Düsseldorf Institute
for Competition Economics

DISCUSSION PAPER

No 189

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June 2015

HEINRICH HEINE
UNIVERSITÄT DÜSSELDORF

d|u|p düsseldorf university press

IMPRINT

DICE DISCUSSION PAPER

Published by

düsseldorf university press (dup) on behalf of
Heinrich-Heine-Universität Düsseldorf, Faculty of Economics,
Düsseldorf Institute for Competition Economics (DICE), Universitätsstraße 1,
40225 Düsseldorf, Germany
www.dice.hhu.de

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ISSN 2190-9938 (online) – ISBN 978-3-86304-188-5

Violations of First-Order Stochastic Dominance as Salience Effects *

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Abstract

In contradiction to expected utility theory, various studies find that splitting events or attributes into subevents and subattributes can reverse a decision maker's choices. Most notably, these effects can induce first-order stochastic dominated choices. These violations of first-order stochastic dominance are framing effects, which expected utility theory, cumulative prospect theory and salience theory of choice under risk cannot account for. However, we propose a version of salience theory which unravels the underlying mechanism triggering such effects and which can explain the impact of event- and attribute-splitting on choices. Hereby, we provide further rationale for the broad validity of the salience mechanism and its strong descriptive power concerning human decision making.

JEL Classification: D8.

Keywords: First-order stochastic dominance, Framing effects, Prospect theory, Salience theory.

*We would like to thank Hans-Theo Normann and Alexander Rasch for their helpful comments.
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1 Introduction

Expected utility theory as the decision theorist's major tool cannot account for a wide range of robust phenomena in decision making under risk, for instance the Ellsberg or the Allais paradox. Thus, cumulative prospect theory (Tversky and Kahneman, 1992) has tackled expected utility theory as the major descriptive theory of decision making under risk.

Recently, *salience theory* (Bordalo et al., 2012; 2013) has emerged as an alternative to (cumulative) prospect theory. According to its underlying *salience mechanism*, a *local thinker* (that is, an agent who is susceptible to salience) choosing between several options overweights the alternatives' eye-catching features. As a result, objective decision weights and also actual choices may be distorted. Thereby, local thinking can account for a broad variety of violations of expected utility theory, like endowment effects, preference reversals, or decoy effects. However, most of these decision biases can be explained by (cumulative) prospect theory as well.

This paper focuses on a particular class of framing effects which salience, but not cumulative prospect theory can account for. In particular, we focus on frames inducing a *violation of first-order stochastic dominance* (FOSD), which is defined as follows. Let option l_i realize a monetary outcome of at least x with probability p^i_x. Then, l_1 is first-order stochastic dominated (fosd) if there is an option l_2 with $p^2_x \geq p^1_x$ for all outcomes x and $p^2_x > p^1_x$ for some x. Equivalently, l_1 is fosd if there is an option l_2 such that $1 - F_1(x) \leq 1 - F_2(x)$ for all x and $1 - F_1(x) < 1 - F_2(x)$ for some x, where F_i denotes the cumulative distribution function of l_i. A violation of FOSD is defined as a decision in favor of a fosd option in the presence of the dominating option. It represents a severe decision error as the opportunity to reach better outcomes without bearing more risk is forgone. Violations of FOSD are contradictory both to cumulative prospect theory (Birnbaum, 2005) and to salience theory of choice under risk (Bordalo et al., 2012; henceforth: BGS12). We, however, propose a version of salience theory which is based on Bordalo et al. (2013; henceforth: BGS13) and which accounts for the subtle framing effects that trigger violations of FOSD.

We consider a typical example from Birnbaum (2005), which gives rise to fosd choices.[1] A decision maker chooses between two lotteries, that is, she can draw a marble either from urn A (*option A*) or urn B (*option B*) with closed eyes. Each urn contains 100 marbles, and each marble provides a gain depending on its color as depicted in Table 1. Urn B is fosd by urn A since the

Urn A	Urn B
90 red marbles to win \$96	85 green marbles to win \$96
05 blue marbles to win \$14	05 black marbles to win \$90
05 white marbles to win \$12	10 yellow marbles to win \$12.

