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Intemperate fourth-order lottery choices under rank-dependent utility

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Abstract

In the experimental literature, Cumulative Prospect Theory (CPT), evaluated from the status quo reference point, and Rank Dependent Utility (RDU) are often assumed to imply the same fourth-order lottery choices. In this note, we show that this equivalence need not hold. The RDU model, calibrated with the standard probability weighting and power value functions, and representative parameter values from Tversky and Kahneman (1992) and Bernheim and Sprenger (2020), chooses the intemperate lottery, whereas the CPT DM, evaluated from the status quo reference point with the same parameter values chooses the temperate lottery. The divergence arises because RDU and CPT assign cumulative probability weights differently in this lottery setting. The result suggests that RDU may help explain the relatively high proportion of intemperate choices reported in experimental studies.

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1 Introduction

The Rank Dependent Utility model of Quiggin (1982), RDU, has been employed in the analysis of a large number of important economic applications such as the evaluation of quality-adjusted life years in health care and household portfolio diversification (see e.g. Bleichrodt and Quiggin (1997); Bleichrodt et al. (2004); Polkovnichenko (2005)). In the experimental literature on lottery choices an RDU DM (decision maker) has been assumed to exhibit the same second, third, and fourth order risk preferences as the decision maker in Cumulative Prospect Theory (Tversky and Kahneman, 1992, hereafter TK) who makes lottery choices from the status-quo reference point, CPT DM. Accordingly, both models have been taken to imply the fourfold pattern of risk in binary lottery choices, prudence rather than imprudence in third order lottery choices and temperance rather than intemperance in fourth order lottery choices[1].

There are two important assumptions in the Rank Dependent Utility model (RDU) that differ from those in Cumulative Prospect Theory, CPT, when determining lottery choices. The first is that in RDU the cumulative weighting of probabilities of payoffs is applied from the lowest to the highest payoff, rather than from the highest to lowest payoff as assumed in CPT. The second is that a probability of 0.5 is not assumed distorted by probability weighting in RDU, Quiggin (1982, p328). In this paper we illustrate that the fourth order lottery preferences of an RDU DM differ from those of a CPT DM for plausible values of probability weights and risk-aversion. We assume the same functional forms and representative parameter values for the probability weighting function and power value function derived from experimental research on binary lottery choices in each model.[2] Our analysis reveals the new finding that in contrast to the CPT DM, who makes the temperate lottery choice, the RDU DM makes the intemperate lottery choice. Further analysis shows that the combinations of the probability-distortion parameter and the risk-aversion parameter required for the RDU DM to choose the temperate rather than the intemperate lottery are outside the range typically reported in the existing experimental literature.

Our new findings are relevant for the interpretation of experimental research on fourth order lottery preferences since they help explain the otherwise seemingly high proportions of intemperate lottery choices that have been reported. For example, Bleichrodt and Bruggen (2022), Brunette and Jacob (2019), Maier and Rüger (2011) and Lau and Yoo (2025) report intemperate proportion choices of their experimental subjects of 59.6%, 31.6% , 42% and 36% respectively, whilst Deck and Schlesinger (2010) report a proportion of only 32% of temperate choices.

In the next section we illustrate with two examples of lottery choices exhibiting relatively low and high values of positive payoffs the different fourth order lottery choices of a RDU DM and a CPT DM The final section is a brief conclusion.

[1]Paya et al. (2023) illustrate that a CPT DM from the status quo reference point will exhibit prudent third order and temperate four order lottery choices.

[2]Wakker and Zank (2002) provide a preference foundation for employing power utility functions in both RDU and CPT.

2 Temperate or Intemperate Lottery Choices by the RDU DM

With the endowment y and positive payoffs[3] g, f and $y-g-f \geq 0$ from the status quo reference point[4] the standard lottery choices that elicit the fourth order Temperate T, or Intemperate IT preferences are given by:

$$\begin{aligned} T &= (0.25, 0.25, 0.25, 0.25, y+g, y+f, y-f, y-g) \\ IT &= (0.125, 0.125, 0.5, 0.125, 0.125, y+g+f, y+g-f, y, y-g+f, y-g-f) \end{aligned}$$

