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On the equivalence of optimal mechanisms with loss and disappointment aversion

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ABSTRACT

We consider a standard, quasi-linear mechanism design setting in which agents' outcomes consist of a binary part and a transfer, thus encompassing applications such as auctions, bilateral trade or public good provision. We augment preferences by allowing for loss aversion (Kőszegi and Rabin, 2007) and disappointment aversion (Bell, 1985; Loomes and Sugden, 1986). While the preferences induced by these models only have a trivial intersection given by classical expected utility (Masatlioglu and Raymond, 2016), we show that the optimal mechanisms for the two types of preferences are equivalent across a broad range of problems and thus display a remarkable robustness.

1. Introduction

The importance of reference-dependent preferences within economics is well-established.[1] However, there seems to be no consensus on how to model such preferences. First and foremost is, of course, the original work on prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1991) in which the reference point is fixed and typically interpreted as the status quo. Alternatively, Spiegler (2012) allows for a fixed reference point but only with feelings of loss and no feelings of gains. Moving beyond a fixed reference point, Kőszegi and Rabin (2006, 2007) (henceforth, KR) propose an endogenously determined reference point, which is given by a lottery's full distribution.[2]

This variety of modeling approaches need not be an issue and might even be considered a strength. However, in some situations it may lead to uncertainty about the right modeling approach. Consider the models by Bell (1985) and Loomes and Sugden (1986) (henceforth, BLS). There the reference point is determined endogenously as in KR, but it corresponds to the lottery's certainty equivalent. Masatlioglu and Raymond (2016) (henceforth, MR) study the reference-dependent risk preferences of KR under their choice-acclimating personal equilibrium (CPE), and, among other, its relation to the models by BLS. As MR note, the models by KR and BLS aim to capture similar psychological processes and have similar formulations, even if they are distinct in their description of the reference-point formation. Remarkably, despite the similarities in the underlying psychology as well as the formulation, MR show that the preferences induced by these models share only a trivial intersection: classical expected utility. Put simply, while these models of reference-dependent preferences appear to be quite similar, they actually are not the same at all and should in general not be treated interchangeably when making modeling choices.[3]

Consider the designer of some economic institution who is aware that individuals' behavior is reference-dependent, but does not know exactly how this unfolds and may thus be uncertain about the right modeling approach. MR's finding that even seemingly similar models may actually induce quite distinct behavior may appear ominous in the face of such uncertainty. In what follows, however, we will see that the potential inability to distinguish between the models of KR and BLS need not pose an issue when designing economic institutions. In particular, we show that when outcomes consist of a binary component and a transfer,

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1 See for instance Camerer (2011) or, more recently, O'Donoghue and Sprenger (2018).

2 Arguably, the model of Kőszegi and Rabin has become the workhorse model, but it is not uncontested. See for instance Heffetz and List (2014) and Gneezy et al. (2017).

3 See Section 5 in O'Donoghue and Sprenger (2018) for a discussion of behavioral differences between the models of KR and BLS.

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encompassing settings such as bilateral trade, auctions or public good provision, the optimal mechanisms when employing either the model by KR or BLS are equivalent across a broad range of problems.

2. Model

An environment $E = [I, X, (\Theta_i, u_i)_{i\in I}, F_i]$ is characterized as follows. There is a finite set of N agents denoted by $I = \{1, \dots, N\}$. The set of social alternatives is given by $X = \{0, 1\}^N \times \mathbb{R}^N$ with typical element $(y_1, \dots, y_N, t_1, \dots, t_N)$ consisting of a binary allocation rule and a transfer for each agent, thus encompassing settings such as auctions, bilateral trade or public good provision. The type of agent i is privately and independently drawn from a distribution F_i with bounded support $[a_i, b_i] = \Theta_i \subset \mathbb{R}_+$. Throughout, we use the conventional notation $\Theta = \prod_{i=1}^N \Theta_i$ and $\Theta_{-i} = \prod_{j\neq i} \Theta_j$, with typical elements θ and θ_{-i}, respectively. The agents and the designer have identical prior beliefs.

A social choice function (SCF) $f : \Theta \to X$ assigns a collective choice $f(\theta_1, \dots, \theta_N) \in X$ to each possible profile of the agents' types $(\theta_1, \dots, \theta_N) \in \Theta$. We denote the set of all SCFs $\mathcal{F}$. A mechanism $\Gamma = (M_1, \dots, M_N, g)$ is a collection of N message sets $(M_1, \dots, M_N)$ and an outcome function $g : M_1 \times \cdots \times M_N \to X$. A pure strategy for agent i in a mechanism Γ is a function $s_i : \Theta_i \to M_i$. Let S_i denote the set of all pure strategies of agent i. Further, we denote the truthful strategy $s_i^t(\theta_i) = \theta_i$.