Table 1: A typical choice problem yielding violations of FOSD (*frame 1*).

probability to gain at least \$$x$ is for no x smaller, but for some x strictly larger if urn A is chosen.

[1]Michael H. Birnbaum has conducted research on violations of FOSD for years, see for example Birnbaum and Navarrette (1998). Therefore, to analyze such violations in the light of the salience mechanism, we consider a representative example from Birnbaum's later work.

Nevertheless, Birnbaum (2005) finds that a majority of people violate FOSD by opting for urn B, which is a puzzle for expected utility theory, cumulative prospect theory and salience theory of choice under risk. [2] These approaches, however, all ignore the fact that the specific juxtaposition of the alternatives in Table 1 may result in distinct pairwise comparisons of outcomes. People may simply compare the three pairs of outcomes ($96, $96), ($14, $90), and ($12, $12). This equalizes the assumption that each of the three rows represents one attribute, each option is uniquely defined by a value in each of the three attributes and options are compared attribute by attribute. Since both options in the preceding example do not differ in their first and their third, but in their second attribute, both options' second attribute is especially salient and thus overvalued by the local thinker such that option B is chosen. Hence, our salience mechanism (which is based on BGS13) can account for the findings by Birnbaum (2005). Consequently, this paper provides further rationale for the validity of salience theory by illustrating in how far it can even account for such severe decision errors like violations of FOSD, which cannot be explained by cumulative prospect theory.

By unravelling the mechanism which induces violations of FOSD, we can also explain the impact of event- and attribute-splitting on a decision maker's consumption choices. For instance, by splitting risks into subrisks, insurance companies can inflate an agent's valuation of a certain insurance and therefore charge higher premiums (Humphrey, 2006; Johnson et al., 1993). Therefore, this paper analyzes an effect which is also of a high practical relevance.

2 Salience Theory

A so called *salience function* $\sigma : \mathbb{R}^2 \backslash (0,0) \to \mathbb{R}^+$ and $\sigma(0,0) = 0$ is defined via the *ordering property*, that is, $[x_1, y_1] \subset [x_2, y_2]$ yields $\sigma(x_1, y_1) < \sigma(x_2, y_2)$. A salience function determines how salient the first argument, x_1, is with respect to the second argument, y_1. The ordering property states that salience increases if the lower value, x_1, drops or if the larger value, y_1, increases. In this paper, we take BGS12's standard salience function

$$\sigma(x_i, y_i) = \frac{|x_i - y_i|}{|x_i| + |y_i| + \theta}$$

for a parameter $\theta \geq 0$.[3]

Let $x = (x_i)_{1 \leq i \leq k}$ and $y = (y_i)_{1 \leq i \leq k}$ be two alternatives which are both uniquely given by their numerical values in k attributes.[4] Given a salience function σ, we say that option x's attribute i is more salient than j if $\sigma(x_i, y_i) > \sigma(x_j, y_j)$ and equally salient as j if $\sigma(x_i, y_i) = \sigma(x_j, y_j)$. We denote $r_i^x \in \{1, \ldots, k\}$ the salience ranking of i for alternative x, where a lower r_i^x indicates a higher

[2] According to the latter, lotteries are compared state by state, where a state is defined by a feasible pair of the urns' outcomes. Nine states (x, y) are feasible, where x denotes A's and y denotes B's potential outcome. The local thinker overestimates a state (x, y)'s probability if the difference in outcomes $x - y$ is relatively large. BGS12 prove that this mechanism obeys FOSD and hence cannot account for the findings by Birnbaum (2005).

[3] While this specification of the salience function satisfies further properties like symmetry, its specific form is not important for our qualitative results.

[4] If one alternative takes values in less than the k attributes, we assume that its value in the remaining attribute(s) is zero.

salience of attribute i. Hence, $r_i^x = z$ signifies that attribute i is the z-most salient attribute of x.

