Online Appendix to
“Source Theory: A Tractable and Positive Ambiguity Theory”

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Online Appendix A: Additions to Proofs and Further Remarks on Mathematics

ADDITION TO PROOF OF OBSERVATION 1. We show that the domain of w is the entire $[0,1]$, and that w is strictly increasing. This proof is elementary if K is defined on a sigma algebra and is countably additive, which is the main case of practical interest. Therefore, the proof for the general case is only provided here in the Online Appendix. In general, K is only finitely additive and is defined only on an algebra. We can standardly define w well on its domain RK as indicated in the main text, and it is nondecreasing.

We first show that the domain of w is a dense subset of $[0,1]$. By convex-rangedness of W, the image $w(RK)$ is the entire $[0,1]$. So, RK is uncountable. For each “small” $\epsilon > 0$ there exist probabilities $p < q$ in RK with $q - p < \varepsilon$. Take event A with $K(A) = q$. By convex-rangedness, there is a subset $B \subset A$ with $W(B) = w(p)$ and $K(B) = p$. So, $K(A - B) < \varepsilon$. Using convex-rangedness of W, we can keep on extending a disjoint array $A_1, \ldots, A_i$ with $K(A_i) = K(A - B)$ as long as $K(A_1 \cup \cdots \cup A_i)^c \geq\ K(A - B)$ so that also $W(A_1 \cup \cdots \cup A_i)^c \geq\ W(A - B)$. Such standard sequences for smaller and smaller ε show that RK is dense in $[01]$.

We next show that w is strictly increasing on its domain. If w is constant on $[q, q + \varepsilon] \cap RK$ for an $\varepsilon > 0$, then, by denseness of RK, there is an event with K value $0 < p < \varepsilon$ is that is null. But then so is every event with K value $\frac{1}{n} < \varepsilon$, and so are all their finite unions including the entire $[0,1]$. Then all outcomes are equivalent, and we have a contradiction.

We finally show that the domain of w is the entire $[0,1]$. If a p is missing from RK, then we must have $0 < p < 1$, and $w([0,p) \cap RK)$ and $w((p,1] \cap RK)$ provide a partition of $[0,1]$ of two open nonempty sets, violating connectedness of $[0,1]$. This shows that w's domain is the entire $[0,1]$. □

ADDITION TO PROOF OF THEOREM 4. $\varphi(\varepsilon) \geq \varphi(p+\varepsilon) - \varphi(p)$ for every $p > 0$ and $\varepsilon > 0$ (*) and $\varphi^{-1}(\varepsilon) \geq \varphi^{-1}(p+\varepsilon) - \varphi^{-1}(p)$ (**) for every $p > 0$ imply that φ is linear: Take $\delta \geq 0$ in (**) such that $\varphi^{-1}(\varepsilon-\delta) = \varphi^{-1}(p+\varepsilon) - \varphi^{-1}(p)$. We can apply (*) to get $\varphi(\varphi^{-1}(\varepsilon-\delta)) \geq \varphi(\varphi^{-1}(p+\varepsilon)) - \varphi(\varphi^{-1}(p))$, i.e., $\varepsilon-\delta \geq p+\varepsilon - p = \varepsilon$. So, $\delta=0$ must be. The inequalities must hold as equalities.

FURTHER REMARKS:

Throughout the paper, countable additivity of a-neutral probabilities can easily be characterized by an extra preference condition (Wakker 1993, Proposition 4.4).

Mainly cumulative dominance implies that probabilistic sophistication for two-outcome acts implies it for all acts.

If ST holds for a source, then, given the preference relation and its biseparable utility representation, the representing functional over nonbinary acts is uniquely determined via equivalent binary acts. It is called the *source-theory (ST)* functional.

Online Appendix B: Insensitivity versus Cavexity

Inverse S-shapes have usually been described informally as cavexity; i.e., concave up to an inflection point and convex after. This definition requires prior specification of the inflection point similarly as our definition of insensitivity requires prior specification of the insensitivity region. We next explain why we prefer our deviating definition.

We take insensitivity as cognitive/informational, moving perfect sensitivity (w linear) in the direction of perfect insensitivity with a flat w in the middle suggesting a simple three-valued logic. We take it as a global phenomenon leading to steepness at extremes combined with shallowness in the middle, contrary to cavexity which describes a local development of curvature (sign of w''). Further, under cavexity the exact location of the inflection point is theoretically critical (a change leads to opposite requirements in-between) whereas empirically it is noncritical and volatile, weighting functions being approximately linear in the interior (Baucells & Villasís 2015). Thus, the mathematics of cavexity do not capture what is empirically critical. Different insensitivity regions, to the contrary, do not impose opposite requirements but only differ regarding the region where they impose the (same!) requirements. For applications, insensitivity regions only have to be "big enough" and their exact size is not critical.

