Assignment 2: Comparative Benefit-Cost Analysis of Dam Construction Projects

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Introduction

This report presents a comparative benefit-cost analysis of two proposed dam construction projects, employing Monte Carlo simulation to evaluate their financial viability and relative performance. Utilizing a structured approach, the analysis estimates benefit-cost ratios (BCRs), visualizes their frequency distributions, calculates descriptive statistics, performs a Chi-square goodness-of-fit test, and determines the probability of each project exceeding various BCR thresholds. The primary objective is to assess the likelihood of one dam project outperforming the other, providing a data-driven foundation for informed decision-making regarding these significant infrastructure investments.

Methodology

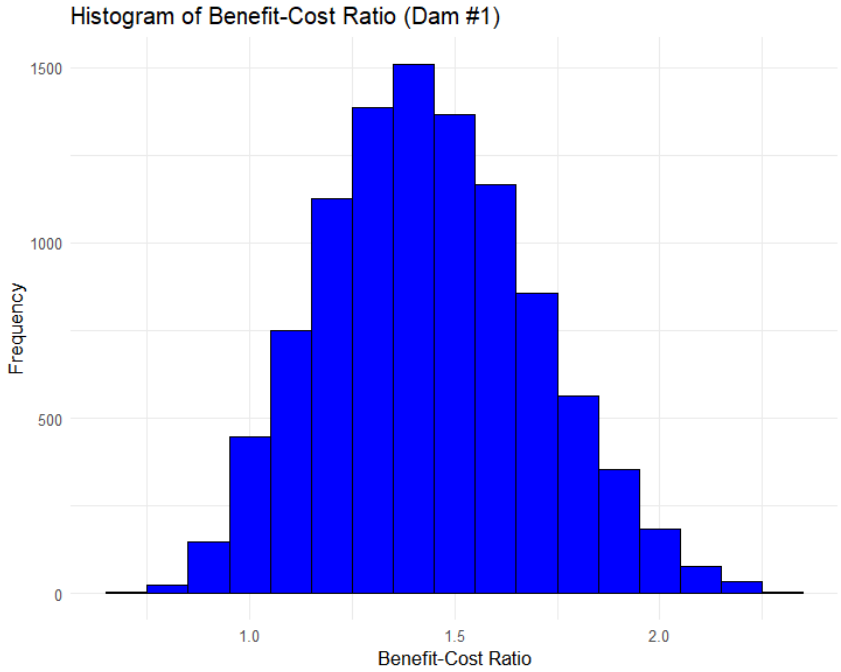
Conducting a Monte-Carlo simulation to ascertain the benefit-cost ratio. Then, we determine the frequency distributions for both dam projects and visualize these simulations with histograms following to compute the descriptive statistics for both dams and perform hypothesis testing to compare the observed distributions with theoretical expectations.

Results and Analysis

Part 1: Monte Carlo Simulations

- **Benefit-Cost Ratio (BCR) Estimation:**
  - This explains how the BCRs (α1 and α2) were calculated. The BCR is a fundamental metric, representing the ratio of the present value of benefits to the present value of costs.
  - The process involves simulating numerous iterations of benefits and costs and then calculating the ratio for each iteration.
- **Frequency Distributions and Visualizations:**
  - Histograms were generated for α1 and α2.
  - α1: Approximately normal distribution with slight right skew.

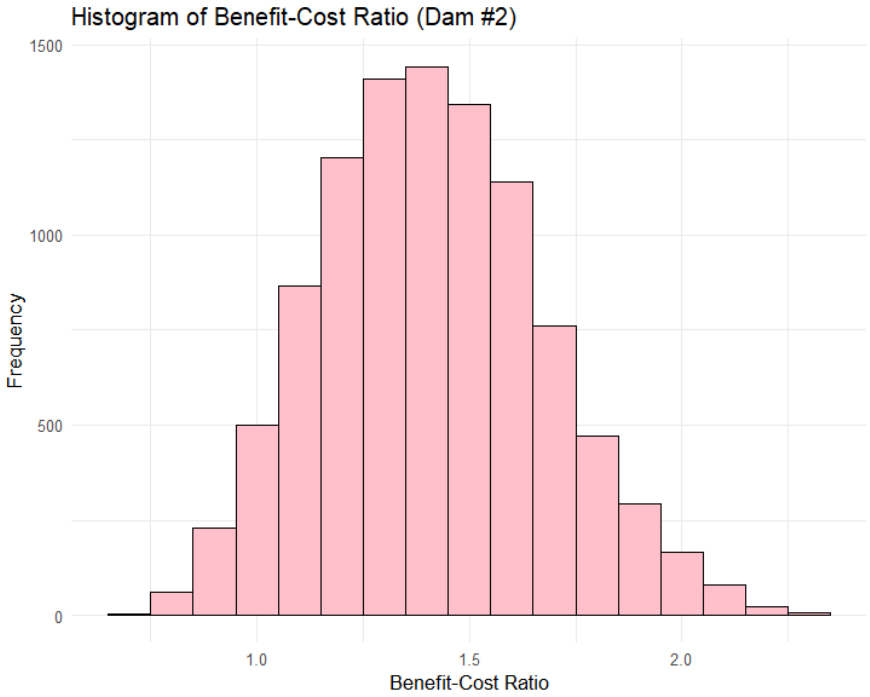
```
# A tibble: 10 × 2
   Interval      Frequency
   <chr>             <dbl>
 1 [0.735,0.891]        58
 2 (0.891,1.05]        541
 3 (1.05,1.2]         1315
 4 (1.2,1.36]         2060
 5 (1.36,1.51]        2301
 6 (1.51,1.67]        1804
 7 (1.67,1.82]        1149
 8 (1.82,1.98]         549
 9 (1.98,2.13]         182
10 (2.13,2.29]          41
```



The histogram reveals an approximately normal distribution with a slight right skew. This indicates that while the data is generally symmetrical, there are some higher-than-average Benefit to Cost Ratio values.

