DISCLOSURE OF CAUSAL VS. CORRELATIONAL INFORMATION IN MARKETS WITH CORRELATION NEGLECT

ANDRIY ZAPECHELNYUK ⓡ DIMITRI MIGROW

We address the question of whether regulators should disclose consumer traits in competitive risk-sharing markets, such as insurance or credit markets, when consumers suffer from correlation neglect. We find that disclosure improves welfare if the trait has a strong causal effect on consumer's risk. However, when correlation plays a dominant role, disclosure of the trait leads to mispricing and lowers market participation. Our results highlight that causal effects support transparency, while correlational effects may justify privacy protection.

KEYWORDS: information disclosure, adverse selection, correlation neglect, causality, correlation, privacy, insurance market, credit market.

1. INTRODUCTION

Policies that promote transparency in insurance, credit, and other risk-sharing markets are often based on the assumption that consumers and firms interpret data in the same way. However, growing empirical evidence suggests that consumers frequently overlook how observable traits such as income, health status, or credit score correlate with unobservable traits such as financial discipline, lifestyle choices, or financial literacy. At the same time, firms that have access to large datasets typically include these correlations into their pricing decisions. We asks whether a regulator should disclose information about observable consumer traits when such a misperception gap between firms and consumers exists. In particular, in a setting where consumers neglect correlation between observable and unobserved traits, we study how such disclosure policies depend on the nature of observable information, namely, whether and to which extent the observable traits causally determine the outcomes, and to which extent they are correlated with the outcomes.

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Andriy Zapechelnyuk: School of Economics, University of Edinburgh, azapech@gmail.com

Dimitri Migrow: School of Economics, University of Edinburgh, dimitri.migrow@gmail.com

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To formalize our argument, we consider a market in which a risk-averse consumer faces a lottery, whose outcome depends on the consumer's observable characteristics and an unobservable shock. Several risk-neutral firms compete by offering fixed payments in exchange for the lottery's outcome. The key feature of the model is how the firms and the consumer interpret the relationship between the observable characteristics and the lottery's outcome. The firms recognize that the consumer characteristics affect the outcome directly, as well as indirectly, through the correlation with the unobservable shock. In contrast, the consumer suffers from correlation neglect. She only takes into account the direct, causal effect of the characteristrics on the outcome. In other words, the consumer believes that the unobserved shock affects the outcome independently of the observable characteristics.

Our main focus in on regulation of information disclosure. We say that a given consumer characteristic is *disclosed* if the regulator allows the firms to condition their payments on it; otherwise, we say that the characteristic is *protected*.

When the characteristic is disclosed, the firms' pricing decisions reflect both causal and correlational effects of the characteristic. Thus, the firms are able to tailor contracts better to the consumer's objective risk type. However, the consumer ignores the correlational effect, thus underestimating the total effect of the characteristic on the outcome. As a result, from the consumer's viewpoint, the firms *misprice* the lottery, upwards or downwards, depending on the realized value of the characteristic. When the lottery is underpriced, the consumer might reject the firm's payment, even though accepting the payment is strictly beneficial under the true model. This leads to reduced participation in the market.

When the characteristic is protected, the firms must treat consumers with different values of that characteristic identically, as they would if they did not observe it at all. In this case, the consumer's correlation neglect plays no role, and no mispricing occurs. However, as the firms's pricing decisions are based on market expectations, the market suffers from adverse selection.

We show that disclosing the characteristic is more beneficial when it affects the outcome more through the causality channel and less through the correlation channel. When the causality effect dominates, the consumer's and firms' interpretations of this effect on the true underlying risk is highly aligned. This helps to alleviate adverse selection without causing any significant mispricing. However, when the correlation channel dominates, disclosure of the characteristic leads to a severe mispricing from the consumer's perspective, which induces a drop in participation and, at the same time, is not very effective in dealing with adverse selection.

Our framework applies to a wide range of markets where pricing depends on consumer risk. In health insurance, for instance, income often strongly correlates with unobserved health risks, such as lifestyle choices. If consumers fail to account for this correlation, disclosing income in competitive health insurance markets may lead to severe mispricing effect resulting in low-income individuals unwilling to purchase the insurance cover. In contrast, in credit markets income might be a more direct determinant of the repayment capacity. Here, even if consumers misunderstand the additional correlation between income and unobserved risks behind pricing adjustments – which happens because income might be correlated with personal fiscal discipline or access to liquidity – the impact of the correlation channel may not be as strong as in health insurance markets. This may make disclosure of income more beneficial for welfare.

