APPLIED ECONOMICS LETTERS
https://doi.org/10.1080/13504851.2019.1602699

Routledge
Taylor & Francis Group

ARTICLE

Differential effects of outcome and probability on risky decision

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ABSTRACT
Decision-making under uncertainty involves two main factors: probability and pay-off (outcome). Subjective expected utility theory argues that when making choices, the decision-maker selects the alternative that maximizes expected utility. Prospect theory argues that the decision-maker chooses the alternative that maximizes weighted value. Both theories argue for a weighted measure based on which the decision-maker makes choices. Neither explains, however, how probability and pay-off affect the decision-maker in making those choices. In addition, evidence exists that shows that utility is variable in relation to lotteries or frames, but how utility changes remains unknown. In this paper, we report an experiment to address this question; that is, how does pay-off or probability affect the decision-maker in making choices under uncertainty? The results show that when faced with gains, the decision-maker pays more attention to probability, whereas when faced with losses, the decision-maker seems equally sensitive to probability and pay-off in making choices under uncertainty.

KEYWORDSGainslosseso-utcomeprobabilitydeci-sion-making under uncertainty

JEL CLASSIFICATION
D81; C44

I. Introduction

Probability and pay-off (outcome) relevant preference are the two main factors that affect how choices are made by the decision-maker under uncertainty. Mainstream theories of decision-making under uncertainty, most significantly subjective expected utility theory (Savage 1972; von Neumann and Morgenstern 1953) and prospect theory (Kahneman and Tversky 1979), require in theory the decision-maker to express probabilistic and preferential judgments separately based on which probabilities and utilities (values) are derived accordingly and then combined into a composite, weighted measure for comparison to make a choice. In practice of utility elicitation, subjects are asked to express probabilistic or preferential judgments so that they are indifferent to a standard lottery, without knowing the relative contribution of probability and pay-off to these judgments.

In particular, those mainstream theories imply that utility (value) is invariant across lotteries or frames. However, recent experiments show that utility is lottery dependent in that the utility for the same monetary value is different if elicited in different lotteries (Lai, Huang, and Haoying 2017). The natural question to ask is: how does probability or pay-off each contribute to the choice of lotteries by the decision-maker? Some studies have addressed partially this question (c. f., Slovic and Lichtenstein 1968; Cohen, Jaffray, and Said 1987; Nygren et al. 1996; Kuhberger, Schulte-Mecklenbeck, and Perner 1999; Rao et al. 2012). The answer to this specific question systematically may improve our understanding of the underlying cognitive mechanism on which the choices under uncertainty are made. We report here an experiment to answer the question. In Section 2, we introduce the experimental design. In Section 3, we report the experimental results. In Section 4, we conclude.

II. Experimental design

In their classic paper, Kahneman and Tversky (1979) reported a series of 14 lotteries and came up with well-known prospect theory. For comparison purposes, we use the first eight pairs of elementary lotteries to explore into the relative contribution of probability and pay-off to decision-making under uncertainty because these eight pairs of elementary lotteries are more transparent and constitute the main body of the

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lotteries based on which prospect theory is constructed. The remaining six pairs of lotteries are designed to test specific psychological traits, such as the isolation effect, and thus are not quite relevant to our purposes here. Note that we are interested in the measurement of *utility* in the subjective expected utility theory rather than *value* in prospect theory. The eight pairs of lotteries are given below. Note that the lotteries were presented in their elementary forms. For example, ($4,000, 0.80) stands for a lottery in which there is an 80% of probability that the player would gain $4,000 and a 20% that he or she would gain nothing. The subjects were asked to select the lottery he or she preferred in a lottery pair. There were 50 subjects participating our experiment with 40 effective questionnaires. The questionnaires of the remaining10 subjects were incompletely filled out and were thus excluded. Each subject was asked to make a series of choices from lottery pairs. Forty sample size is greater than the minimum sample size of 30 to fulfil the requirement of the central limit theorem to allow us to conduct meaningful statistical tests (Chang et al. 2008). All the subjects were undergraduate students from the Department of Real Estate and Built Environment at National Taipei University, Taiwan and each subject was rewarded an NTD 200 as remuneration. One US dollar is roughly equivalent to 30 NT dollar.