We extend BGS13 by allowing for risky outcomes and impose a crucial condition on a choice task's framing.[5] Let each alternative x and y represent a lottery with monetary outcomes. The framing of x and y, that is, the way in which their outcomes are listed, induces a unique classification of outcomes into attributes $\{1, \ldots, k\}$ as follows: if and only if the framing of the options induces the pairwise comparison of outcome x_i with y_j, where $i, j \in \{1, \ldots, k\}$, then $i = j$ (that is, x_i and y_j belong to the same attribute). Accordingly, the framing of outcomes is decisive as a pair of outcomes (x_i, y_i) forms an attribute. In our following examples, these attributes are given by the lines of the table in which the lotteries are presented. Then, as we explain in the following, alternatives are valued attribute by attribute as in BGS13.[6]

Let a subject's utility be additively separable in an alternative's attributes and linear in the monetary outcome. The objective decision weight on attribute i of option x is the probability p_i^x of outcome x_i. However, a local thinker's decision weights are distorted due to salience. Each local thinker can be assigned a parameter $\delta \in (0, 1)$, which states in how far her objective decision weights are affected: the smaller δ, the stronger the distortion. The salience-induced distorting factor on option x's attribute i for local thinker δ is

$$w_i^x = \frac{\delta^{r_i^x}}{\sum_j \delta^{r_j^x} p_j^x}.$$

Hence, the rational decision maker ($\delta = 1$) has $w_i^x = 1$, whereas the local thinker overweights a relatively salient attribute i, that is, $w_i^x > 1$, and underweights a much less salient attribute j, that is, $w_j^x < 1$. Let $v^L(.)$ denote the local thinker's utility function. Consequently, the local thinker values option x as $v^L(x) = \sum_i w_i^x p_i^x x_i$.[7]

Thus, the framing of options induces the grouping of outcomes into attributes: not the state space is important as in BGS12, but how outcomes are listed and which outcomes are pairwisely compared determines the evaluation of risky options. A salience function ranks each option's attributes according to their salience and this ranking determines in how far decision weights, i.e., subjective probabilities, are distorted.

3 Salience and first order stochastic dominance

We reconsider the example in Table 1. Both options A and B are designated by three outcomes, which we assume to be compared pairwise.[8] Each line represents one attribute of the lotteries and

[5]Note that we base our analysis on BGS13 which- in contrast to BGS12- does not allow for risky outcomes. We do not need to establish a state space like in BGS12 since we claim that the state space, as suggested in BGS12, may not be decisive for decision making. Instead, we propose that the categorization of outcomes may be decisive. In the following, we explain how the framing of outcomes influences the valuation of lotteries. Predictions by BGS12, however, were invariant toward differences in framing since they were based on a well-defined state space.

[6]Whereas we specialize on a choice set comprising two lotteries, the given definitions are extendable to finitely many alternatives, similar to the extension in the Online-Appendix of BGS12.

[7]Note that the valuation of x also depends on the unchosen alternative y. Thus, strictly speaking, $v^L(.)$ is a function of the chosen alternative x and the choice set of all available options $C := \{x, y\}$.

[8]Whereas we assumed that the outcomes' classification into pairs is unique, our qualitative results on the example do not depend on this classification, but hold for *any* pairwise comparison of outcomes.

lotteries are compared attribute-wise.[9] The second attribute, which takes the values $A_2 = \$14$ and $B_2 = \$90$, is most salient, whereas $\sigma(14, 90) > \sigma(12, 12) = \sigma(96, 96) = 0$ shows that the first and the third attribute are of the same low degree of salience for both options. Thus, the local thinker overvalues both alternatives' second branch such that $r_2^A = r_2^B = 1$. Hence, the subjective probabilities for A_2 and B_2 exceed the respective objective probabilities, whereas the probabilities for all other outcomes are underrated such that $r_1^A = r_1^B = r_3^A = r_3^B = 2$.