Our paper contributes to the growing literature on the consequences of behavioral misperceptions for market outcomes and welfare, particularly the effect of correlation neglect by consumers. The correlation neglect has been well documented both in empirical studies and in lab experiments (e.g., Brunnermeier, 2009, Coval et al., 2009, Hellwig, 2009, Eyster and Weizsacker, 2010, Ortoleva and Snowberg, 2015, Enke and Zimmermann, 2019, Jiao et al., 2020). Theoretical literature has modeled environments where decision-makers suffer from varying degrees of correlation misperception or misspecification (DeMarzo et al., 2003, Eyster and Piccione, 2013, Ortoleva and Snowberg, 2015, Levy and Razin, 2015, 2022). Ellis and Piccione (2017) provide an axiomatic foundation for individual choice in an environment where agents fail to account for complexity.

Our work also connects to the broader literature on economic decision-making under misspecified models which examines errors in interpreting causal relationships such as mistakes driven by the reverse-causality error (Spiegler, 2022), or wrong inference from data, where decision-makers have a flawed understanding of causality (Spiegler, 2020).

We also relate to the literature on information disclosure in markets (Bergemann et al., 2015, Azevedo and Gottlieb, 2017, Roesler and Szentes, 2017, Hidir and Vellodi, 2021, Garcia and Tsur, 2021, Farinha Luz et al., 2023, Zapechelnyuk and Migrow, 2025). Our key departure from the existing literature lies in introducing correlation neglect on the consumer side, allowing us to identify a novel mispricing effect that affects regulatory disclosure decisions in competitive risk-sharing markets.

2. MODEL

A consumer faces a lottery y determined by real-valued random variables x and ε through a causality equation

$$y = \alpha + \beta x + \varepsilon,$$

where $\alpha \in \mathbb{R}$ and $\beta \in [0, 1]$ are parameters. Variable x is a consumer's observable characteristic that our analysis focuses on. We will refer to x as the consumer's *type*. All other observable information is fixed and summarized in the parameter α. Variable ε summarizes unobservable information. W.l.o.g., assume[1]

$$\mathbb{E}[x] = \mathbb{E}[\varepsilon] = 0.$$

The consumer is a risk-averse expected utility maximizer. Her utility from lottery y given x is $\mathbb{E}[u(y)|x]$, where u is a strictly increasing and strictly concave utility function.

There are several risk-neutral firms that offer nonrandom payments to the consumer in exchange for the lottery y. The firms may or may not observe x (we will analyse and compare both cases). Let I denote what firms observe. The firms compete for the consumer, so the consumer will only trade y for the highest offered payment. Thus, in equilibrium, this payment will be equal to the expected value of the lottery given information I:

$$p_I = \mathbb{E}[y|I].$$

The key novelty of our model is that the firms and the consumer have different understanding of the joint distribution of x and ε.

The firms believe that x and ε are correlated; specifically, $\mathbb{E}[\varepsilon|x] = (1 - \beta)x$. Thus, the random payoff y is affected by x directly (with weight β) and indirectly through correlation with ε (with weight $1 - \beta$). Parameter β captures the degree of *causality* of x. The higher β, the more x directly causes y and the less it affects y through correlation with ε. So, x is a pure causality variable when $\beta = 1$ and it is a pure correlation variable when $\beta = 0$.

Unlike the firms, the consumer suffers from correlation neglect and thinks that x and ε are independent. For tractability, assume that from the firms' perspective ε can be written

[1] This assumption is w.l.o.g., as if $\mathbb{E}[x] \neq \mathbb{E}[\varepsilon]$, then we can define $y = \hat{\alpha} + \beta x + \hat{\varepsilon}$ with $\hat{\varepsilon} = \varepsilon + \mathbb{E}[x] - \mathbb{E}[\varepsilon]$ and $\hat{\alpha} = \alpha - \mathbb{E}[x] + \mathbb{E}[\varepsilon]$.

as the sum of its expected value $(1-\beta)x$ and noise z with zero mean:

$$\varepsilon = (1-\beta)x + z, \text{ with } \mathbb{E}[z|x] = 0.$$

From the consumer's perspective, ε is pure noise:

$$\varepsilon = z.$$

In summary, substituting ε with the respective interpretations of the firms and the consumer, we obtain:

$$\text{Firms' model: } y = \alpha + x + z,$$
$$\text{Consumer's model: } y = \alpha + \beta x + z.$$

Assume that x has convex support $X \subseteq \mathbb{R}$ and density $f(X)$, and z has convex support $Z \subseteq \mathbb{R}$ and conditional density $g(z|x)$ for each $x \in X$.