Translating from MR to our quasi-linear setting, the riskless total utility from alternative x of an agent with type θ_i is given by

$$u_i(x, r_i, \theta_i) = \underbrace{y_i\theta_i - t_i}_{\text{material utility}} + \underbrace{\eta_i^1\mu_i^1(y_i\theta_i - r_i^1\theta_i) + \eta_i^2\mu_i^2(r_i^2 - t_i)}_{\text{gain–loss utility}} \tag{1}$$

where $\eta_i^k \geq 0$ are the weights put on gain–loss utility in the consumption and money dimension, respectively, and $\mathbf{r}_i = \{r_i^1, r_i^2\}$ are the so-called riskless reference levels. The value functions

$$\mu_i^k(s) = \begin{cases} s & s \geq 0, \\ \lambda_i^k s & s < 0, \end{cases}$$

with $\lambda_i^k > 1$ capture loss aversion. As noted in the introduction, the difference between KR and BLS preferences lies in the formation of the reference point. In KR it is given by the full distribution of outcomes, whereas it corresponds to the certainty equivalent in BLS. Thus, expected utility of message m_i given the other agents' strategies in the case of KR utility is given by[4]

$$\begin{aligned} U_i^{KR}(m_i, s_{-i}|\theta_i) = &\int_{\Theta_{-i}} y_i(m_i, s_{-i})\theta_i - t_i(m_i, s_{-i})\, dF_{-i}(\theta_{-i}) \\ &+ \int_{\Theta_{-i}}\int_{\Theta_{-i}} \eta_i^1\mu_i^1\left(y_i(m_i, s_{-i})\theta_i - y_i(m_i, s'_{-i})\theta_i\right)\, dF_{-i}(\theta'_{-i})dF_{-i}(\theta_{-i}) \\ &+ \int_{\Theta_{-i}}\int_{\Theta_{-i}} \eta_i^2\mu_i^2\left(t_i(m_i, s'_{-i}) - t_i(m_i, s_{-i})\right)\, dF_{-i}(\theta'_{-i})dF_{-i}(\theta_{-i}) \end{aligned} \tag{2}$$

and in the case of BLS utility by

$$\begin{aligned} U_i^{BLS}(m_i, s_{-i}|\theta_i) = &\int_{\Theta_{-i}} y_i(m_i, s_{-i})\theta_i - t_i(m_i, s_{-i})\, dF_{-i}(\theta_{-i}) \\ &+ \int_{\Theta_{-i}} \eta_i^1\mu_i^1\left(y_i(m_i, s_{-i})\theta_i - \int_{\Theta_{-i}} y_i(m_i, s'_{-i})\theta_i dF_{-i}(\theta'_{-i})\right) dF_{-i}(\theta_{-i}) \\ &+ \int_{\Theta_{-i}} \eta_i^2\mu_i^2\left(\int_{\Theta_{-i}} t_i(m_i, s'_{-i})dF_{-i}(\theta'_{-i}) - t_i(m_i, s_{-i})\right) dF_{-i}(\theta_{-i}) \end{aligned} \tag{3}$$

Following Eisenhuth (2019) we obtain extensions of standard results from mechanism design with quasi-linear utility.[5] In particular, a SCF f is incentive compatible (IC) if the truthful profile is an equilibrium strategy in the direct mechanism, allowing us to focus on direct mechanisms and thus simplify notation accordingly. Next, defining

$$\begin{aligned} \tilde{v}_i^{KR}(m_i) = &\int_{\Theta_{-i}} y_i(m_i, \theta_{-i})dF_{-i}(\theta_{-i}) \\ &+ \eta_i^1 \int_{\Theta_{-i}}\int_{\Theta_{-i}} \mu_i^1\left(y_i(m_i, \theta_{-i}) - y_i(m_i, \theta'_{-i})\right)\, dF_{-i}(\theta'_{-i})dF_{-i}(\theta_{-i}) \\ = &\bar{v}_i^{KR}(m_i) + \nu_i^{KR}(m_i) \end{aligned}$$