Thus, the local thinker values the options as follows,

$$v^L(A) = \frac{0.05\delta \cdot 14 + 0.05\delta^2 \cdot 12 + 0.9\delta^2 \cdot 96}{0.05\delta + 0.05\delta^2 + 0.9\delta^2}$$

and

$$v^L(B) = \frac{0.05\delta \cdot 90 + 0.10\delta^2 \cdot 12 + 0.85\delta^2 \cdot 96}{0.05\delta + 0.10\delta^2 + 0.85\delta^2}.$$

Consequently, B is preferred over A as long as $\delta < 19/21$. Note that this condition is not very strict. Given our assumptions on utility and on the salience function, Bordalo et al. estimate $\delta = 0.7$ for an average subject in a stochastic choice model. With this calibration, a majority of subjects who face the choice between urns A and B as framed in Table 1 are expected to violate FOSD. Hence, local thinkers who evaluate lotteries outcome by outcome are expected to conform with violations of FOSD as found by Birnbaum (2005).

In our example, violations of FOSD are driven by the fact that option A has more relative downsides than option B, that is, there are more attributes in which option A performs worse than option B than attributes in which A outperforms B. Decision makers do not thoroughly consider the objective relevance of all outcomes, but overrate the risk of getting only \$14 while forgoing \$90. As Birnbaum (2005) has argued, subjects violate *coalescing*. This means that the splitting up of an option's branch can alter choices even if the option itself is not modified at all. Thus, the number of downsides, not the objective relative weights on these downsides, may be crucial for decision making.[10]

Even though our salience model is quite general, it yields falsifiable predictions. Since we propose a theory of framing, our results depend crucially on the underlying frame. For example, the splitting up of branches does not only alter actual decision making (Birnbaum, 2005), but reverses also the predictions of our model. Our reasoning implies that FOSD is not violated if the preceding choice task is framed as in Table 2 (*frame 2*).[11] The splitting up of A's first and B's last outcome results in four attributes and a different grouping of outcomes. Hence, in frame 2 both lotteries have two relative upsides and two downsides, whereas in the original framing (*frame 1*) A only had one upside and two downsides. If people compare the lotteries outcome by outcome, then the transition from frame 1 to frame 2 eliminates violations of FOSD. Indeed, the latter frame

[9]Note that this assumption, made in the previous section, gives the important difference from BGS12, who assume that lotteries are compared according to the underlying state space.

[10]Note, however, that the heuristic according to which options are evaluated solely on their numbers of relative up- and downsides while probabilities are entirely neglected does not provide reasonable results as we will exemplify in the following.

[11]In contrast, the splitting up of branches does not alter the set of feasible states, so that salience theory of choice under risk obeys coalescing and cannot account for differences in choice patterns between frames 1 and 2.

Urn A	Urn B
85 red marbles to win \$96	85 green marbles to win \$96
5 red marbles to win \$96	5 yellow marbles to win \$12
5 white marbles to win \$12	5 yellow marbles to win \$12
5 blue marbles to win \$14	5 black marbles to win \$90

Table 2: An alternative framing of the same choice problem (*frame 2*).

resembles choice tasks in the filler trials by Birnbaum (2005), where violations of FOSD are not an issue anymore.

4 Discussion

4.1 Salience vs. Prospect Theory

As various studies document systematic violations of FOSD (Birnbaum and Navarette, 1998; Birnbaum, 2005), a profound behavioral theory of individual decision making should account for fosd choices. As cumulative prospect theory satisfies the axiom of coalescing, it cannot explain fosd choices. In contrast, however, non-linear probability distortions as proposed in the original version of prospect theory (Kahneman and Tversky, 1979) allow for violations of coalescing and FOSD. As Kahneman and Tversky regarded such effects as implausible, they regarded the violation of FOSD as a weakness of their model and therefore proposed an editing phase preceding the actual decision phase in which fosd options are removed from the choice set. Nevertheless, the actual mechanism in Kahneman and Tversky (1979) allows for fosd choices.

In the following, we argue why our salience-based approach gives a better fit to experimental data on fosd choices than prospect theory. First, we exemplify that non-linear probability distortions may have to be unreasonably strong in order to account for violations of FOSD. Second, as Birnbaum (2005) points out, prospect theory does not satisfy *probability monotonicity*, that is, the likelihood with which prospect theory predicts violations of FOSD does not monotonically decrease if the dominated lottery's relative downsides become more likely.

