Assessing the Impact of Income Status on Early Childhood Educational Progression

1. Introduction

Securing a solid foundation in the early educational stages is crucial for the development of children. However, disparities in academic achievement are a persistent challenge. In addressing this issue, we wanted to explore how different income groups affect children's achievement in spring terms, and during this process we should also take fall scores from the previous year into account as they provide a baseline measure of students' abilities at the beginning of the academic year.

This study conducts a comprehensive quantitative analysis of educational progression in kindergarten students, focusing on the relationship between family income levels and their effect on reading and math scores. Utilizing the dataset 'INF2178_A3_data.csv', we explore how income groups influence the academic performance over the academic year, from fall 1998 to spring 1999, particularly analyzing spring reading and math scores while controlling for fall math and reading scores as baselines. Our aim is to uncover the extent to which socioeconomic status impacts early learning and to identify potential areas for policy intervention to bridge the educational divide.

Based on the above purpose, our analysis will focus on two primary research questions:

1. **Research Question 1:** How do income groups influence the spring reading scores among kindergarten students, after controlling for their fall reading scores?
2. **Research Question 2:** How do income groups influence the spring math scores among kindergarten students, after controlling for their fall math scores?

2. Data Cleaning and Data Wrangling

Our dataset comprised a total of **9 columns** with **11,933** entities (**rows**), and there are no missing values in most of the columns. Since we are interested in studying the effect of different income groups, we first make sure it is a categorical variable, and we will focus on related columns and leave out other unrelated columns. Below is the description of each related column:

- **fallreadingscore:** Reading score that kindergarten children received during the fall term in 1998
- **fallmathscore:** Math score that kindergarten children received during the fall term in 1998
- **springreadingscore:** Reading score that kindergarten children received during the spring term in 1999
- **springmathscore:** Math score that kindergarten children received during the spring term in 1999
- **incomegroup**: Derived by ‘incomeinthousands’ column, it is a categorical variable which groups kindergarten children into different income categories based on their

family's total household income, where 1 means income lower than $40,000, 2 means income between $40,000 and $70,000, 3 means income above $70,000.

3. Exploratory Data Analysis (EDA)

First, we would like to proceed with a comprehensive EDA before conducting further analysis such as one-way ANCOVA, to gain a thorough insights. We will first look at the summary statistic table and boxplots presenting the relationship between income groups and different scores.

	fallreadingscore	fallmathscore	springreadingscore	springmathscore	incomeinthousands
count	11,933	11,933	11,933	11,933	11,933
mean	35.95	27.13	47.51	37.80	54.32
std	10.47	9.12	14.33	12.03	36.64
min	21.01	10.51	22.35	11.90	0.001
25%	29.34	20.68	38.95	29.27	27
50%	34.06	25.68	45.32	36.41	47
75%	39.89	31.59	51.77	44.22	72
max	138.51	115.65	156.85	113.80	150