Assuming a power value function and the probability-weighting function employed in prominent experimental research in CPT, e.g. TK and Bernheim and Sprenger (2020, hereafter BS), and also in theoretical analysis assuming RDU (see e.g.Wakker and Zank (2002)) the expected utility of the temperate ($V^{RDU}(T)$), and intemperate ($V^{RDU}(IT)$) lottery choices in RDU are given by:

$$\begin{aligned} V^{RDU}(T) &= \frac{.25^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}(y-g)^{\alpha} \\ &+\left(\frac{.5^{\delta}}{(.5^{\delta}+.5^{\delta})^{\frac{1}{\delta}}}-\frac{.25^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}\right)(y-f)^{\alpha} \\ &+\left(\frac{.75^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}-\frac{.5^{\delta}}{(.5^{\delta}+.5^{\delta})^{\frac{1}{\delta}}}\right)(y+f)^{\alpha} \\ &+\left(1-\frac{.75^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}\right)(y+g)^{\alpha} \end{aligned} \tag{1}$$

$$\begin{aligned} V^{RDU}(IT) &= \frac{.125^{\delta}}{(0.875^{\delta}+.125^{\delta})^{\frac{1}{\delta}}}(y-g-f)^{\alpha} \\ &+\left(\frac{.25^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}-\frac{.125^{\delta}}{(.875^{\delta}+.125^{\delta})^{\frac{1}{\delta}}}\right)(y-g+f)^{\alpha} \\ &+\left(\frac{.75^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}-\frac{.25^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}\right)(y)^{\alpha} \\ &+\left(\frac{.875^{\delta}}{(.875^{\delta}+.125^{\delta})^{\frac{1}{\delta}}}-\frac{.75^{\delta}}{(.75^{\delta}+.25^{\delta})^{\frac{1}{\delta}}}\right)(y+g-f)^{\alpha} \\ &+\left(1-\frac{.875^{\delta}}{(.875^{\delta}+.125^{\delta})^{\frac{1}{\delta}}}\right)(y+g+f)^{\alpha} \end{aligned} \tag{2}$$

[3]The condition $y-g-f \geq 0$ ensures that all lottery outcomes are positive final wealth levels. This keeps the analysis within the domain of the power value function used in the RDU valuation and avoids mixing with loss-domain.

[4]The status quo reference point is the decision maker's initial endowment, y, relative to which the gains and losses in the temperate and intemperate lotteries are defined.

Risk-aversion, in the absence of probability distortion, which is standard expected utility, implies the temperate lottery choice, see e.g. Deck and Schlesinger (2014). Consequently following the method of Paya et al. (2023) we assume risk neutrality to determine how probability weighting impacts on the temperate or intemperate lottery choices in the absence of risk-aversion. Assuming risk-neutrality and all positive payoffs the necessary condition for probability weighting to imply the **intemperate** choice by a RDU DM or the **temperate** choice by the CPT DM, (see Paya et al. (2023)), is given by the same condition, namely (see the equation derivation in Appendix A):

$$1 + 2w(0.5) > 2w(0.125) + 2w(0.875) \tag{3}$$

We evaluate condition (3) for the RDU DM assuming the probability weighting function specified in (1) and (2) with parameter values derived from binary lottery choices and also imposing no distortion of the 0.5 probability. This evaluation reveals that the condition holds for the RDU DM for values of the probability distortion parameter reported by TK , $\delta = 0.61$ and BS, $\delta = 0.715$ (See Appendix A). Therefore assuming risk neutrality, the necessary conditions for the intemperate lottery choice by the RDU DM or the temperate choice by the CPT DM are met for plausible values of the probability distortion parameter. Since risk-aversion implies the temperate lottery choice in the absence of probability distortion the RDU DM will only make the intemperate lottery choice if the effect of probability distortion reverses the effect of risk-aversion.

To illustrate the fourth order choices of RDU DM we employ the representative parameter values for the power exponent, α, and the probability weighting function, δ, reported by Tversky and Kahneman (1992) ($\alpha = 0.88, \delta = 0.61$) and Bernheim and Sprenger (2020) ($\alpha = 0.941, \delta = 0.715$). These parameter values were estimated from second order binary lottery choices where the CPT DM and RDU DM make the same lottery choices except for those with 0.5 probabilities. Quiggin (1982, p328) assumed that in binary lottery choices a probability of 0.5 would not be distorted[5]. As a further check to determine how imposition of this restriction impacts on the fourth order lottery choices of the RDU DM, we also report evaluations of fourth order lottery choices imposing $w(0.5) = 0.5$.