Lottery Pair 1: Lottery Pair 2:
A: ($4,000, 0.80) A: ($4,000, 0.20)
B: ($3,000, 1.00) B: ($3,000, 0.25)
Lottery Pair 3: Lottery Pair 4:
A: ($6,000, 0.45) A: ($6,000, 0.001)
B: ($3,000, 0.90) B: ($3,000, 0.002)
Lottery Pair 5: Lottery Pair 6:
A: (-$4,000, 0.80) A: (-$4,000, 0.20)
B: (-$3,000, 1.00) B: (-$3,000, 0.25)
Lottery Pair 7: Lottery Pair 8:
A: (-$6,000, 0.45) A: (-$6,000, 0.001)
B: (-$3,000, 0.90) B: (-$3,000, 0.002)

For each pair of lotteries, a series of 20 pairs of lotteries were designed by systematically varying probability and pay-off, respectively, while keeping the difference of expected values of each pair of lotteries constant. In such design, we could record and observe how probability and pay-off would affect the 40 subjects in making choices in the 20 pairs of lotteries by minimizing noise from unknown factors. A list of all such 20 pairs of lotteries for Lottery Pair 1 through 8 is provided in Appendix 1.

III. Results

For each of the original lottery pair, we could plot the percentages of the 40subjects who chose A or B in the 20 systematic pairs of lotteries. As shown in Figure 1, one can observe that the percentages of the 40 subjects remain stable who chose A or B for the first 10 pairs of lotteries where the probabilities were held constant, or probability-constant lottery pairs. In contrast, the percentages of the 40 subjects fluctuate significantly who chose A or B for the last 10 pairs of lotteries where the pay-offs were held constant, or pay-off-constant lottery pairs. This observation shows that the subjects' would be more sensitive to the variation of probability than the pay-off. Appendix 2 shows all the distribution diagrams of the percentages of the 40 subjects choosing A or B for the remaining sets of systematic pairs of lotteries.

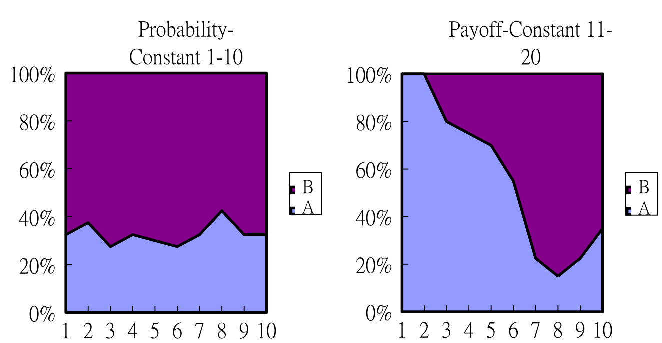

Figure 1. The percentages of subjects choosing A or B in the 20 systematic pairs of lotteries for lottery pair 1.

One can immediately observe that except for Lottery Pair 6 and Lottery Pair 7, all other original lottery pairs show significant differences in distribution of percentages between the probability-constant lottery pairs and the pay-off-constant lottery pairs. Note that the pay-offs in Lottery Pair 6 and Lottery Pair 7 are all negative, or losses, and that though the pay-offs in Lottery Pair 5 and Lottery Pair 8 are also losses, their associated probabilities are to some extent extremes of one or negligibility. On the face of it, we could conclude that when faced with gains, the decision-maker would be more sensitive to probability than pay-off in making choices under uncertainty and that when faced with losses, he or she would be equally sensitive to probability and pay-off in making such choices.

In a closer look at how probability or pay-off would affect the subjects' choices, we adopted the Gray Relation Analysis (Liu, Yang, and Forrest 2017) to compare the arrays of choices made by each subject in the probability-constant pairs of lotteries and the pay-off-constant pairs of lotteries derived from each original lottery pair. Appendix 3 depicts how the Grey Relation Analysis is conducted, and Table 1 shows the results of the Grey Relation Analysis.

Based on the Grey Relation Analysis we can conclude that when faced with gains, the decision-maker pays more attention to probability in making choices under uncertainty (Lottery Pairs 1 to 4), that when faced with losses, the decision-maker seems equivalently sensitive to probability and pay-off in making choices under uncertainty (Lottery Pairs 5 to 7). However, when the probability is negligible and faced with losses, the decision-maker focuses more on probability than pay-off in making choices under uncertainty (Lottery Pair 8).