Figure 1: Data Summary Statistic

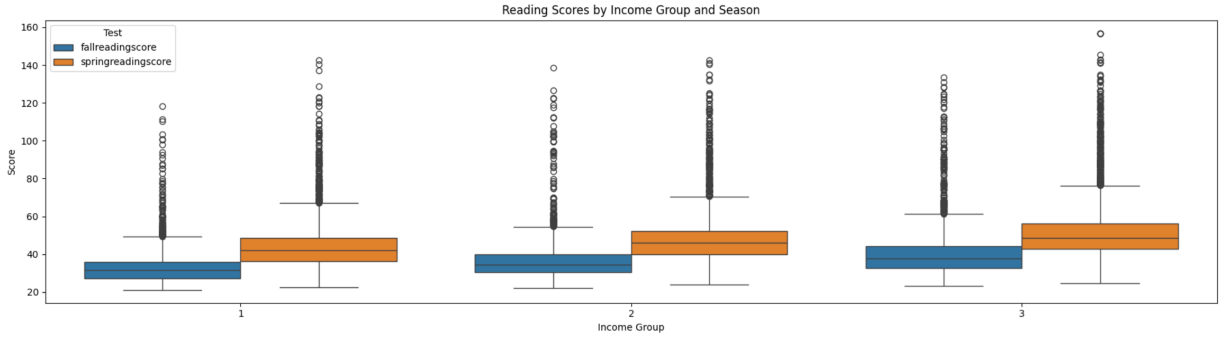

Figure 2: Boxplot of Reading Scores by Income Group and Season

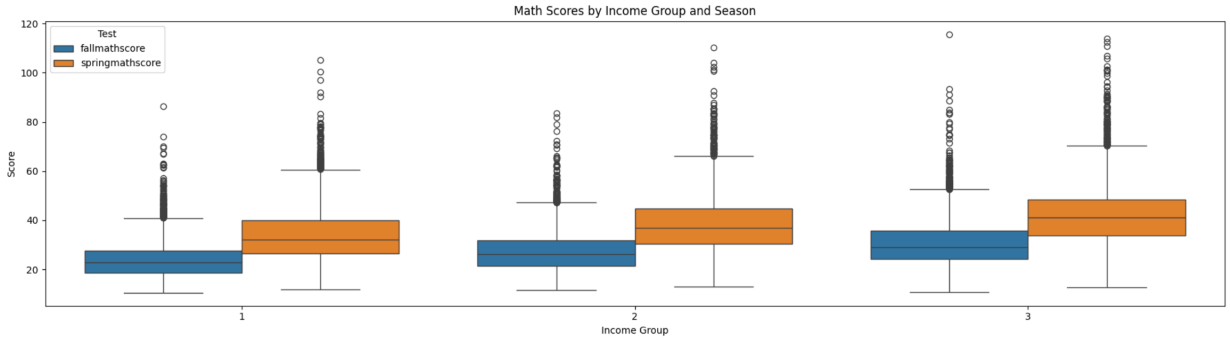

Figure 3: Boxplot of Math Scores by Income Group and Season

From the above boxplots we can see that there is an increase in the score in spring terms compared with fall terms for both reading and math across all income groups, but it is uncertain whether income groups play a significant role in affecting students' scores for the spring term, or whether students' results in the previous fall terms act like a covariate during this process. The next step is to conduct two one-way ANOVA tests to explore our research questions.

4. Influence of Income Groups on Spring Reading Scores, Adjusted for Fall Baseline

Research Question #1: How do income groups influence the spring reading scores among kindergarten students, after controlling for their fall reading scores?

In order to address this question, we will first look at the interaction plot comparing the relationship between fall and spring reading scores for different income groups:

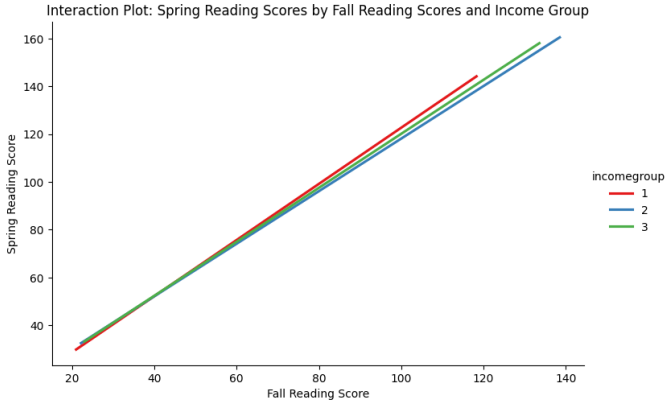

Figure 4: Interaction Plot of Spring Reading Scores for Different Income Groups, with Fall Reading Score as a Covariate

From the interaction plot we can see a consistent positive correlation between the scores in both seasons across the groups, and it also checks for homogeneity of slopes. However, the lines don't show a clear separation with each other, indicating similar rates of improvement regardless of income group. Therefore, we need to conduct the test to see if the effect of income group is statistically significant or not.

Source	Sum of Squares	df	F	PR(>F)	η^2
Income group	513.12	2	4.06	0.02	<0.001
Fall Reading score	1547042	1	24455.4	<0.001	0.67
Residual	754625.60	11929			

Figure 5: One-way ANCOVA Test for Comparing Spring Reading Score and Income Group, Controlling for Fall Reading Score

The null hypothesis is that there is no difference in the means of spring reading scores among the different income groups after adjusting for the variance due to fall reading scores. From this ANCOVA table we can see that both fall reading scores and income group have a statistically significant effect on spring reading scores, and we reject the null hypothesis. Although according to the partial eta squared (η^2) value, the impact of fall reading scores is much more pronounced.

To determine which specific group or groups differ from each other, a **post-hoc test** would be necessary, and we use **Tukey HSD test** to test the difference. From the table below we can see that there are statistically significant differences in mean scores between all pairs of income groups, and group 3 (highest income group) has a higher mean score than any other 2 groups. Therefore, statistically speaking higher income group will result in higher average reading scores.

Group 1	Group 2	Mean Difference	PR(>F)	Lower Bound	Upper Bound	Reject Null Hypothesis
1	2	4.34	<0.001	3.76	4.93	TRUE
1	3	8.54	<0.001	7.95	9.14	TRUE
2	3	4.20	<0.001	3.57	4.83	TRUE

Figure 6: Tukey HSD Post-Hoc Comparisons for Different Income Groups on Spring Reading Scores

Shapiro-Wilk	
Statistic	**PR(>F)**
0.91	<0.001

Figure 7: Shapiro-Wilk Test of Normality for Different Income Groups

In order to properly complete the ANCOVA test, we also need to check if **assumptions** are satisfied. To begin with, the **normality check** was done by the **Shapiro-Wilk test**, and the result is in the table on the left. From the normality check table, we can see that the normal distribution assumption is violated.