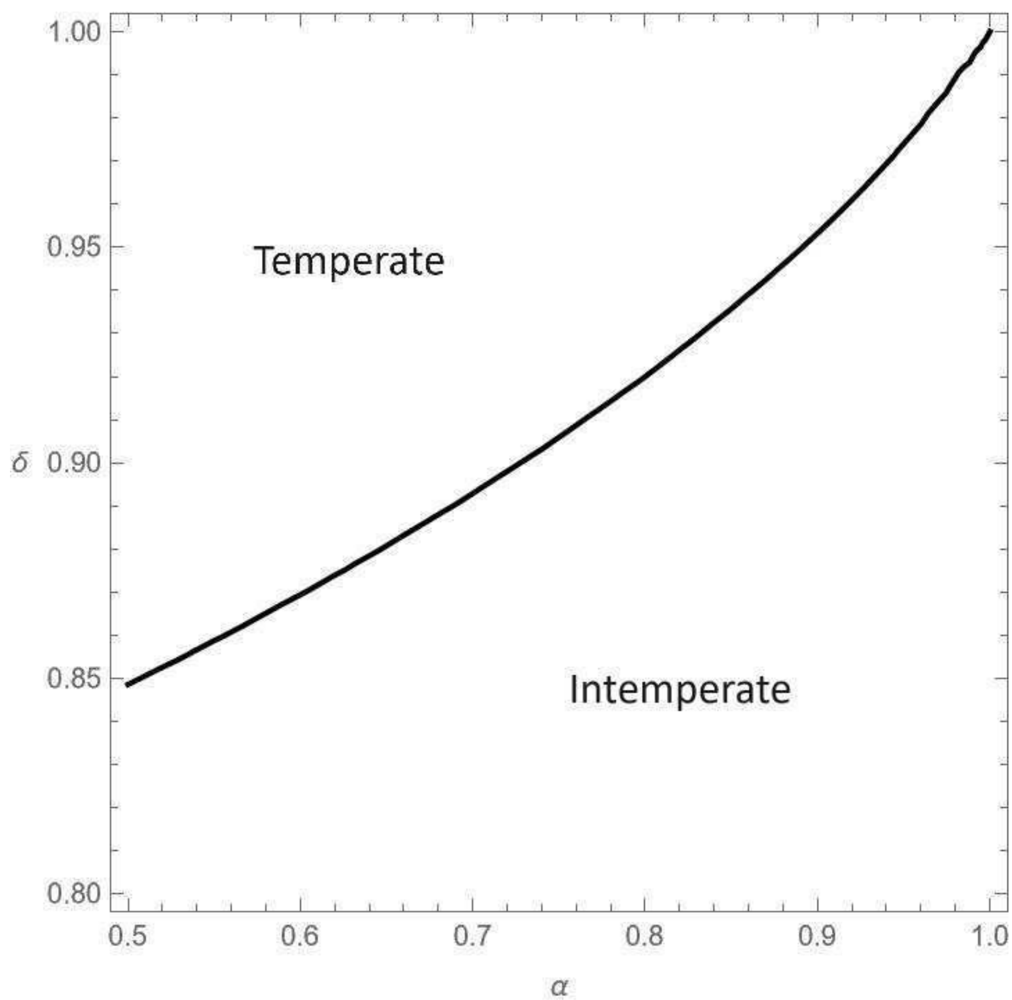
In Table I we report two examples of lottery choices exhibiting relatively high and low values of the endowment y. The expected values of the lottery choices exhibited in Table 1 reveal that the RDU DM prefers the intemperate lottery for both high and low values of y. We also note that the imposition of no probability distortion in RDU when $p = 0.5$ slightly increases the difference in the expected values of the temperate and intemperate lottery choices. Consequently the analysis appears robust and illustrates that the RDU DM and CPT DM make different fourth order lottery choices for a range of plausible parameter values of the probability weighting function and power value function.

[5]Quiggin (1982, p328) wrote “The claim that 50-50 bets will not be subjectively distorted seems reasonable”.