Table 1. Comparison of effects of pay-off and probability on subjects' choices through grey relation analysis.

Lottery pair	Affected by pay-off	Affected by probability	Affected equally by pay-off and probability	Total
1	5	31	4	40
2	8	29	3	40
3	7	24	9	40
4	1	38	1	40
5	10	21	9	40
6	10	16	14	40
7	13	19	8	40
8	3	36	1	40

IV. Conclusions

Gains and losses are two distinct behavioural regimes in which decisions are made dramatically different. In the gains regime, the decision-maker is risk aversion, less sensitive to values, and focuses more on probability in making choices under uncertainty, whereas in the losses regime, the decision-maker becomes risk-seeking, more sensitive to values, and is equivalently sensitive to probability and pay-off in making these choices. Previous attempts are inconclusive in answering the question of how probability and pay-off contribute to decision-making under uncertainty. We report here an experiment to address this fundamental question. According to the experimental results, we argue that when faced with gains, the decision-maker pays more attention to probability than pay-off in making choices under uncertainty and that when faced with losses, he or she seems equivalently sensitive to probability and pay-off in making these choices. In addition, when the probability is negligible and faced with losses, the decision-maker focuses more on probability than payoff.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Ministry of Science and Technology, Taiwan [103WFA1300061].

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References

Chang, H.-J., C.-H. Wu, J.-F. Ho, and P.-Y. Chen. 2008. "On Sample Size in Using Central Limit Theorem for Gamma Distribution." *International Journal of Information and Management Sciences* 19 (1): 153–174.

Cohen, M., J.-V. Jaffray, and T. Said. 1987. ""Experimental Comparison of Individual Behavior under Risk and under Uncertainty for Gains and for Losses." *Organizational Behavior and Human Decision Processes* 39 (1): 1–22. doi:10.1016/0749-5978(87)90043-4.

Kahneman, D., and A. Tversky. 1979. “Prospect Theory: An Analysis of Decision under Risk.” *Econometrica* 47 (2): 263–291. doi:10.2307/1914185.

Kuhberger, A., M. Schulte-Mecklenbeck, and J. Perner. 1999. “The Effects of Framing, Reflection, Probability, and Payoff on Risk Preference in Choice Tasks.” *Organizational Behavior and Human Decision Process* 78 (3): 204–231. doi:10.1006/obhd.1999.2830.

Lai, S.-K., J.-Y. Huang, and H. Haoying. 2017. “Land Development Decisions and Lottery Dependent Utility.” *Real Estate Finance* 34 (2): 39–45. https:www.researchgate.net.

Liu, S., Y. Yang, and J. Forrest. 2017. *Grey Data Analysis: Methods, Models and Applications*. Signapore: Springer Science+Business Media.

Nygren, T. E., A. M. Isen, P. J. Taylor, and J. Dulin. 1996. “The Influence of Positive Affect on the Decision Rule in Risk Situations: Focus on Outcome (And Especially Avoidance of Loss) Rather than Probability.” *Organizational Behavior and Human Decision Processes* 66 (1): 59–72. doi:10.1006/obhd.1996.0038.

Rao, L., S. Li, T. Jiang, and Y. Zhou. 2012. “Is Payoff Necessarily Weighted by Probability When Making a Risky Choice? Evidence from Functional Connectivity Analysis.” *PloS one* 7 (7): e41048. doi:10.1371/journal.pone.0041048.

Savage, L. J. 1972. *The Foundations of Statistics*. New York: Dover Books.

Slovic, P., and S. Lichtenstein. 1968. “Relative Importance of Probabilities and Outcomes in Risk Taking.” *Journal of Experimental Psychology* 78 (3, Pt.2): 1–18.

von Neumann, J., and O. Morgenstern. 1953. *Theory of Games and Economic Behavior*. Princeton, NJ: Princeton University Press.