We evaluate the welfare from ex-ante perspective (before x is realized), using the firm's model. We interpret the consumer as being mistaken by neglecting the existing correlation between x and ε.

In what follows, for any given function $\phi(x,z)$, we use the notation

$$\mathbb{E}[\phi(x,z)|x] = \int_Z \phi(x,z)g(z|x)\mathrm{d}z \text{ and } \mathbb{E}[\phi(x,z)] = \int_{X\times Z} \phi(x,z)g(z|x)f(x)\mathrm{d}z\mathrm{d}x.$$

3. ANALYSIS

In this section, we first analyze two cases: x is disclosed (the firms can condition their payments on x) and x is protected (the firms must offer the same payment for all x), where we use subscripts D and P to refer to disclosure and protection, respectively. We then compare these cases and provide a comparative statics.

3.1. *Variable x is disclosed*

Suppose that x is disclosed, so $I = x$. As the firms can condition their payments on x, we have

$$p_x = \mathbb{E}[y|x] = \mathbb{E}[\alpha + \beta x + (1-\beta)x + z|x] = \alpha + x.$$

Given x, the consumer gets $u(\alpha+x)$ by accepting the payment and $\mathbb{E}[u(\alpha+\beta x+z)|x]$ by rejecting it. Let $X_D^*(\beta)$ be the subset of values of x such that the consumer accepts payment $p_x=\alpha+x$:

$$X_D^*(\beta)=\big\{x\in X: u(\alpha+x)\geq \mathbb{E}[u(\alpha+\beta x+z)|x]\big\}. \tag{1}$$

The welfare is given by

$$W_D(\beta)=\int_{x\in X_D^*(\beta)} u(\alpha+x)f(x)\mathrm{d}x+\int_{x\notin X_D^*(\beta)} \mathbb{E}[u(\alpha+x+z)|x]f(x)\mathrm{d}x. \tag{2}$$

PROPOSITION 1: *There exists $\beta_1\in[0,1]$ such that*
(i) $X_D^*(\beta)=X$ and $W_D(\beta)=\mathbb{E}[u(\alpha+x)]$ for all $\beta\geq\beta_1$, and
(ii) $X_D^*(\beta)$ and $W_D(\beta)$ are strictly increasing[2] in β for all $\beta<\beta_1$.

The proof of this and other propositions are deferred to the Appendix.

3.2. *Variable x is protected*

Suppose that x is protected, so $I=\varnothing$. As the firms are not allowed to condition their payments on x, they must give the same payment p to all types x. Denote

$$\underline{x}=\inf X \quad\text{and}\quad \overline{x}=\sup X.$$

Note that $\underline{x}$ and $\overline{x}$ may be infinite if X is unbounded.

Given a payment p and a type x, the consumer gets $u(p)$ by accepting the payment and $\mathbb{E}[u(\alpha+\beta x+z)]$ by rejecting it. As the expected utility is monotone in x, in equilibrium, there exist a payment $p^*(\beta)$ and a participation threshold $x_P^*(\beta)$ such that consumers with types $x\leq x_P^*(\beta)$ accept $p^*(\beta)$ and consumers with types $x>x_P^*(\beta)$ reject it. We set $x_P^*(\beta)=\overline{x}$ if all types accept the payment and $x_P^*(\beta)=\underline{x}$ if all reject the payment. By zero profit, the equilibrium payment must satisfy

$$p^*(\beta)=\mathbb{E}\left[\alpha+x+z|x\leq x_P^*(\beta)\right]=\alpha+\mathbb{E}\left[x|x\leq x_P^*(\beta)\right].$$

[2]Here and below, set $X_D^*(\beta)$ is increasing in β if, for all $\beta'<\beta''$, $X_D^*(\beta')\subseteq X_D^*(\beta'')$; moreover, it is strictly increasing if the set $X_D^*(\beta'')\backslash X_D^*(\beta')$ has nonempty interior.

