Title

Does Wealth Lead to Health? Exploring the Association Between GDP and Life Expectancy Over Time

Introduction

 Two decades ago, the benefits of economic growth seemed obvious. However, rising inequality, climate change, and the economic shocks from the COVID-19 pandemic have led some to question economic growth. The most severe critics now advocate for the opposite of economic growth: "degrowth" (see: https://www.cnbc.com/video/2021/05/20/degrowth-is-it-time-to-live-better-with-less.html). In light of this debate, this analysis asks: is economic growth associated with higher life expectancy? To do so, I will examine *gapminder*, a dataset that collects information on a battery of measures (including GDP per capita and life expectancy) for every country every five years. If economic growth is indeed associated with higher life expectancy, the degrowth movement's potential success will have drastic consequences.

GDP and Life Expectancy in 2007

 To begin, I examine life expectancy vs. GDP per capita in 2007. The relationship is hard to interpret because there are some observations with a very high GDP per capita (> 40,000) while the bulk of the points have a low GDP per capita (< 15,000). To fix this scaling issue, I transform GDP per capita to log (base 10) GDP per capita. The scale of GDP per capita then becomes a multiplicative increase for each unit increase, which best encapsulates the large range of this variable. Figure 1 demonstrates that taking the log of GDP per capita also straightens out the relationship between this variable and life expectancy. I additionally plot a LOESS smoother weighted by population (the red line). A LOESS smoother is a line that follows local patterns in the data as it moves across the range of the data. The very straight LOESS smoother indicates that the relationship is indeed straight. The correlation between these variables is 0.81. This pattern can be well-described by a linear model.

Figure 1. Life Expectancy vs. GDP per Capita (Logged)
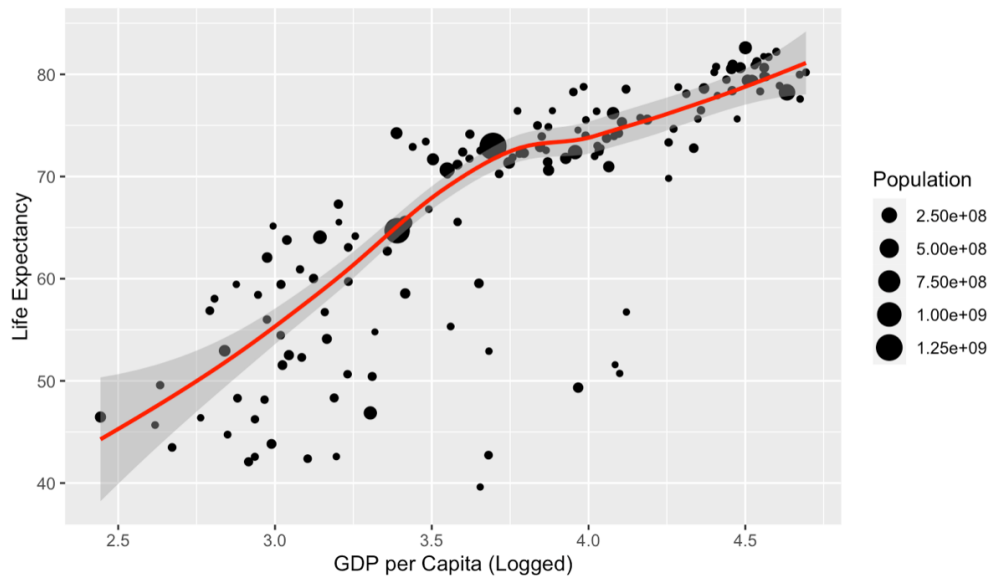
To further examine the relationship between GDP per capita (logged) and life expectancy, I break the data down by continent in Figure 2. Again, LOESS smoothers weighted by population are plotted (except for Oceania as it only contains two points). The relationship between GDP per capita and life expectancy is linear in the Americas, Asia, and Europe. However, the relationship is slightly less strong in Europe, which suggests exploring a main effect for continent. The relationship between GDP per capita and life expectancy in Africa appears to be nonparametric (not following a well-defined pattern). This suggests building two models for the 2007 data: a nonparametric model to describe Africa and a linear model to describe the rest of the continents.


Figure 2. Life Expectancy vs. GDP per Capita (Logged) by Continent
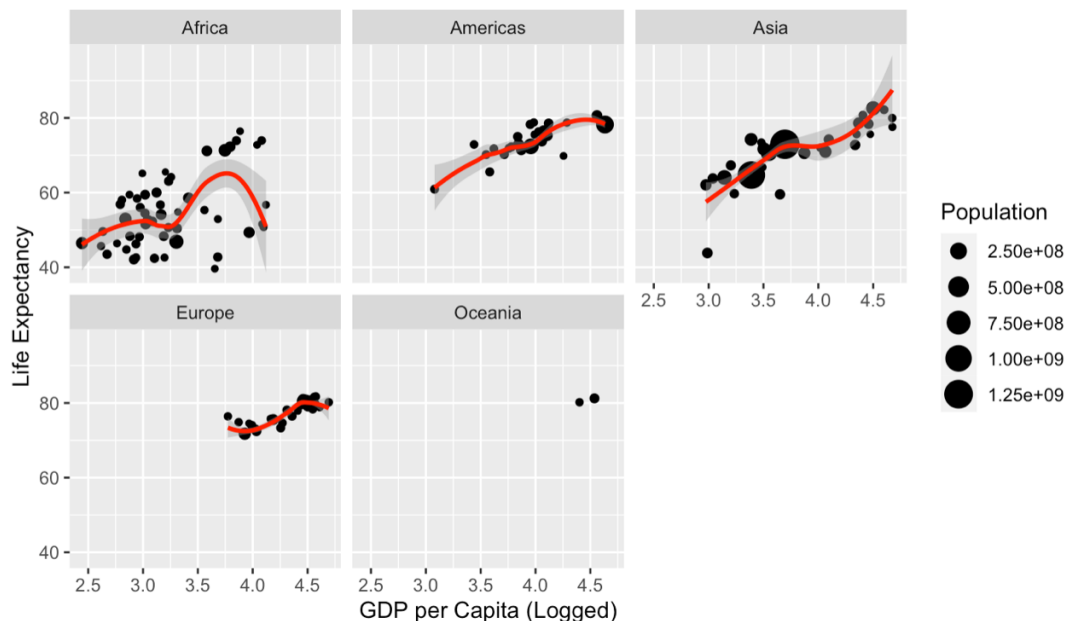
Life Expectancy Over Time by Continent