Appendix 1. Systematic Lottery Pairs Derived from Lottery Pair 1

The original Lottery Pair 1 is as follows:

Lottery Pair 1:
A: ($4,000, 0.80)
B: ($3,000, 1.00)

Based on this original lottery, we designed 20 subsequent lotteries. The first 10 pairs of lotteries were designed by fixing the probabilities and varying the pay-offs incrementally so that the difference of the expected values between any pair of lotteries remained the same. The last 10 pairs of lotteries were designed by fixing the pay-offs and varying the probabilities incrementally so that the difference of the expected values between any pair of lotteries remained the same. By eliminating possible unknown noise, this design, and the ensuing analyses, would allow us to observe how probability and pay-off each would affect the subjects' choices in the lotteries. The systematic pairs of lotteries for the remaining seven original pairs of lotteries were designed in a similar way as shown in the website with the URL at https://www.researchgate.net/publication/331521781_Appendix_1_Systematic_Lottery_Pairs_Derived_from_Lottery_Pair_1?_sg = 9TPYABCyn-2eEMy1Bf6t4EmHHLk5PIYGVLhveU2sQV__CLpZLWMknrW0yJ3zUpXeMq32n1kSsB28hT9CFxTzdgkW022yG9Su PNYnG94O.iBcX9KVaz3IGl6VVeCNKpmdRTGRi_FXamGl8E2nVMtIQlxljPUgPfSZRh-wzo38TCLckJtKsoWAENNfZEvc8qA

Appendix 2. Distribution Diagrams of Percentages of Subjects' Choices for All Lottery Pairs

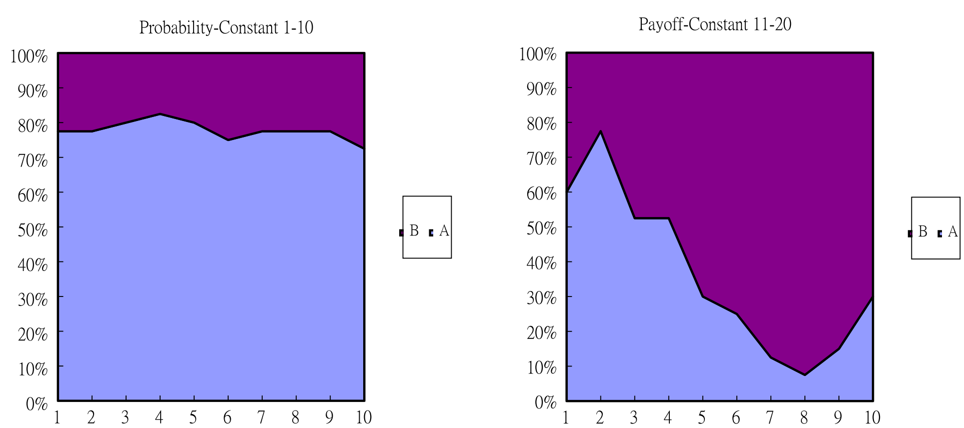

Figure A1. The percentages of subjects choosing A or B in the Systematic 20 pairs of lotteries for lottery pair 2.

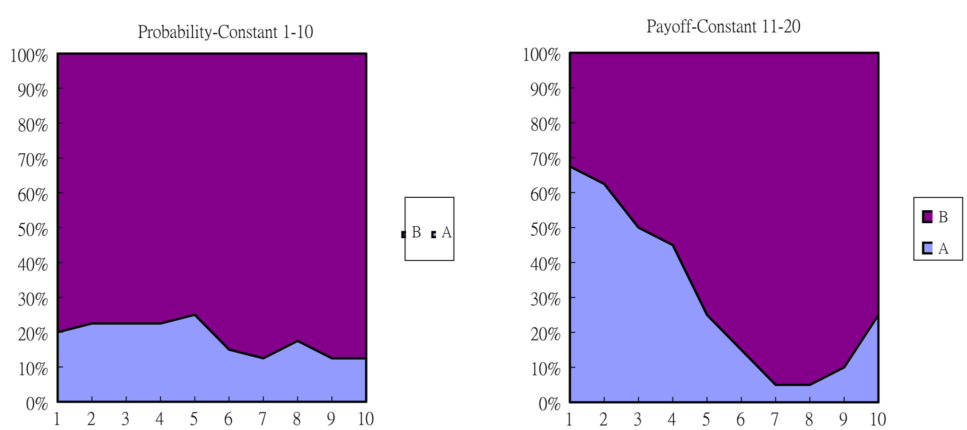

Figure A2. The percentages of subjects choosing A or B in the Systematic 20 pairs of lotteries for lottery pair 3.