Denote by $\Delta(x^*,\beta)$ the difference of the utility of consumer with type x^* from accepting and rejecting the payment $p^* = \alpha + \mathbb{E}[x|x \leq x^*]$:

$$\Delta(x^*,\beta) = u(\alpha + \mathbb{E}[x|x \leq x^*]) - \mathbb{E}[u(\alpha + \beta x^* + z)|x^*])]. \tag{3}$$

Due to free entry, the equilibrium participation threshold is the highest x^* such that consumers with types $x \leq x^*$ accept $p^* = \alpha + \mathbb{E}[x|x \leq x^*]$, and there does not exist a higher payment with the same property:

$$x^*_P(\beta) = \max\left\{x^* \in X : \Delta(x^*,\beta) \geq 0\right\}, \tag{4}$$

with the convention that $x^*_P(\beta) = \underline{x}$ if $\Delta(x^*,\beta) < 0$ for all $x^* \in X$, and $x^*_P(\beta) = \overline{x}$ if $\Delta(x^*,\beta) \geq 0$ for all $x^* \in X$.

Note that (4) is conceptually identical to the standard adverse selection problem in a competitive market setting, with the only difference in a distortion of the consumer's participation decision when $\beta < 1$. To obtain a clean comparative statics with respect to β, some of our results will require the following assumption:

$$x^*_P(\beta) \text{ is continuous in } \beta. \tag{A$_1$}$$

Loosely speaking, this assumption holds if the primitives of the problem are "regular" enough to prevent discontinuous jumps of the equilibrium in response to small changes of β. We further discuss this assumption in Section 4.

The welfare is given by

$$W_P(\beta) = u\left(\alpha + \mathbb{E}[x|x \leq x^*_P(\beta)]\right) \int_{x \leq x^*_P(\beta)} f(x)\mathrm{d}x + \int_{x > x^*_P(\beta)} \mathbb{E}[u(\alpha + x + z)|x] f(x)\mathrm{d}x. \tag{5}$$

PROPOSITION 2: *There exists $\beta_0 \in [0,1]$ such that*
(i) $x^*_P(\beta) = \overline{x}$ and $W_P(\beta) = u(\alpha)$ for all $\beta \leq \beta_0$, and
(ii) if Assumption (A$_1$) holds, then $x^*_P(\beta)$ and $W_P(\beta)$ are decreasing in β.

3.3. *Comparative Statics*

We now evaluate the difference in welfare between disclosed and protected x, and analyze how this difference changes as β goes up, that is, as variable x becomes more causal.

Let us introduce some notation. Consider the case where x is protected, and suppose that the consumer is forced to accept the contract (mandatory participation). Then, adverse selection is absent and the equilibrium payment is $p^* = \mathbb{E}[\alpha + x + z] = \alpha$. Since there is mandatory participation, the welfare is $u(\mathbb{E}[\alpha + x + z]) = u(\alpha)$.

Next, consider the case where x is disclosed and the consumer has no correlation neglect, so $\beta = 1$. Then the equilibrium payment is $p_x = \mathbb{E}[\alpha + x + z|x] = \alpha + x$. For each x, the consumer prefers to accept the payment of $\alpha + x$. Thus, the welfare is $\mathbb{E}[u(\alpha + x)]$.

Using the above notation, we can write

$$W_D(\beta) - W_P(\beta) = \Big(W_D(\beta) - \mathbb{E}[u(\alpha+x)]\Big) + \Big(\mathbb{E}[u(\alpha+x)] - u(\alpha)\Big) + \Big(u(\alpha) - W_P(\beta)\Big).$$

The part $\Big(W_D(\beta) - \mathbb{E}[u(\alpha + x)]\Big)$ is the *correlation neglect effect* as it compares the surplus when x is disclosed with and without correlation neglect of the consumer. This effect is negative, and it vanishes when $\beta = 1$.

The part $\Big(\mathbb{E}[u(\alpha + x)] - u(\alpha)\Big)$ is known in the literature as the *price dispersion effect*, as it compares the surplus with and without disclosure of x under full participation. This effect is always negative.[3]

The part $\Big(u(\alpha) - W_P(\beta)\Big)$ is the *adverse selection effect*, as it compares the surplus under nondisclosure of x with and without mandatory participation. This effect is positive, and it vanishes when $\beta = 0$.

As β goes up, so variable x affects y more through the causality channel and less through the correlation channel, the correlation neglect effect diminishes by Proposition 1, the adverse selection effect strengthens by Proposition 2 with Assumption (A_1), and the price dispersion effect is not affected by β. It follows that $W_D(\beta) - W_P(\beta)$ is increasing in β, so the more causal x is, the more reason to disclose it.

