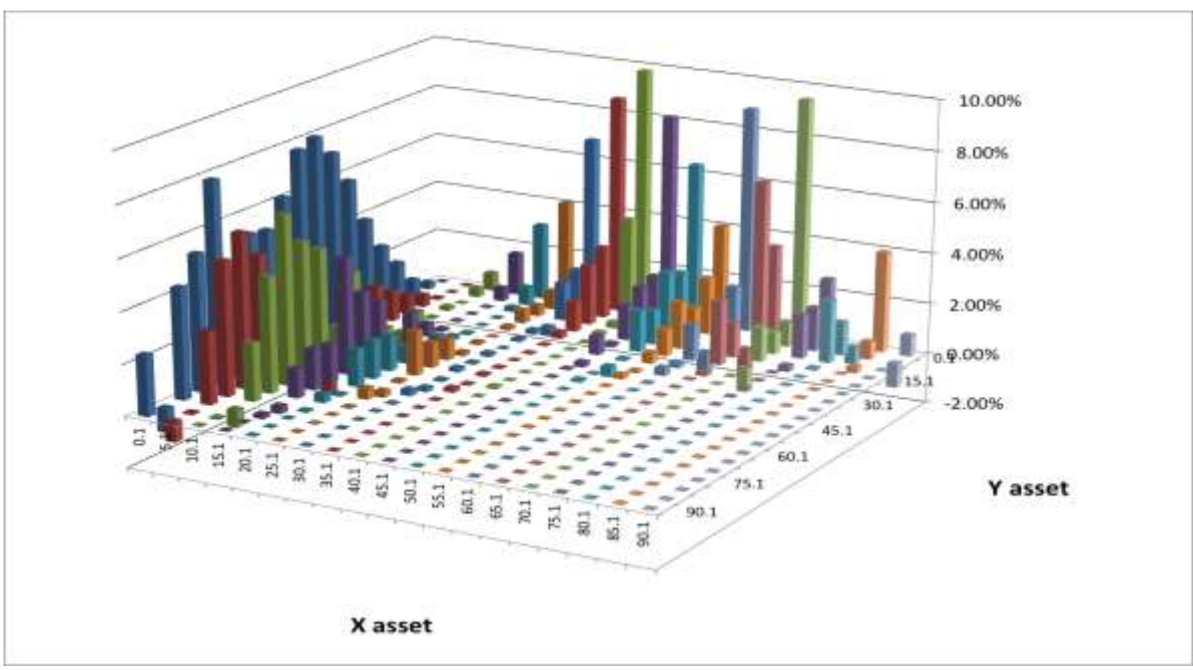

Table 1

Consistency versus Violations of Payoff Dominance: Matched vs. Mismatched subject
Fisher tests of proportions for each category
(number of observations listed, proportion of sample in parenthesis)

Category	All $ln\left(\frac{P_x}{P_Y}\right)$ (n=10,100)	$\left|ln\left(\frac{P_x}{P_Y}\right)\right| < .10$ (n=2,203)	$\left|ln\left(\frac{P_x}{P_Y}\right)\right| < .05$ (n=1,156)
Relatively cheap X **Dominance consistent choice**	$N_{Matched}$=2128 (73.46%) $N_{Mismatched}$=1647 (74.42%)	$N_{Matched}$=371 (57.61%) $N_{Mismatched}$=295 (59.84%)	$N_{Matched}$=193 (53.76%) $N_{Mismatched}$=143 (55.21%)
Relatively cheap Y **Dominance consistent choice**	$N_{Matched}$=2208 (77.39%) $N_{Mismatched}$=1687 (78.94%)	$N_{Matched}$=393 (63.80%) $N_{Mismatched}$=311 (69.11%)	$N_{Matched}$=204 (63.75%) $N_{Mismatched}$=140 (64.22%)
Relatively cheap X **Dominance violated choice**	$N_{Matched}$=769 (26.54%) $N_{Mismatched}$=566 (25.58%)	$N_{Matched}$=273 (42.39%) $N_{Mismatched}$=198 (40.16%)	$N_{Matched}$=166 (46.24%) $N_{Mismatched}$=116 (44.79%)
Relatively cheap Y **Dominance violated choice**	$N_{Matched}$=645 (22.61%) $N_{Mismatched}$=450 (21.06%)	$N_{Matched}$=223 (36.20%) $N_{Mismatched}$=139 (30.89%)	$N_{Matched}$=116 (36.25%) $N_{Mismatched}$=78 (35.78%)
FISHER'S EXACT TEST	**0.465**	**0.247**	**0.948**

Table 2

Interquantile regression on share in Y (Y/(Y+X))

VARIABLES	No bootstrap	Bootstrap at the subject level
Mismatched	0.085***	0.085**
	[0.012]	[0.042]
	(0.000)	(0.041)
Constant	0.107***	0.107***
	[0.008]	[0.023]
	(0.000)	(0.000)
Observations	10,094	10,094

Standard errors in brackets, p-values in parentheses.
Only decisions over positive prices are included.
*** p<0.01, ** p<0.05

Table 3

Tobit estimates of the certainty equivalents as a proportion of the expected value of the lottery

VARIABLES	All lotteries	X <> Y	$\lvert\ln(x/y)\rvert >$ $\lvert\ln(1/1.1)\rvert$	$\lvert\ln(x/y)\rvert >$ $\lvert\ln(1/10)\rvert$	$\lvert\ln(x/y)\rvert >$ $\lvert\ln(1/100)\rvert$
Mismatched	0.044***	0.044***	0.044	0.067	0.088
	[0.006]	[0.006]	[0.033]	[0.049]	[0.061]
	(0.000)	(0.000)	(0.178)	(0.172)	(0.148)
Constant	3.188***	3.186***	1.890***	2.174***	2.188***
	[0.007]	[0.007]	[0.129]	[0.167]	[0.149]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	72,922	71,710	65,852	10,504	6,868

Dummy variables per lottery included, 202 clusters (subjects)
Robust standard errors in brackets, p-values in parentheses. *** p<0.01, ** p<0.05

Table 4

Price elasticity on y/(y+x)

VARIABLES	
$\ln(p_y/p_x)$	-0.160***
	[0.007]
	(0.000)
$\ln(p_y/p_x)$*Mismatched	-0.026**
	[0.012]
	(0.028)
Mismatched	0.002
	[0.007]
	(0.710)
Constant	0.503***
	[0.005]
	(0.000)
Observations	10,094
R-squared	0.387

Robust standard errors in brackets, p-value in parentheses.

Errors clustered at the subject level.

Only decisions over positive prices are included. *** p<0.01, ** p<0.05