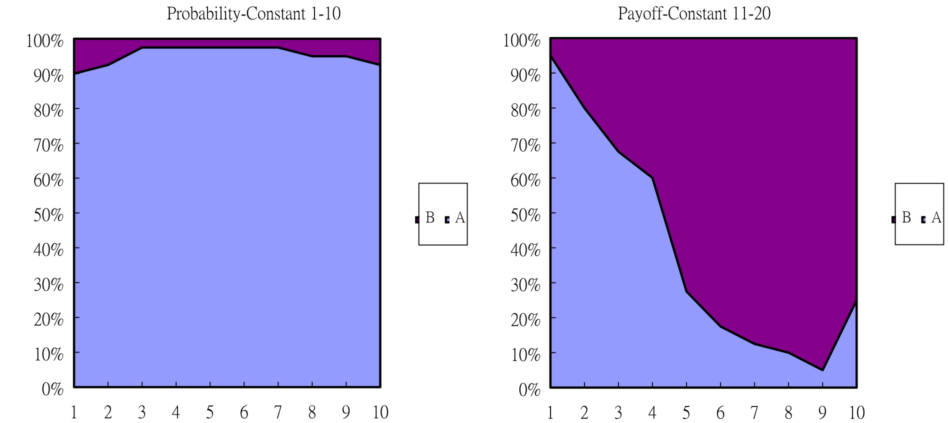

Figure A3. The percentages of subjects choosing A or B in the systematic 20 pairs of lotteries for lottery pair 4.

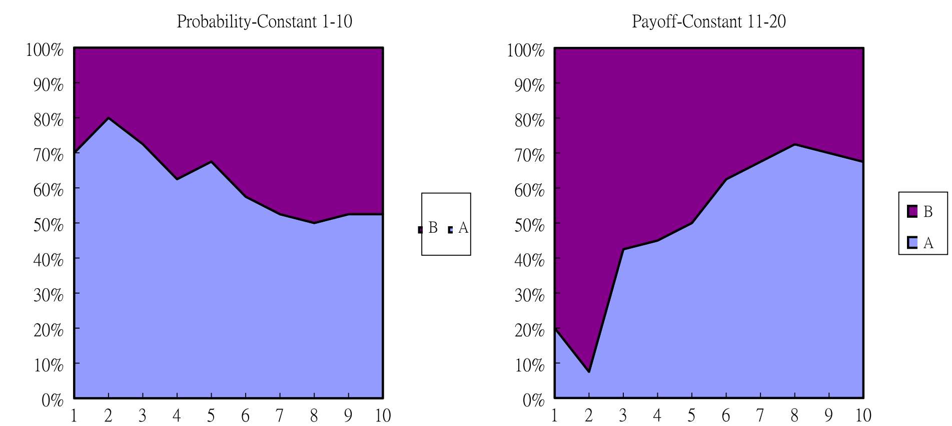

Figure A4. The percentages of subjects choosing A or B in the Systematic 20 pairs of lotteries for lottery pair 5.

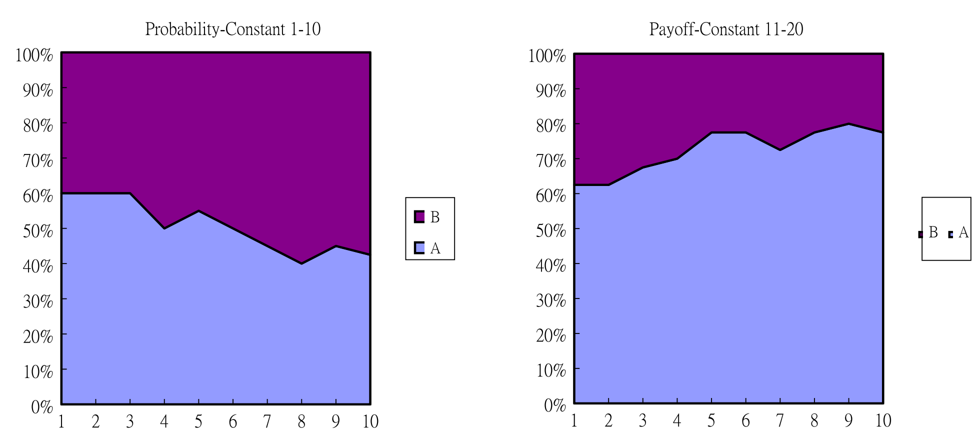

Figure A5. The percentages of subjects choosing A or B in the Systematic 20 pairs of lotteries for lottery pair 6.