When Assumption (A_1) does not hold, we cannot establish a monotone comparative statics of the adverse selection effect in β. Yet, we can compare the extreme cases.

[3] The literature on price dispersion goes back to Hirshleifer (1971); for recent papers, see Farinha Luz et al. (2023) and Veiga (2024).

Suppose that β is small, namely, $\beta \leq \beta_0$, where β_0 is the constant in Proposition 2. In words, variable x affects y predominantly through the correlation channel, which is neglected by the consumers. Then, by Proposition 2, the adverse selection effect is absent, whereas, by Proposition 1, the correlation neglect is maximal. It is then unambiguous that $W_D(\beta) < W_P(\beta)$, so it is optimal to protect x.

Now, suppose that β is large, namely, $\beta \geq \beta_1$, where β_1 is the constant in Proposition 1. In words, variable x affects y predominantly through the causality channel. In this case, the consumers' and the firms' evaluation of y are closely aligned, and, by Proposition 1, the correlation neglect is absent. This becomes the standard adverse selection story without any novel elements. Whether it is better to disclose or to protect x depends on whether adverse selection dominates price dispersion or vice versa, which is a well known tradeoff in the literature.

4. DISCUSSION

Competition. We assume that the market is competitive. If we relax this assumption, then a new reason to protect x appears: the protection of the consumer's information rent. Nevertheless, the tradeoff exposed in our analysis that emerges due to the consumer's correlation neglect remains valid and relevant in a setting of oligopolistic or monopolistic markets.

Parameter β. We assume that the parameter β that captures the degree of causality of x is in $[0, 1]$. However, the model remains valid if β is allowed to be in $\mathbb{R}$.

When $\beta < 0$, the consumer believes that x affects y negatively, but the correlation of x and ε is so strong that it flips the sign of the relationship. Qualitatively, this case is very similar to the case of $\beta = 0$. There is no adverse selection, and thus, disclosure of x brings no benefit. So, welfare is maximized by protecting x.

When $\beta > 1$, the consumer believes that x affects y more than it actually does. The correlation neglect effect is absent if β is close enough to 1, but it emerges and becomes stronger as β increases. Under Assumption (A_1), the adverse selection also becomes stronger as β increases. The net effect – whether disclosure of x is desirable – is ambiguous for a range of values of β. But when β is large enough, the correlation neglect effect eventually dominates, and welfare is maximized by protecting x.

Assumption (A_1). It is difficult to provide an economic interpretation to Assumption (A_1), as it is a technical condition on an endogenous object, $p^*(\beta)$. In this section, we provide a different sufficient condition for part (ii) of Proposition 2 and discuss when this condition is satisfied.

PROPOSITION 2′: *If*

$$u(\alpha + \mathbb{E}[x|x \leq 0]) \geq \mathbb{E}[u(\alpha + z)|x = 0], \tag{A$_2$}$$

then $x^*_P(\beta)$ *and* $W_P(\beta)$ *are decreasing in* β.

To understand assumption (A_2), consider the traditional adverse selection setting, which, in our model, corresponds to $\beta = 1$ and x protected. Then, (A_2) means that the firms do not make losses by offering payment $p = \mathbb{E}[\alpha + x + z|x \leq 0] = \alpha + \mathbb{E}[x|x \leq 0]$. Indeed, if p is offered, (A_2) states that the consumer with type $x = 0$ weakly prefers to accept the payment p, and thus, all consumers with types below 0 also prefer to accept p. The immediate implication is that the equilibrium threshold type, $x^*(\beta)$ with $\beta = 1$, is weakly above the average type, $x = 0$. This can be interpreted as the condition that the adverse selection is not too severe: at least the types below the average type participate in equilibrium.

Suppose that x and z are independent random variables, so $g(z|x) = g(z)$. We now discuss in more detail how the model primitives, namely, utility u and densities f and g affect whether assumption (A_2) holds or not. Let

$$\begin{aligned}\Phi(u, f, g) &= \alpha + \mathbb{E}[x|x \leq 0] - u^{-1}\left(\mathbb{E}[u(\alpha + z)]\right) \\ &= \alpha + \frac{1}{F(0)}\int_{x\leq 0} x f(x)\mathrm{d}x - u^{-1}\left(\int_Z u(\alpha + z)g(z)\mathrm{d}z\right),\end{aligned} \tag{6}$$

where F denotes the CDF of f. Note that (A_2) holds if and only if $\Phi(u, f, g) \geq 0$.