Levene's Test	
Statistic	**P-Value**
39.55	<0.001

Figure 8: Levene's Test for Homogeneity of Variances for Difference Income Groups

Then we conduct **Levene's test** to check the homogeneity of variances across all income groups for spring reading scores. From the test result table on the left, we reject the null hypothesis and there is a statistically significant difference in variances between the different income groups. Thus, the assumption of equal variances is also violated for the groups being compared.

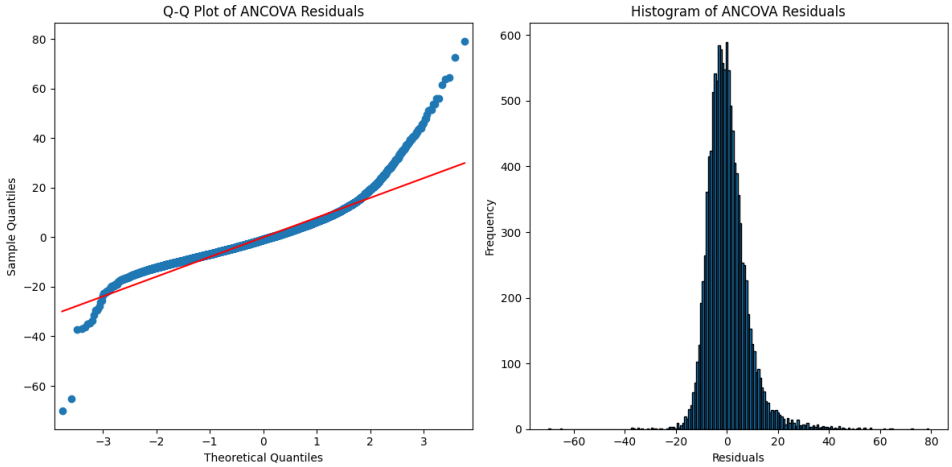

Figure 9: Q-Q Plot and ANCOVA Residuals Analysis

The above **Q-Q plot** and histogram also suggests that while the residuals are roughly normal in the center of the distribution, there are deviations from normality, particularly in the tails. This could potentially affect the validity of statistical tests that assume normality of residuals.

The last assumption is that the observations (and also errors) are independent of each other, here we assume this assumption is satisfied. Given the above violation of assumption findings, however, we still proceed our analysis and conclude that there a statistically significant difference in spring reading scores among different income groups, when we include fall reading scores as a baseline.

5. Influence of Income Groups on Spring Math Scores, Adjusted for Fall Baseline

Research Question #2: How do income groups influence the spring math scores among kindergarten students, after controlling for their fall math scores?

Apart from reading scores, we also want to study how different income groups affect students' spring math scores, and just like reading scores, analyzing math scores can provide valuable insights into how socioeconomic factors impact educational achievement, informing educators and policymakers about where support is needed most.

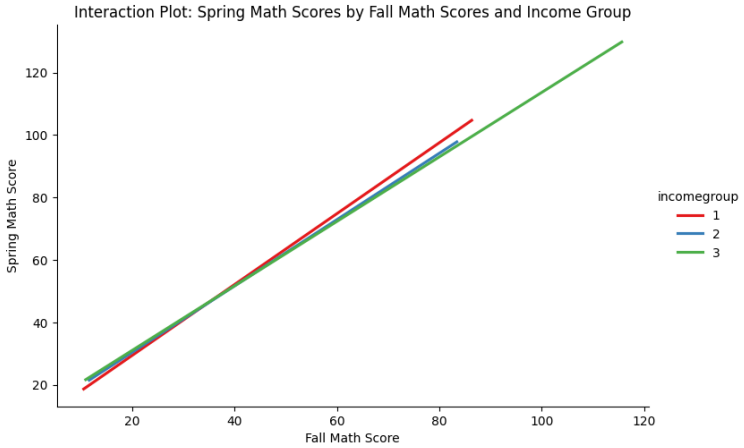

Figure 10: Interaction Plot of Spring Math Scores for Different Income Groups, with Fall Math Score as a Covariate

We will first look at the **Interception Plot** which displays the relationship between fall math scores and spring math scores for three different income groups. Similar with the interaction plot for reading scores, this diagram suggests that income level may be associated with the math performance and it also checks for homogeneity of slopes, but we need to conduct more tests to see whether there is any significance.