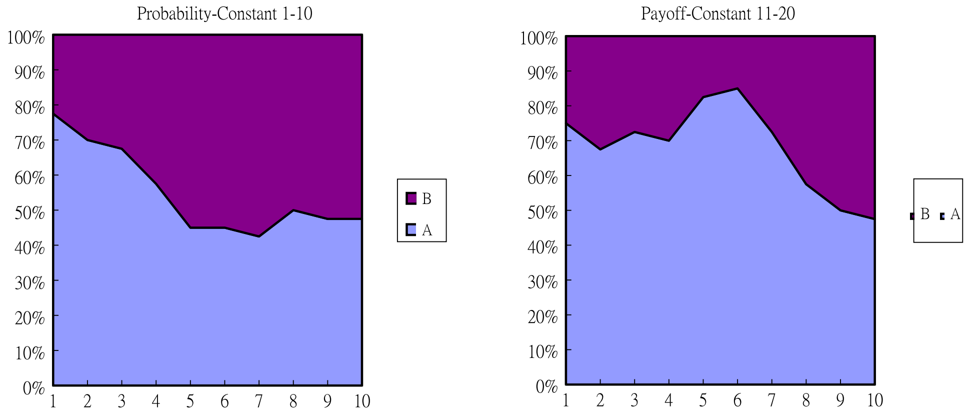

Figure A6. The percentages of subjects choosing A or B in the Systematic 20 pairs of lotteries for lottery pair 7.

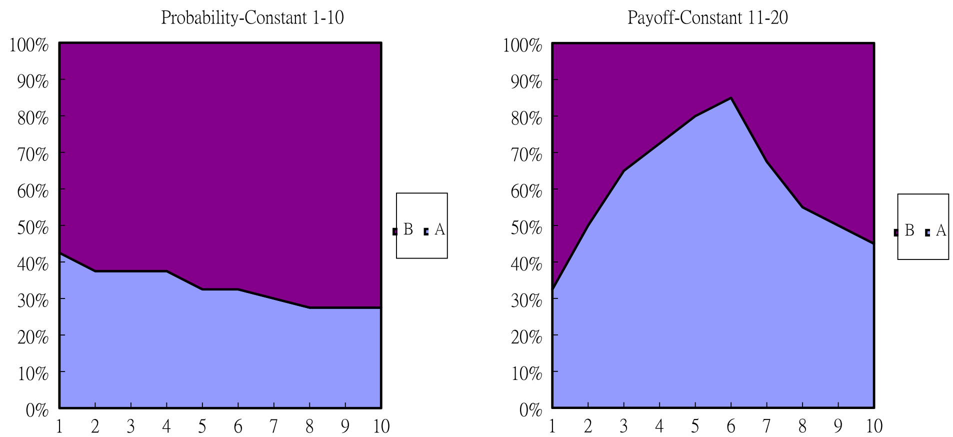

Figure A7. The percentages of subjects choosing A or B in the Systematic 20 pairs of lotteries for lottery pair 8.

Appendix 3. Example of Grey Relation Analysis

A Grey Relation Analysis (Liu, Yang, and Forrest 2017) is conducted to demonstrate how the relation between two arrays of data is computed by Equations 1 and 2. This appendix shows how the Grey Relation Analysis is carried out. The subjects' responses to each systematic lottery pair were re-coded and calculated according to Equations 1 and 2 to derive the Grey Relation Coefficients to determine whether his or her response to the original lottery pair was mainly affected by probability or pay-off. The greater Grey Relation Coefficient implies that the associated array (by either fixing probability or pay-off) has a greater impact on the subjects' responses. For details of the recoding and calculation, the reader is encouraged to refer to the website with the URL at https://www.researchgate.net/publication/322487953_OP_Experiment_Dataset?_sg = HmUd4I7pYU6iWRGa1BD5J3N2h3rXVxNXSEc1hEb5uvULvseCUfKNpY-umxQP3-bwhoONQeMCwebu_y3l8f2bz1qRZRyAC99e55t4JPTX.OTohqwCbZ2UeJFPzgRWNr9FFyXIazgde_8HIuyUCjrZsJyjg0DLEe55Bf5aqghL7WrOr2Zy5TK7vfldcSeXkLw