According to Kahneman and Tversky (1979), a decision maker evaluates the objective probability p_i^x for outcome i of option x according to an inverse-S-shaped weighting function, that is,

$$\omega_i^x(p_i^x) = \frac{(p_i^x)^\beta}{\left(\sum_j (p_j^x)^\beta\right)^{1/\beta}}$$

for $\beta \in [0, 1)$. Accordingly, small (high) probabilities are overweighted (underweighted). While the limit case $\beta = 1$ describes the rational decision maker, typically β is estimated to be between 0.56 and 0.71 (see Kahneman and Tversky, 1992; Camerer and Ho, 1994; Wu and Gonzalez, 1996). Therefore, such probability distortions cannot account for dominated choices if probabilities are rather equally distributed among the branches. Furthermore, we reconsider our main example (Table 1) and modify the dominated lottery's probability distribution as depicted in Table

Urn A	Urn B
90 red marbles to win $96	55 green marbles to win $96
05 blue marbles to win $14	35 black marbles to win $90
05 white marbles to win $12	10 yellow marbles to win $12

Table 3: A different choice problem yielding violations of FOSD.

Urn A	Urn B
90 red marbles to win $96	01 green marbles to win $96
05 blue marbles to win $14	01 black marbles to win $90
05 white marbles to win $12	98 yellow marbles to win $12

Table 4: A choice problem probably satisfying FOSD.

3. Kahneman and Tversky (1979) predict that for no $\beta \in [0,1)$ a decision maker chooses the fosd option B over option A. Thus, prospect theory cannot explain violations of FOSD in this example. However, Birnbaum (2005) finds that a majority of 61% of all subjects violate FOSD and choose option B. As Bordalo et al. estimate that on average $\delta = 0.7$ holds, our salience mechanism provides a better fit to the data. In fact, the salience ranking of the outcomes is the same as in the original example (Table 1) and a local thinker prefers option B if and only if $\delta < 0.69$.

Finally, we consider an extreme example illustrating the importance of probability monotonicity which is satisfied by the salience mechanism, but not by prospect theory. Probability monotonicity implies that a local thinker is more likely to choose an option A when B's probability distribution is manipulated in a way such that low outcomes become more and high outcomes become less likely. Birnbaum's (2005) data supports probability monotonicity as fosd choices become less frequent if the dominated options' low outcomes become more likely. Hence, consider the example depicted in Table 4. In this variant of the example provided in Table 3, B's lowest outcome is realized with 98% probability. Reasonably, our salience approach predicts fewer violations of FOSD as the dominated option is chosen if and only if $\delta < 0.02$. Since prospect theory incorporates the overweighting of small probabilities, however, it violates probability monotonicity and provides counterintuitive predictions on the frequency of dominated choices. In fact, it predicts that in Table 4 any decision maker with $\beta < 0.3$ chooses the dominated option. Thereby, prospect theory suggests that violations of FOSD are more frequent for the choice problem depicted in Table 4 than for that in Table 3.

4.2 Salience vs. the TAX-model

Birnbaum (2005) proposes five alternative theories to prospect theory which drop the assumption of coalescing and, via this, account for violations of FOSD.[12] While among the five models, Birn-

[12]Relatedly, Rubinstein (1988) gives an axiomatic approach to model binary choices between lotteries which either yield a gain or an outcome of zero. Therefore, each lottery is defined by its values in the two dimensions *prize* and *(winning) probability*. Rubinstein assumes that a decision maker neglects a dimension in which the lotteries are similar, that is, in which the lotteries differ only by a sufficiently small amount. Thereby, he can explain for instance the Allais

baum's *transfer of attention exchange model* (TAX) fits his experimental data best, our salience-based explanation has different appeals. In particular, it can account for many biases of riskless decision making such as the endowment effect and decoy effects (BGS13) which the TAX-model cannot account for. Due to its wide applicability and its explanatory power with regard to various decision biases, salience theory is the more promising behavioral meta-theory of individual decision making.