$$\begin{aligned} \tilde{t}_i^{KR}(m_i) = &\int_{\Theta_{-i}} t_i(m_i, \theta_{-i})\, dF_{-i}(\theta_{-i}) \\ &- \eta_i^2 \int_{\Theta_{-i}}\int_{\Theta_{-i}} \mu_i^2\left(t_i(m_i, \theta'_{-i}) - t_i(m_i, \theta_{-i})\right)\, dF_{-i}(\theta'_{-i})dF_{-i}(\theta_{-i}) \\ = &\bar{t}_i^{KR}(m_i) - \tau_i^{KR}(m_i) \end{aligned}$$

and analogously $\tilde{v}_i^{BLS}$ and $\tilde{t}_i^{BLS}$, allows us to write utility compactly as $U_i(m_i) = \theta_i\tilde{v}_i(m_i) - \tilde{t}_i(m_i)$. It then follows, as in the classical case without reference-dependence, that a SCF f is incentive compatible if and only if,

(i) $\tilde{v}_i$ is non-decreasing, and
(ii) we can write utility as

$$U_i(\theta_i, \theta_{-i}|\theta_i) = U_i(a_i, \theta_{-i}|a_i) + \int_{a_i}^{\theta_i} \tilde{v}_i(t)\, dt. \tag{4}$$

3. Equivalence of optimal mechanisms

One can think of various maximization problems in the present context. Arguably, the most natural problems are the maximization of the designer's revenue and the maximization of some notion of agents' welfare. In the latter case the designer may choose to maximize total welfare, including the gain–loss utility, or only material utility, or some convex combination of them, depending on what is deemed an appropriate welfare criterion. Formally, consider the problems

$$\max_{(y_1,\dots,y_N,t_1,\dots,t_N)} \sum_{i=1}^N \int_{a_i}^{b_i} \bar{t}_i(\theta_i)\, dF_i(\theta_i) \tag{RM}$$

subject to IC and participation constraints, and

$$\max_{(y_1,\dots,y_N,t_1,\dots,t_N)} \sum_{i=1}^N \int_{a_i}^{b_i} \alpha\left(\theta_i\bar{v}_i(\theta_i) - \bar{t}_i(\theta_i)\right) + \beta\left(\theta_i\nu_i(\theta_i) + \tau_i(\theta_i)\right) dF_i(\theta_i) \tag{UM}$$

subject to IC as well as participation and budget constraints. Problem (RM) aims to maximize the designer's revenue. Problem (UM) aims to maximize agents' utility, where material and gain–loss utility are weighted by α and β with $\alpha + \beta = 1$, respectively.

[4] To economize notation we suppress dependence on the mechanism and write s_{-i} instead of $s_{-i}(\theta_{-i})$.

[5] Whenever we suppress the KR/BLS label on the utility function, we are referring to both kinds of preferences.

To illustrate, consider the revenue maximization problem. Making use of incentive compatibility, we can rewrite the objective function to

$$\sum_{i=1}^{N}\int_{a_i}^{b_i}\left(\theta_i\tilde{v}_i(\theta_i)+\tau_i(\theta_i)-\int_{a_i}^{\theta_i}\tilde{v}_i(s)-U_i(a_i)\,ds\right)\,dF_i(\theta_i), \tag{5}$$

subject to $\tilde{v}_i$ being non-decreasing for all $i\in I$ and the participation constraint, from which $U_i(a_i)=0$ follows. The following Lemmas are proved in the appendix.

Lemma 1. *We have $\tau_i(\theta_i)\le 0$ for all i and $\theta_i\in\Theta_i$ and $\tau_i(\theta_i)=0$ if and only if the transfer of an agent with type θ_i does not depend on the types θ_{-i}.*

This slightly generalizes the analogous result in Eisenhuth (2019) beyond auctions and to BLS preferences. In words, expected gain–loss utility is weakly negative and zero if and only if there is no variation in transfers from an interim perspective.

Lemma 2. *We have $\tilde{v}_i^{KR}=\tilde{v}_i^{BLS}$ for all $i\in I$.*

Thus, regarding gain–loss utility in the consumption dimension, the two different specifications of the reference point in KR and BLS are equivalent. This result is driven by the lack of "mixed feelings", i.e., experiencing both gains and losses at the same time. In BLS mixed feelings never arise and they do not arise in KR because of the binary nature of the consumption outcomes.[6]

Going back to the formulation of the revenue maximization problem in Eq. (5), we see that the designer will optimally choose transfers such that $\tau_i(\theta_i)=0$. Further, it follows from Lemma 2 that the maximization problem is the same for either KR or BLS preferences, thus the same mechanism is optimal in either case.