- α2: Normal distribution with minimal right skew.

	Interval	Frequency
	<chr>	<dbl>
1	[0.701,0.872]	102
2	(0.872,1.04]	706
3	(1.04,1.22]	1659
4	(1.22,1.39]	2297
5	(1.39,1.56]	2348
6	(1.56,1.73]	1661
7	(1.73,1.9]	864
8	(1.9,2.07]	278
9	(2.07,2.24]	75
10	(2.24,2.41]	10



The histogram shows a more symmetrical normal distribution with minimal right skew, suggesting a more consistent distribution of Benefit to Cost Ratios.

- **Descriptive Statistics:**
  - **Dam 1 (α1):**

```
# A tibble: 6 × 3
  Dam1_Project                Observed Theoretical
  <chr>                          <dbl>       <dbl>
1 Benefits(Mean)                  29.5        4.87
2 Benefits(SD)                     4.42       4.74
3 Costs(Mean)                     20.7        9.55
4 Costs(SD)                        2.09       6.58
5 Benefit-Cost Ratio(Mean)         1.44      NA
6 Benefit-Cost Ratio(SD)           0.258     NA
>
```

Mean Benefits: The observed mean benefits are significantly higher than the theoretical mean, indicating that the simulation predicts higher benefits than initially expected.

Mean Costs: Observed costs are also higher than theoretical costs, suggesting potential cost overruns.

Mean BCR: The mean Benefit to Cost Ratio of 1.44 indicates that, on average, the benefits exceed the costs.

Cost Variability: The observed cost variability is lower than the theoretical variability, suggesting that actual costs are more predictable.

- **Dam 2 (α2):**

```
# A tibble: 6 × 3
  Dam2_Project                Observed Theoretical
  <chr>                          <dbl>       <dbl>
1 Benefits(Mean)                 30.8         5.25
2 Benefits(SD)                    4.62        4.25
3 Costs(Mean)                    22.1        10.8
4 Costs(SD)                       2.36        7.14
5 Benefit-Cost Ratio(Mean)        1.41       NA
6 Benefit-Cost Ratio(SD)          0.263      NA
```

- Similar trends are observed for Dam 2, with higher observed benefits and costs than theoretical values.
- The mean BCR is 1.41, also indicating positive returns.
- Cost variability is also lower than theoretical.

Key takeaway: The descriptive statistics provide a clear picture of the central tendency and variability of the simulated data.

Part 2: Probability Distribution Analysis

- **Chi-Square Goodness-of-Fit Test:**
  - H0: Simulated distribution is not significantly different from the theoretical distribution.
  - H1: Simulated distribution is significantly different from theoretical distribution.
  - α = 0.05, df = 9, χ^2_critical = 16.92.
  - χ^2 = 84.986, p < 0.00000000000001642.

```
        Chi-squared test for given probabilities

data:  observed_freq
X-squared = 84.986, df = 9, p-value = 0.00000000000001642
```

  - **Result:** The null hypothesis is rejected, indicating that the simulated distributions significantly deviate from the theoretical distribution.

Part 3: Comparative Analysis and Probability Calculations

- **Key Statistical Comparisons:**

```
# A tibble: 7 × 3
  Statistic          Alpha1 Alpha2
  <chr>               <dbl>  <dbl>
1 Minimum             0.735  0.723
2 Maximum             2.29   2.35
3 Mean                1.44   1.41
4 Median              1.42   1.40
5 Variance            0.0666 0.0691
6 Standard Deviation  0.258  0.263
7 Skewness            0.241  0.262
```

- α1 has a slightly higher mean and median Benefit to Cost Ratio, suggesting a marginally better average performance.
- α2 exhibits higher variance and standard deviation, indicating greater variability in its outcomes.
- Both distributions are positively skewed, indicating a tendency for higher-than-average Benefit to Cost Ratio values.
- **Probability Calculations:**

	Threshold	P_Alpha1	P_Alpha2
1	2.0	0.0179	0.0185
2	1.8	0.0890	0.0788
3	1.5	0.3879	0.3581
4	1.2	0.8108	0.7763
5	1.0	0.9666	0.9489

-
```
[1] "P(α1 > α2) = 0.5297"
```

- This section calculates the probability of α1 being greater than α2 (P(α1 > α2)), which is 52.97%.
- It also compares the probability of each dam exceeding various BCR thresholds.
- The results show that P(α1) is consistently higher than P(α2) for all thresholds, indicating that Dam 1 has a higher likelihood of achieving favourable outcomes.
- **Summary:**

Dam 1 has a slightly higher probability of exceeding the Benefit to Cost Ratio thresholds.

Conclusion

The Monte Carlo simulation revealed positive Benefit to Cost Ratios for both dam projects, but significant deviations from the theoretical distribution were observed. Dam 1 (α1) demonstrates a slightly higher probability of achieving positive economic outcomes.

References

Albright, S. C. (2016). Business analytics (6th ed.). Cengage Learning.

Bluman, A. G. (2018). Elementary statistics: A step-by-step approach (10th ed.). McGraw Hill.

Kabacoff, R. I. (2022). R in action: Data analysis and graphics with R and tidyverse (3rd ed.). Manning Publications.