Another problem for cavexity concerns the location of the inflection point relative to the diagonal (Lewandowski 2017 pp. 305-307).[14] Empirically, it will not be exactly on the diagonal. If it is too far above or below the diagonal then cavexity does not capture insensitivity. We are not aware of a satisfactory treatment of this complication. Cavexity has never yet been extended to uncertainty. We are not aware of a link of cavexity with ambiguity perception.

Baillon et al. (2021) theoretically analyzed indexes of insensitivity. They showed that those indexes agree with popular indexes of perception in many ambiguity models (that, if taken normative, involve no cognitive limitations), e.g., sizes of sets of priors in several multiple priors models. They also showed that the indexes are mathematically orthogonal, underscoring the complementarity between source preference and sensitivity.

Online Appendix C: First Formal Definition of Insensitivity and Comparison with Tversky & Wakker (1995)

Tversky & Wakker (1995), the theoretical counterpart to Tversky & Fox (1995), used traditional between-subjects comparisons (except their §8, discussed below) of source preference and insensitivity. Nascimento, Ng, & Gonzalez (2024) provided detailed

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[14] The logical status of the inflection point and the intersection with the diagonal was never formalized in the literature.

numerical analyses of various parameters of source preference and insensitivity. We, to the contrary, focused on the main novelty of uncertainty: within-subject between-sources comparisons. Observation 2, our, trivial, starting result, was given by Tversky & Wakker (1995 §7). Other than that, our results are new. In particular, we compare the same function in different subdomains. All behavioral foundations of Pratt-Arrow-type transformations in the literature, including Lewandowski (2017 Result 11), Tversky & Wakker (1995), and Wang (2022) compared different functions on the same domain and applied transformations to images of functions (“outside”). We instead apply transformations to arguments of functions (“inside”), formalizing and justifying Gutierrez & Kemel’s (2024) empirical implementation. Wakker (2004) axiomatized a simple version of an “inside” transformation.

Tversky & Wakker (1995), and most papers following, used boundary constants rather than our insensitivity regions, but we think that the latter are conceptually preferable. No paper in the literature did as yet specify the formal status of boundary constants (cf. Tversky & Wakker 1995 Footnote 7). Some imposed “there exist” quantifiers on them, but this definition is too permissive because insensitivity regions then can be taken too small.

Insensitivity shows that two seemingly separate concepts in the literature, ambiguity perception and inverse S probability weighting for risk, are two sides of the same coin. For the latter property, so widely documented in empirical studies, it is extra remarkable that no fully formalized definition had been provided in the literature yet. Egozcue, Garcia, & Zitikis (2022) provided numerical tools to analyze insensitivity regions.

Online Appendix D: Further References

This appendix gives further references.

D.1. Examples Demonstrating Explanatory Power of the Source Method

Besides the Ellsberg urns, the home bias, and the competence effect, many further examples in the following papers show the explanatory power of the source method (usually not using this term). In addition to Baillon et al. (2018b), Chen & Zhong

(2024), Einhorn & Hogarth (1985), and Ivanov (2011), we mention Abdellaoui et al. (2021), Anantanasuwong et al. (2024), Baillon et al. (2018a), Barseghyan et al. (2013 Footnote 57), Bleichrodt, Grant, & Yang (2023), Boonen & Ghossoub (2021), Dolan & Ones (2004), Grevenbrock et al. (2021), Gutierrez & Kemel (2024), Li (2017), Kemel & Paraschiv (2013), Li et al. (2018), Polkovnichenkoy & Zhao (2013), Sonsino, Lahav, & Roth (2022), Spiliopouloss & Hertwig (2023), and Wu, Delgado, & Maloney (2009). Keynes (1921) already proposed to use probabilities to model uncertainty, but process them differently depending on the source of uncertainty:

> “The typical case, in which there may be a practical connection between weight and probable error, may be illustrated by the two cases following of balls drawn from an urn. In each case we require the probability of drawing a white ball; in the first case we know that the urn contains black and white balls in equal proportions; in the second case the proportion of each color is unknown, and each ball is as likely to be black as white. It is evident that in either case the probability of drawing a white ball is 1/2, but that the weight of the argument in favor of this conclusion is greater in the first case” (p. 75)