$$\Gamma(x_0(k), x_i(k)) = \frac{\min_i \min_k \left|x_0(k) - x_i(k)\right| + \xi \max_i \max_k \left|x_0(k) - x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \xi \max_i \max_k \left|x_0(k) - x_i(k)\right|} \tag{1}$$

$$\Gamma(x_0, x_i) = \left(\frac{1}{n}\right)\left(\sum\nolimits_{k=1}^{n} \Gamma(x_0(k), x_i(k))\right) \tag{2}$$

1. Let the target array X_0 and two internal relation arrays X_1 and X_2 be as follows:

$$X_0 = (1.0, 3.0, 6.0, 10.0, 15.0, 21.0, 28.0, 36.0)$$

$$X_1 = (1.0, 2.5, 4.5, 7.0, 10.0, 13.5, 17.5, 22.0)$$
$$X_2 = (1.0, 1.0, 4.0, 5.0, 10.0, 12.0, 19.0, 22.0)$$

2. Transform the three arrays to unit-free arrays as follows:

$$X_0^{'} = (1.0, 3.0, 6.0, 10.0, 15.0, 21.0, 28.0, 36.0)$$
$$X_1^{'} = (1.0, 2.5, 4.5, 7.0, 10.0, 13.5, 17.5, 22.0)$$
$$X_2^{'} = (1.0, 1.0, 4.0, 5.0, 10.0, 12.0, 19.0, 22.0)$$

3. Compute differences between arrays.

$$\Delta 1 = (0.0, 0.5, 1.5, 3.0, 5.0, 7.5, 10.5, 14.0)$$
$$\Delta 2 = (0.0, 2.0, 2.0, 5.0, 5.0, 9.0, 9.0, 14.0)$$

4. Select the maximum and minimum values in the different arrays.

$$M = Max\ _iMax\ _k\Delta_i(k) = 14;\ m = Min\ _iMin\ _k\Delta_i(k) = 0$$

5. Compute Grey Relation Coefficients for X'_0 and X'_1 by setting ξ to be 0.5.

$$\Gamma(x_0(1), x_1(1)) = 1.00;\ \Gamma(x_0(2), x_1(2)) = 0.93;$$
$$\Gamma(x_0(3), x_1(3)) = 0.82;\ \Gamma(x_0(4), x_1(4)) = 0.70;$$
$$\Gamma(x_0(5), x_1(5)) = 0.58;\ \Gamma(x_0(6), x_1(6)) = 0.48;$$
$$\Gamma(x_0(7), x_1(7)) = 0.40;\ \Gamma(x_0(8), x_1(8)) = 0.33;$$

6. Compute Grey Relation Coefficients for X'_0 and X'_2 by setting ξ to be 0.5.

$$\Gamma(x_0(1), x_2(1)) = 1.00;\ \Gamma(x_0(2), x_2(2)) = 0.78;$$
$$\Gamma(x_0(3), x_2(3)) = 0.78;\ \Gamma(x_0(4), x_2(4)) = 0.58;$$
$$\Gamma(x_0(5), x_2(5)) = 0.58;\ \Gamma(x_0(6), x_2(6)) = 0.44;$$
$$\Gamma(x_0(7), x_2(7)) = 0.44;\ \Gamma(x_0(8), x_2(8)) = 0.33;$$

7. Compute Grey Relation Degree for X_0 and X_1.

$$\Gamma(x_0, x_1) = (1.00 + 0.93 + 0.82 + 0.70 + 0.58 + 0.48 + 0.40 + 0.33)/8 \cong 0.66$$

8. Compute Grey Relation Degree for X_0 and X_2.

$$\Gamma(x_0, x_2) = (1.00 + 0.78 + 0.78 + 0.58 + 0.58 + 0.44 + 0.44 + 0.33)/8 \cong 0.62$$

9. Rank the Grey Relation Degrees.

$$\Gamma(x_0, x_1) \cong 0.66 > \Gamma(x_0, x_2) \cong 0.62$$