Also with respect to decision making under risk, the proposed salience mechanism can account for choice patterns which remain unexplained by the TAX model. Given that options differ in their number of attributes they are characterized by, Birnbaum (2007) finds that decision makers select the option with the larger number of branches leading to favorable consequences. While this effects remains unexplained by the TAX model, the proposed salience mechanism predicts choices in favor of the option with more relative upsides, as long as probability differences between the up- and downsides are not too large. As our mechanism incorporates the intuitive assumption that missing attributes are regarded as zero, salience can account for the data in Birnbaum (2007).

5 Conclusion

Even though the empirical evidence for violations of FOSD is strong, the main behavioral theory of choice under risk, that is, cumulative prospect theory, cannot account for such phenomena. We have depicted how salience theory can explain such violations if alternatives are compared outcome by outcome and not according to the underlying state space as in salience theory of choice under risk (BGS12). Therefore, our mechanism of salience can account for subtle framing effects which have proved to be important, like for example the property of coalescing. If, in contrast, lotteries' valuations are based on the underlying state space as in BGS12, such framing effects remain unexplained. As Kőszegi and Szeidl (2013) point out, the question in which situations alternatives are indeed compared state by state is an important question for future research. In typical settings which trigger violations of FOSD, however, we take outcome by outcome comparisons for granted due to their intuitive appeal and the clear, supportive experimental findings. Hence, we have proven how one of salience theory's major challenges can be easily cleared up, which complements the comparison of prospect and salience theory started in BGS12.

The effect we delineated in the present paper has also important practical implications. Violations of first-order stochastic dominance are typically driven by violations of coalescing, that is, splitting events or attributes impacts on the valuation of goods, which can be explained by the salience mechanism we presented. For instance, *event-splitting* has important consequences for the demand for insurance. As Humphrey (2006) notes, insurance companies can enhance the impression of cover by splitting risks, which allows to charge larger premiums. Closely related, consumers pervasively overinsure modest-scale risks (Cicchetti and Dubin, 1994; Sydnor, 2010). Rabin and Thaler (2001) argue that the tremendous willingness to pay for small-scale risks is due

paradox. Rubinstein makes the important point that the decision procedure itself might lead to choices which violate transitivity. Thereby, he shows a fundamental conflict between such psychologically valid decision-making procedures and expected utility theory.

to event-splitting as there would be no demand for a comprehensive insurance policy covering all potential risks at the sum of the individual premiums, while there is demand for these insurances separately. In this line, Johnson et al. (1993) experimentally confirm that the consumers' willingness to pay for 'sub-risks' covered by a policy, e.g., health or flight insurance policies, is subadditive. Humphrey (2006) illustrates this effect as follows:

"Insurance cover for having your wallet stolen from your house and having your wallet stolen whilst out of the house may appear more attractive than cover for simply having your wallet stolen."

Splitting the covered risks into its 'sub-risks' renders the coverage salient. As a consequence, by choosing certain frames, insurance companies could exploit violations of coalescing which our salience approach, but neither expected utility theory nor cumulative prospect theory can account for.

Furthermore, our model predicts that doubling or splitting attributes, that is, dividing an attribute into certain subattributes, can increase a consumer's valuation of a good. Business literature indicates that this subadditivity of valuations plays an important role for consumption decisions. For instance, Bateman et al. (1997) suggest that it is not just an artefact of erroneous experimental elicitation procedures, but a basic property of individuals' preferences. Closely related, those attributes which are described in more detail than others tend to be overweighted. Thus, firms can manipulate consumers' evaluation of a product by providing more detailed information (Weber, 1988). Alba and Marmorstein (1987) find that providing the same information repeatedly increases the valuation of an advertised good. As providing information on an attribute twice can be interpreted as doubling the good's attribute, our approach explains why an increased frequency with which some piece of information is provided can enhance a good's valuation.

Finally, in the preceding examples event- or attribute-splitting shifts a decision maker's attention toward certain features of the alternatives at hand. Thus, a model of distorted attention represents a plausible and appealing approach in order to account for these effects. Salience theory as proposed by BGS13 provides such a general, but tractable model on distorted attention and its impact on decision making.

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ISSN 2190-9938 (online)
ISBN 978-3-86304-188-5