Theorem 1. *The optimal mechanisms for the problems (RM) and (UM) coincide for KR and BLS preferences. Further, if utility derived in the money dimension is not reference dependent, that is, $\eta_i^2=0$ for all $i\in I$, then the optimal mechanisms in* any *problem coincide for KR and BLS preferences.*

Proof. The proof for the problem (RM) follows directly from the derivations in the text above. For the problem (UM) note that $\tau_i(\theta_i)\le 0$ by Lemma 1 and thus $\tau_i(\theta_i)=0$ is optimal. By Lemma 2, all terms in the objective function and the constraints coincide conditional on $\tau_i(\theta_i)=0$ for all i and $\theta_i\in\Theta_i$ and so the same mechanism will be optimal for both types of preferences.

If $\eta_i^2=0$ for all $i\in I$, the expected utility of agents coincides for KR and BLS preferences for any problem by Lemma 2, implying that optimal mechanisms coincide, too. □

4. Conclusion

The present paper contributes to the literature on robust mechanism design by deriving mechanisms which are optimal, even when the designer does not know the exact specification of the reference-point formation in agents' preferences.[7] As such, this robustness is much closer to the notion of "behavioral robustness" given different degrees of reciprocity among agents studied in Bierbrauer and Netzer (2016), rather than the more classical approach in Bergemann and Morris (2005). Beyond this general insight, our result has some immediate applications. First, the optimal auction derived in Eisenhuth (2019) using KR preferences (with narrow bracketing) is also optimal if one assumes BLS preferences. Second, the optimal mechanisms derived in a bilateral trade setting augmented by KR preferences in Benkert (2022) carry over to the case of BLS preferences, too. Finally, Balzer et al. (2021) compare the Dutch and the first-price auction when bidders have KR preferences. While they do not consider the problem of designing optimal mechanisms, our result nevertheless offers some insights: Given the binary outcomes in both consumption (getting the good or not) *and* money (paying the bid or not), we can apply Lemma 2 on both dimensions, implying that the expected utility of a KR and a BLS agent coincide. Thus, their results using KR preferences with CPE extend to BLS preferences.

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Appendix. Proofs

Proof of Lemma 1

We begin with KR utility. Recall that

$$\tau_i^{KR}(\theta_i) = \eta_i^2\int_{\Theta_{-i}}\int_{\Theta_{-i}}\mu_i^2\left(t_i^f(\theta_i,\theta'_{-i})-t_i^f(\theta_i,\theta_{-i})\right)\,dF_i(\theta'_{-i})\,dF(\theta_{-i}).$$

We can rewrite these expressions as follows

$$\begin{aligned}
\tau_i^{KR}&(\theta_i)\\
&=\eta_i^2\int_{\Theta_{-i}}\int_{\Theta_{-i}}\mu^2\left(t_i^f(\theta_i,\theta'_{-i})-t_i^f(\theta_i,\theta_{-i})\right)\,dF_i(\theta'_{-i})\,dF(\theta_{-i})\\
&=\eta_i^2\int_{\Theta_{-i}}\int_{\Theta_{-i}}\left(t_i^f(\theta_i,\theta'_{-i})-t_i^f(\theta_i,\theta_{-i})\right)\mathbb{1}[t_i^f(\theta_i,\theta'_{-i})\\
&\quad-t_i^f(\theta_i,\theta_{-i})>0]\,dF_i(\theta'_{-i})\,dF(\theta_{-i})\\
&\quad+\eta_i^2\int_{\Theta_{-i}}\int_{\Theta_{-i}}\lambda^2\left(t_i^f(\theta_i,\theta'_{-i})-t_i^f(\theta_i,\theta_{-i})\right)\mathbb{1}[t_i^f(\theta_i,\theta'_{-i})\\
&\quad-t_i^f(\theta_i,\theta_{-i})<0]\,dF_i(\theta'_{-i})\,dF(\theta_{-i})\\
&=\eta_i^2\int_{\Theta_{-i}}\int_{\Theta_{-i}}\left(t_i^f(\theta_i,\theta'_{-i})-t_i^f(\theta_i,\theta_{-i})\right)\mathbb{1}[t_i^f(\theta_i,\theta'_{-i})\\
&\quad-t_i^f(\theta_i,\theta_{-i})>0]\,dF_i(\theta'_{-i})\,dF(\theta_{-i})\\
&\quad-\eta_i^2\lambda_i^2\int_{\Theta_{-i}}\int_{\Theta_{-i}}\left(t_i^f(\theta_i,\theta_{-i})-t_i^f(\theta_i,\theta'_{-i})\right)\mathbb{1}[t_i^f(\theta_i,\theta_{-i})\\
&\quad-t_i^f(\theta_i,\theta'_{-i})>0]\,dF_i(\theta'_{-i})\,dF(\theta_{-i})\\
&=\eta_i^2(1-\lambda_i^2)\int_{\Theta_{-i}}\int_{\Theta_{-i}}\left(t_i^f(\theta_i,\theta_{-i})-t_i^f(\theta_i,\theta'_{-i})\right)\mathbb{1}[t_i^f(\theta_i,\theta_{-i})\\
&\quad-t_i^f(\theta_i,\theta'_{-i})>0]\,dF_i(\theta'_{-i})\,dF(\theta_{-i}),
\end{aligned}$$