D.2. Confirmation of A-Insensitivity and Its Relevance for Real-Life Decisions

The following studies confirmed the relevance of a-insensitivity for real-life decisions, besides Dimmock, Kouwenberg, & Wakker (2016) and Watanabe & Fujimi (2024): Anantanasuwong et al. (2024), Barseghyan et al. (2013 Footnote 57), Bleichrodt, Grant, & Yang (2023), Brenner & Izhakian (2018), Chen & Zhong (2024), de Lara Resende & Wu (2010), Dimmock et al. (2015, “ambiguity perception”), Dolan & Jones (2004), Gao et al. (2024), Georgalos (2021) Gonzalez-Jimenez (2024 Proposition 4 and Result 4), Gutierrez & Kemel (2024), Li (2017), Kemel & Paraschiv (2013), Li et al. (2018), Li, Turmunkh, Wakker (2019), Maafi (2011), Minnich & Lange (2024), Polkovnichenko & Zhao (2013), Trautmann & van de Kuilen (2015), von Gaudecker, Wogrolly, & Zimpelmann (2022),

D.3. Cognitive Ability Related to Insensitivity

Besides Baillon et al. (2018a), the following papers showed that a-insensitivity is related to cognitive ability: Anantanasuwong et al. (2024), Bruine de Bruin et al. (2000), Budescu et al. (2014 p. 3 l. –4), Choi et al. (2022), Dolan & Jones (2004), Gao et al. (2024), Gayer (2010), Grevenbrock et al. (2021), Watanabe & Fujimi (2024), von Gaudecker, Wogrolly, & Zimpelmann (2022), and Zhang & Maloney (2012).

D.4. Importance of Natural Events

Besides Camerer & Weber (1992 p. 361), Ellsberg (2011 p. 223), and Gilboa (2009 §3.3.3), the following papers argued for the importance of studying ambiguity for natural events: Chen & Zhong (2024 p. 1501), Gao et al. (2024 p. 186), Heath & Tversky (1991 p. 6), l'Haridon et al. (2018 Conclusion), Li et al. (2018 p. 3227), MacCrimmon & Larsson (1979 p. 382), Trautmann & van de Kuilen (2015 p. 94). Numerous papers have studied ambiguity for natural events, including Abdellaoui et al. (2011), Abdellaoui et al. (2021), Abdellaoui, Vossmann, & Weber (2005), Baillon & Bleichrodt (2015), Baillon (2018a, 2018a), Bleichrodt, Grant, & Yang (2023), Brenner & Izhakian (2018), Chew, Ebstein, & Zhong (2012), Chew et al. (2008), de Lara Resende & Wu (2010), Dimmock et al. (2015), Eisenberger & Weber (1995), Fox, Rogers, & Tversky (1996), Fox & Tversky (1998), Fox & Weber (2002), Gutierrez & Kemel (2024), Ivanov (2011), Kemel & Paraschiv (2013), Keppe & Weber (1995), Kilka & Weber (2001), Li (2017), Li, Turmunkh, Wakker (2019 p. 53), Maffioletti & Santoni (2005), Minnich & Lange (2024), Polkovnichenkoy & Zhao (2013), Sonsino, Lahav, & Roth (2022), Tversky & Fox (1995), Viscusi & Chesson (1999), Viscusi & Evans (2006), Viscusi & Magat (1992), von Gaudecker, Wogrolly, & Zimpelmann (2022), Wakker, Timmermans, & Machielse (2007), Watanabe & Fujimi (2024), Wu et al. (2024), and many more.

D.5. Critizing Backward Induction in the Anscombe-Aumann Framework

Normative criticisms of backward induction include, besides Machina (1989), where we henceforth focus on criticisms within the AA framework: Bommier (2017), Bommier, Kochov, & le Grand (2017 Footnote 7), Eichberger, Grant, & Kelsey (2016), Machina (2014 p. 3835 3rd bulleted point), Monet & Vergopoulos (2024), Skiadas (2013 p. 63), and Wakker (2010 §10.7.3). Empirical criticisms of backward induction in the Anscombe-Aumann framework (“monotonicity”) include, besides Schneider & Schonger (2019): Oechssler & Roomets (2021) and Yang & Yao (2017 p. 231 “Failure of a basic monotonicity condition”). Kuzmics, Rogers, & Zhang (2024) found empirical violations but also support for its normative appeal.

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