To investigate the research question further, we use another **one-way ANCOVA** test to see if there are interaction effect between these two features. From the **ANCOVA table below**, we can see similar patterns with analysis for reading scores. Both fall math scores and income group have a statistically significant effect on spring math scores. Thus, we reject the null hypothesis and states that there is statistically significant difference in the means of spring math scores among the different income groups after adjusting for the variance due to fall math scores. Although according to the partial eta squared (η^2) value, the impact of fall math scores is much more pronounced (0.65) compared with different income groups (0.003).

Source	Sum of Squares	df	F	PR(>F)	η^2
Income group	1712.76	2	18.52	<0.001	0.003
Fall Math score	1026489.00	1	22203.08	<0.001	0.65
Residual	551499.40	11929			

Figure 11: One-way ANCOVA Test for Comparing Spring Math Score and Income Group, Controlling for Fall Math Score

The next step is also to conduct a **post-hoc test** to determine which specific group or groups differ from each other. The result table below also shows that there are statistically significant differences in mean scores between all pairs of income groups, and group 3 (highest income group) has a higher mean score than any other 2 groups. Therefore, statistically speaking higher income group will result in higher average math scores as well.

Group 1	Group 2	Mean Difference	PR(>F)	Lower Bound	Upper Bound	Reject Null Hypothesis
1	2	4.58	<0.001	4.11	5.06	TRUE
1	3	8.53	<0.001	8.04	9.01	TRUE

2	3	3.95	<0.001	3.43	4.46	TRUE

Figure 12: Tukey HSD Post-Hoc Comparisons for different income groups on spring math scores

Just like for the first research question, we should perform **assumption check** to ensure the validity of the test's results for the second research question, and below are the results tables of the normality and homoscedasticity check. It can be seen from the two tables below that the dataset failed both assumptions. In addition, the combination of the Q-Q plot and histogram indicates that while the residuals are approximately normally distributed, there are indications of outliers or extreme values. These could potentially influence the results of the ANCOVA, as the assumption of normality is slightly violated in the tails. Finally, we can assume errors are independent to each other. As above, we still conclude that income groups and fall math scores have a statistically significant impact on spring math scores.

Shapiro-Wilk	
Statistic	**PR(>F)**
0.965	<0.001

Figure 13: Shapiro-Wilk Test of Normality for Different Income Groups

Levene's Test	
Statistic	**P-Value**
18.90	<0.001

Figure 14: Levene's Test for Homogeneity of Variances for Difference Income Groups

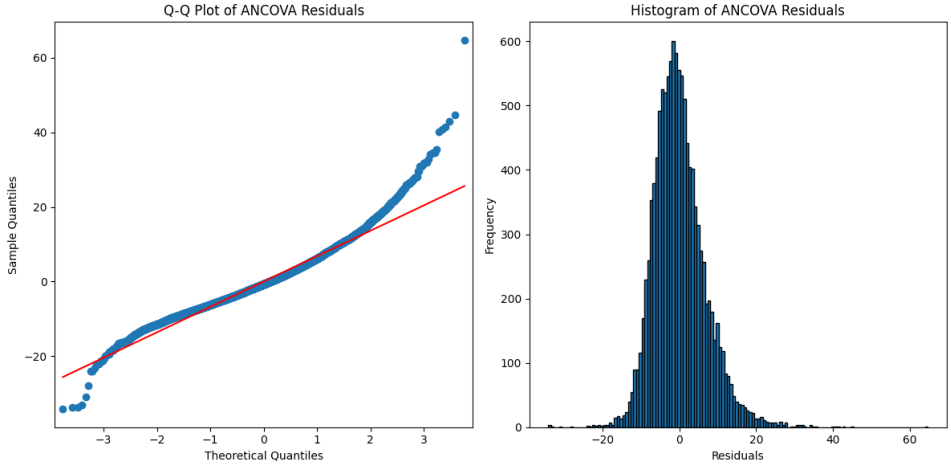

Figure 15: Q-Q Plot and ANCOVA Residuals Analysis

6. Conclusion

In conclusion, despite the violations of normality and homogeneity of variances assumptions indicated by the Shapiro-Wilk and Levene's tests, the ANCOVA analyses conducted on both reading and math scores from fall to spring terms among kindergarten students have demonstrated statistically significant effects of income groups and baseline fall scores on spring scores. Higher income groups were associated with higher average scores in both reading and math, suggesting that socioeconomic status plays a role in educational outcomes. These findings underscore the importance of considering socioeconomic factors in educational strategies and interventions aimed at supporting students' academic growth. As we close our investigation, we acknowledge the limitations imposed by assumption checks but maintain the relevance of our findings in informing educational policy and practice.