[6] Herweg et al. (2010) offer an insightful discussion of the difference between KR and BLS in their principal–agent setting. They argue that the optimal payment scheme differs under BLS from KR, precisely because KR allows for such mixed feelings.

[7] There is a connection to the literature on behavioral industrial organization, too. Karle and Möller (2020) examine competition with loss-averse consumers à la KR in an advance purchase setting. They show that their results are comparable to those obtained using BLS preferences but do not obtain equivalence.

where $\mathbb{1}$ denotes the indicator function. Thus, since $\lambda_i^2 > 1$ we find $\tau_i(\theta_i) \leq 0$. For the case of BLS utility we have

$$\tau_i^{BLS}(\theta_i) = \eta_i^2 \int_{\Theta_{-i}} \mu_i^2 \left(\int_{\Theta_{-i}} t_i^f(\theta_i, \theta'_{-i}) dF_i(\theta'_{-i}) - t_i^f(\theta_i, \theta_{-i}) \right) dF(\theta_{-i}).$$

Thus, by Jensen's inequality we get

$$\begin{aligned}\tau_i^{BLS}(\theta_i) &= \eta_i^2 \int_{\Theta_{-i}} \mu_i^2 \left(\int_{\Theta_{-i}} t_i^f(\theta_i, \theta'_{-i}) dF_i(\theta'_{-i}) - t_i^f(\theta_i, \theta_{-i}) \right) dF(\theta_{-i}) \\ &\leq \eta_i^2 \mu_i^2 \left(\int_{\Theta_{-i}} \left(\int_{\Theta_{-i}} t_i^f(\theta_i, \theta'_{-i}) dF_i(\theta'_{-i}) - t_i^f(\theta_i, \theta_{-i}) \right) dF(\theta_{-i}) \right) \\ &= 0.\end{aligned}$$

Proof of Lemma 2

Noting that $y_i(\theta_i, \theta_{-i}) \in \{0, 1\}$ we have

$$\begin{aligned}&\tilde{v}_i^{BLS}(\theta_i) \\ &= \int_{a_i}^{b_i} \eta_i^1 \mu_i^1 \left(y_i(\theta_i, \theta_{-i})\theta_i - \int_{\Theta_{-i}} y_i(\theta_i, \theta'_{-i})\theta_i dF_{-i}(\theta'_{-i}) \right) dF_{-i}(\theta_{-i}) \\ &= \theta_i \eta_i^1 \int_{a_i}^{b_i} y_i(\theta_i, \theta_{-i}) \left(1 - \int_{a_i}^{b_i} y_i(\theta_i, \theta'_{-i}) dF_{-i}(\theta'_{-i}) \right) dF_{-i}(\theta_{-i}) \\ &- \theta_i \eta_i^1 \int_{a_i}^{b_i} \lambda_i^1 (1 - y_i(\theta_i, \theta_{-i})) \int_{a_i}^{b_i} y_i(\theta_i, \theta'_{-i}) dF_{-i}(\theta'_{-i}) \, dF_{-i}(\theta_{-i}) \\ &= \theta_i \eta_i^1 \int_{a_i}^{b_i} \int_{a_i}^{b_i} y_i(\theta_i, \theta_{-i}) \left(1 - y_i(\theta_i, \theta'_{-i})\right) \\ &- \lambda_i^1 (1 - y_i(\theta_i, \theta_{-i})) y_i(\theta_i, \theta'_{-i}) dF_{-i}(\theta'_{-i}) dF_{-i}(\theta_{-i}) \\ &= \theta_i \eta_i^1 \int_{a_i}^{b_i} \int_{a_i}^{b_i} \mu_i^1 (y(\theta_S, \theta'_B) - y(\theta_S, \theta_B)) \, dF_{-i}(\theta'_{-i}) dF_{-i}(\theta_{-i}) \\ &= \tilde{v}_i^{KR}(\theta_i).\end{aligned}$$

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