For two strictly increasing and strictly concave functions u_1 and u_2, say that u_1 *is more concave than* u_2 if $u_1(u_2^{-1})$ is concave.[4]

PROPOSITION 3:

(i) If u_1 *is more concave than* u_2*, then* $\Phi(u_1, f, g) \geq \Phi(u_2, f, g)$.

(ii) If g_1 *is a mean-preserving spread of* g_2*, then* $\Phi(u, f, g_1) \geq \Phi(u, f, g_2)$.

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[4]Note that when u_1 and u_2 are strictly increasing and twice differentiable, $u_1(u_2^{-1})$ is concave if and only if $u_1'(x)/u_2'(x)$ is decreasing, or equivalently, the Arrow-Pratt measure of risk aversion is uniformly higher for u_1 than for u_2, that is, $-u_1''(x)/u_1'(x) \geq -u_2''(x)/u_2'(x)$ for all x.

(iii) If f_1 is a mean-preserving spread of f_2 and $F_1(0) \leq F_2(0)$, then $\Phi(u, f_1, g) \leq \Phi(u, f_2, g)$.

The implication of Proposition 3 is that primitives (u, f, g) do not satisfy (A_2) if either the utility u is not concave enough, or the distribution of z is not spread out enough, or, loosely speaking, the distribution of x is too spread out to the left of its mean. For example, if u belongs to the constant relative risk aversion (CARA) family, $u(x) = -e^{-\gamma x}$ with risk aversion parameter $\gamma > 0$, and x and z are independent and normally distributed with zero mean and standard deviations σ_x and σ_z, respectively, then (A_2) simplifies to

$$\sqrt{\frac{2}{\pi}} \leq \frac{\gamma \sigma_z^2}{\sigma_x}$$

In words, (A_2) holds if the consumer is sufficiently risk averse (γ is high enough), the noise variable z has a high enough variance, and the observable variable x has a low enough variance. The above inequality also shows the relative strength of different effects, for example, the variance of z is more impactful than the variance of x.

APPENDIX

Proof of Proposition 1. Let β_1 be the smallest element of the set

$$B_1 = Closure\left(\left\{\beta \in [0,1] : u(\alpha + x) \geq \mathbb{E}[u(\alpha + \beta x + z)|x]\right\}\right).$$

Note that $1 \in B_1$ as if $\beta = 1$, then we have $u(\alpha + x) \geq \mathbb{E}[u(\alpha + x + z)]$ by the concavity of u and $\mathbb{E}[z] = 0$.

Part (i). Consider $\beta \geq \beta_1$. By (1), (2), and definition of β_1, we have $X_D^*(\beta) = X$ and $W_D(\beta) = \mathbb{E}[u(\alpha + x)]$ for all $\beta \geq \beta_1$.

Part (ii). Consider $\beta', \beta'' \in [0, 1]$ such that $\beta' < \beta'' \leq \beta_1$. For each $x \geq 0$ we have

$$u(\alpha + x) - \mathbb{E}[u(\alpha + \beta x + z)|x] \geq u(\alpha + x) - u(\alpha + \beta x) \geq 0,$$

where the first inequality is because u is concave and $\mathbb{E}[z] = 0$, and the second inequality is because u is increasing and $x \geq 0$. Thus, by (1), we have:

$$\text{If } x \geq 0, \text{ then } x \in X_D^*(\beta) \text{ for all } \beta. \tag{7}$$

Next, because u is strictly increasing, we have

$$\text{If } x < 0, \text{ then } \mathbb{E}[u(\alpha + \beta x + z)|x] \text{ is strictly decreasing in } \beta. \tag{8}$$

By (1), $\beta' < \beta_1$, and definition of β_1, the set $X \backslash X_D^*(\beta')$ has nonempty interior. Since $\mathbb{E}[u(\alpha + \beta x + z)|x]$ is strictly decreasing in β when $x < 0$, it follows from (1), (7), and (8) that $X_D^*(\beta') \subsetneq X_D^*(\beta'')$, and moreover, $X_D^*(\beta'') \backslash X_D^*(\beta')$ has nonempty interior. Finally, we have

$$W_D(\beta'') - W_D(\beta') = \int_{x \in X_D^*(\beta'') \backslash X_D^*(\beta')} (u(\alpha + x) - \mathbb{E}[u(\alpha + x + z)|x]) f(x) \mathrm{d}x > 0,$$

where the equality is by (2) and $X_D^*(\beta') \subsetneq X_D^*(\beta'')$, and the inequality is because u is strictly concave, $\mathbb{E}[z] = 0$, and $X_D^*(\beta'') \backslash X_D^*(\beta')$ has a positive measure under f. *Q.E.D.*