Table I. Values of Temperate and Intemperate Lotteries

Lottery Name	Setting (y,g,f)	(Probabilities; Payoffs)	
$L1b$	Temperate$(120, 8, 2)$	$(0.25, 0.25, 0.25, 0.25; 128, 122, 118, 112)$	
$L1a$	Intemperate$(120, 8, 2)$	$(0.125, 0.125, 0.5, 0.125, 0.125; 130, 126, 120, 114, 110)$	
$L2b$	Temperate$(12, 8, 2)$	$(0.25, 0.25, 0.25, 0.25; 20, 14, 10, 4)$	
$L2a$	Intemperate$(12, 8, 2)$	$(0.125, 0.125, 0.5, 0.125, 0.125; 22, 18, 12, 6, 2)$	
	CPT(TK,BS)	RDU(TK,BS) no restriction imposed	RDU(TK,BS) 0.5 restriction imposed
$L1b$	$(66.97, 90.08)$	$(68.12, 90.85)$	$(67.97, 90.74)$
$L1a$	$(66.90, 90.04)$	$(68.18, 90.88)$	$(68.18, 90.88)$
$L2b$	$(7.97, 9.82)$	$(9.50, 10.71)$	$(9.30, 10.59)$
$L2a$	$(7.81, 9.76)$	$(9.53, 10.73)$	$(9.53, 10.73)$

Figure 1. Values of α and δ for the RDU DM's Temperate and Intemperate Lottery choices, $y = 120, g = 8, f = 2$



As a further test of the robustness of our results in Figure 1 we illustrate diagrammatically the temperate or intemperate lottery choices $L1b$ and $L1a$ of the RDU DM for all the feasible values of the risk-aversion and probability distortion parameters, α and δ.

For the lottery pair considered in Figure 1, the RDU DM will not choose the temperate lottery unless the probability distortion and risk-aversion parameters satisfy approximately $\delta > 0.85$ and $\delta > \alpha$. Parameter values of these relative magnitudes, or even close to these values, have not been reported in the extant experimental literature.

3 Conclusion

Employing a standard probability weighting function and a power value function exhibiting representative parameter values we have demonstrated the new finding that an RDU DM will make intemperate rather than temperate fourth order lottery choices. This finding offers a new explanation for the relatively high proportions of intemperate lottery choices reported in the extant experimental research.

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Appendix A Probability Weighting and the Intemperate Choice under Rank-Dependent Utility

To isolate the role of probability weighting from risk -aversion in the choice between the temperate and intemperate lotteries, we follow the approach of Paya et al. (2023) and assume risk neutrality. Expected utility theory and hence risk-aversion, in the absence of probability distortion, implies a preference for the temperate lottery (Deck and Schlesinger, 2014). In contrast, assuming rank dependent utility (RDU), the probability weighting function can change this ranking.

For the temperate lottery, L_1, the RDU valuation is

$$\begin{aligned} V(L_1) = {} & w(0.25)(y-g) \\ & + \big[w(0.5) - w(0.25)\big](y-f) \\ & + \big[w(0.75) - w(0.5)\big](y+f) \\ & + \big[1 - w(0.75)\big](y+g). \end{aligned}$$

For the intemperate lottery, L_2, the RDU valuation is

$$\begin{aligned} V(L_2) = {} & w(0.125)(y-g-f) \\ & + \big[w(0.25) - w(0.125)\big](y-g+f) \\ & + \big[w(0.75) - w(0.25)\big]y \\ & + \big[w(0.875) - w(0.75)\big](y+g-f) \\ & + \big[1 - w(0.875)\big](y+g+f). \end{aligned}$$

Expanding both expressions and cancelling common terms, the decision maker prefers the intemperate lottery whenever

$$V(L_2) > V(L_1)$$

which is equivalent to

$$1 + 2w(0.5) > 2w(0.125) + 2w(0.875)$$

Imposing $w(0.5) = 0.5$ and using the Tversky–Kahneman probability weighting function, the difference

$$D = [1 + 2w(0.5)] - [2w(0.125) + 2w(0.875)]$$

is approximately 0.22 for the TK (parameter value $\delta = 0.61$) and 0.10 for the BS (parameter value $\delta = 0.715$). Since $D > 0$ in both cases, the probability weighting condition is satisfied under both parameterizations, implying that the RDU decision maker prefers the intemperate lottery, $V(L2) > V(L1)$, under risk neutrality.