Proof of Proposition 2. Let β_0 be the greatest element of the set

$$B_0 = Closure\left(\left\{\beta \in [0,1] : u(\alpha) \geq \mathbb{E}[u(\alpha + \beta x + z)|x]) \text{ for all } x \in X\right\}\right).$$

Note that $0 \in B_0$ as if $\beta = 0$, then we have $u(\alpha) \geq \mathbb{E}[u(\alpha + \beta x + z)|x])$ by the concavity of u and $\mathbb{E}[z] = 0$.

Part (i). Consider $\beta \leq \beta_0$. By (4) and definition of β_0, we have $x_P^*(\beta) = \overline{x}$, and thus, $\mathbb{E}[x|x \leq x_P^*(\beta)] = \mathbb{E}[x] = 0$. Therefore, by (5), we have $W_P(\beta) = u(\alpha)$ for all $\beta \leq \beta_0$.

Part (ii). We use the following lemma.

LEMMA 1: *Suppose that $x_P^*(\beta) \geq 0$ for all $\beta \in [0,1]$. Then $x_P^*(\beta)$ and $W_P(\beta)$ are decreasing in β.*

PROOF: Consider $\beta', \beta'' \in [0,1]$ such that $\beta'' > \beta' \geq \beta_0$. We have

$$\begin{aligned}
\Delta(x^*, \beta'') &= u(\alpha + \mathbb{E}[x|x \leq x^*]) - \mathbb{E}[u(\alpha + \beta'' x^* + z)|x^*])] \\
&< u(\alpha + \mathbb{E}[x|x \leq x^*]) - \mathbb{E}[u(\alpha + \beta' x^* + z)|x^*])]) \\
&= \Delta(x^*, \beta') < 0, \quad \text{for all } x^* > x_P^*(\beta'),
\end{aligned} \tag{9}$$

where the equalities are by (3), the first inequality is because, by assumption, $x_P^*(\beta') \geq 0$, u is strictly increasing, $\beta'' > \beta'$, and, $x^* > x_P^*(\beta')$, and the second inequality is because

$x^*_P(\beta')$ satisfies (4) and $x^* > x^*_P(\beta')$. It follows from (9) and the definition of $x^*_P(\beta'')$ by (4) that $x^*_P(\beta'') \leq x^*_P(\beta')$.

Finally, denote

$$W(x^*, \beta) = u\left(\alpha + \mathbb{E}[x|x \leq x^*]\right) \int_{x \leq x^*} f(x)\mathrm{d}x + \int_{x > x^*} \mathbb{E}[u(\alpha + x + z)|x] f(x)\mathrm{d}x. \quad (10)$$

For all $x^* \geq 0$, we have

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}x^*} W(x^*, \beta) &= \left(\mathbb{E}[u(\alpha + x^* + z)|x^*] - u\left(\alpha + \mathbb{E}[x|x \leq x^*]\right)\right) f(x^*) \\ &\quad + u'\left(\alpha + \mathbb{E}[x|x \leq x^*]\right) \frac{\mathrm{d}\mathbb{E}[x|x \leq x^*]}{\mathrm{d}x^*} \int_{x \leq x^*} f(x)\mathrm{d}x \\ &\geq \left(\mathbb{E}[u(\alpha + \beta x^* + z)|x^*] - u\left(\alpha + \mathbb{E}[x|x \leq x^*]\right)\right) f(x^*) \\ &= -\Delta(x^*, \beta) f(x^*), \end{aligned} \quad (11)$$

where the inequality is because u is increasing, $\mathbb{E}[x|x \leq x^*]$ is increasing w.r.t. x^*, $\beta \leq 1$, and $x^* \geq 0$, and the last equality is by (3). Thus, for almost all $\beta > \beta_0$ we obtain[5]

$$\frac{\mathrm{d}W_P(\beta)}{\mathrm{d}\beta} = \left.\frac{\mathrm{d}W(x^*, \beta)}{\mathrm{d}x^*}\right|_{x^* = x^*_P(\beta)} \times \frac{\mathrm{d}x^*_P(\beta)}{\mathrm{d}\beta} \leq -\Delta(x^*_P(\beta), \beta) f(x^*_P(\beta)) \frac{\mathrm{d}x^*_P(\beta)}{\mathrm{d}\beta} = 0,$$

where the first equality is by (5) and (10), the inequality is by (11) and because $x^*_P(\beta)$ is decreasing in β, and the last equality is because $x^*_P(\beta)$ satisfies (4) and $\beta > \beta_0$, so $\Delta(x^*_P(\beta), \beta) = 0$. *Q.E.D.*

It remains to show that if Assumption (A_1) holds, then $x^*_P(\beta) \geq 0$ for all $\beta \in [0, 1]$. Then, part (ii) of Proposition 2 is immediate by Lemma 1.

Suppose that (A_1) holds. By part (i) of Proposition 2, when $\beta = 0$, we have $x^*_P(0) = \overline{x} > 0$. Suppose by contradiction that $x^*_P(\beta') < 0$ for some $\beta' > 0$. Then, by (A_1), there exists $\beta'' \in (0, \beta']$ such that $x^*_P(\beta'') = 0$. Also, since $x^*_P(\beta')$ and $x^*_P(\beta'')$ satisfy (4) under β' and β'', respectively, we must have $\Delta(0, \beta') < 0 = \Delta(0, \beta'')$. However, by (3), the expression

$$\Delta(0, \beta) = u(\alpha + \mathbb{E}[x|x \leq x^*]) - \mathbb{E}[u(\alpha + z)|x^*])]$$

[5] As $x^*_P(\beta)$ is monotone, it is almost everywhere differentiable.

is independent of β, which contradicts $\Delta(0,\beta') < 0 = \Delta(0,\beta'')$. We have shown that $x_P^*(\beta) \geq 0$ for all $\beta \in [0,1]$. *Q.E.D.*

Proof of Proposition 2′. By (3) and Assumption (A_2), we have $\Delta(0,\beta) \geq 0$ for all $\beta \in [0,1]$. It follows from (4) that $x_P^*(\beta) \geq 0$ for all $\beta \in [0,1]$. Then, by Lemma 1, we obtain that $x_P^*(\beta)$ and $W_P(\beta)$ are decreasing in β. *Q.E.D.*

Proof of Proposition 3. *Part (i)*. Since $u_1(u_2^{-1})$ is concave, we have

$$u_1(u_2^{-1}(\mathbb{E}[u_2(\alpha+z)])) \geq \mathbb{E}[u_1(u_2^{-1}(u_2(\alpha+z)))] = \mathbb{E}[u_1(\alpha+z)].$$

Applying u_1^{-1} to both sides of the above inequality, we obtain

$$u_2^{-1}\left(\mathbb{E}[u_2(\alpha+z)]\right) \geq u_1^{-1}\left(\mathbb{E}[u_1(\alpha+z)]\right),$$

which, by (6), is equivalent to $\Phi(u_1,f,g) \geq \Phi(u_2,f,g)$.

Part (ii). Since u is a concave function, if g_1 is a mean-preserving spread of g_2, then

$$\int_Z u(\alpha+z)g_1(z)\mathrm{d}z \leq \int_Z u(\alpha+z)g_2(z)\mathrm{d}z,$$

which, by (6) and that u^{-1} is increasing, is equivalent to $\Phi(u,f,g_1) \geq \Phi(u,f,g_2)$.

Part (iii). Since $\min\{x,0\}$ is a concave function, if f_1 is a mean-preserving spread of f_2, then

$$\int_{x\leq 0} x f_1(x)\mathrm{d}x = \int_{x\in X} \min\{x,0\} f_1(x)\mathrm{d}x \leq \int_{x\in X} \min\{x,0\} f_2(x)\mathrm{d}x = \int_{x\leq 0} x f_2(x)\mathrm{d}x.$$

Note that $F_i(0) > 0$ for each $i = 1,2$, since F_i is a CDF (so $F_i(t) = \mathbb{P}[x \leq t]$), and $\mathbb{E}[x] = 0$. Thus, since $F_2(0) \geq F_1(0) > 0$, we obtain

$$\frac{1}{F_1(0)}\left(-\int_{x\leq 0} x f_1(x)\mathrm{d}x\right) \geq \frac{1}{F_2(0)}\left(-\int_{x\leq 0} x f_2(x)\mathrm{d}x\right),$$

which, by (6), is equivalent to $\Phi(u,f_1,g) \leq \Phi(u,f_2,g)$. *Q.E.D.*

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