Figure 3 plots average life expectancy (weighted) vs. year, with each line representing a different continent. No matter the date, the ordering of continents by life expectancy remains the same: Oceania, Europe, the Americas, Asia, and Africa. Oceania, Europe, and the Americas all saw a similar increase in life expectancy from 1952 to 2007 at a similar rate resulting in a constant gap between these three continents. Asia witnessed a faster increase in life expectancy from 1950 to 1987, and a similar rate of increase as the other three continents from 1987 onward. This is somewhat surprising as Asia also witnessed a decrease in life expectancy from 1957 to 1962, the only decrease in the dataset. I suspect this is due to the Great Chinese Famine of 1959 - 1961. Events in China are capable of driving patterns in the Asian continent because data is weighted by population and China is one of the most populous countries in the world. To verify that this is indeed the case, I reproduce the graph omitting China from the analysis (see Appendix). Without China, the average life expectancy for Asia no longer decreases from 1957 - 1962. Additionally, while the gap between Asia and the three leading continents shrinks, it does not shrink as much as when China is included in the analysis.

Figure 3. Average Life Expectancy vs. Year
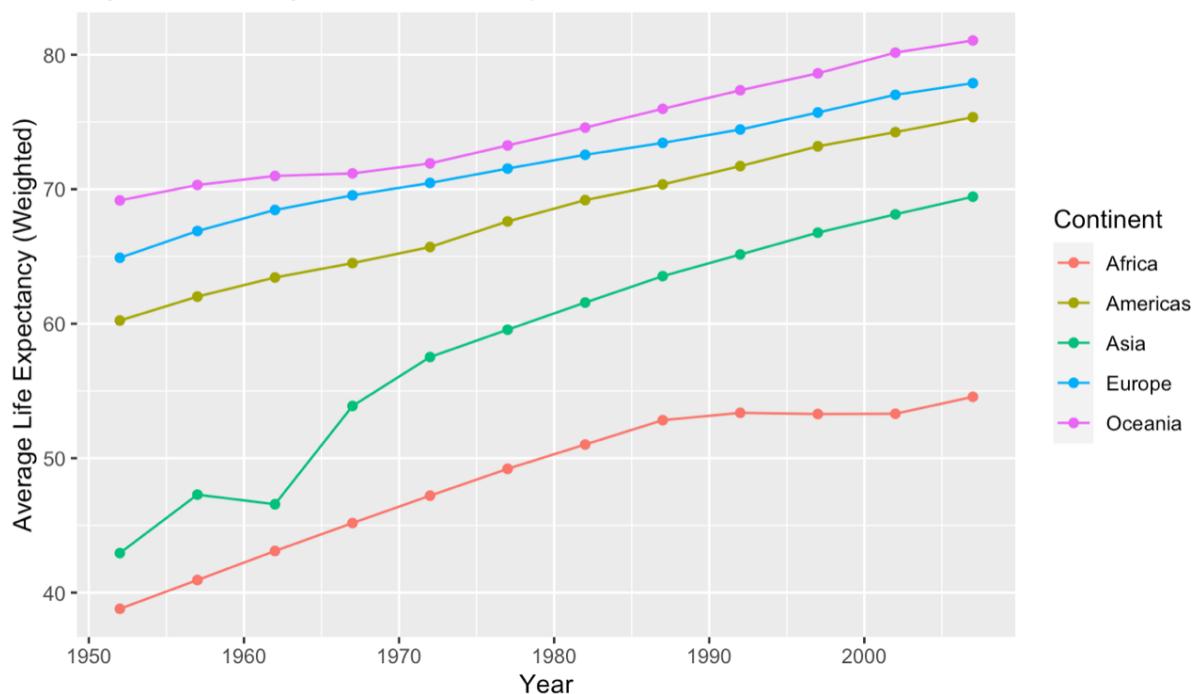
Again, Africa stands out among the continents. From 1952 to 1987, Africa's average life expectancy increased at a slightly higher rate than the other continents (bar Asia) resulting in a shrinking life expectancy gap. However, from 1986 - 2007 Africa's average life expectancy was flat. To explore whether this trend was driven by a few outlier countries or a widespread plateauing in life expectancy, I calculate the difference in life expectancy for each country in Africa between 2007 and 1987. The average increase in life expectancy for each country in Africa is 1.46 years over this time frame, while the average increase in life expectancy for the other continents is about 6 years. In fact, only slightly more than 25% of countries in Africa

witnessed in increase in life expectancy this large. To make matters worse, Swaziland and Zimbabwe experienced a decline in life expectancy of 18 years and 19 years respectively. Reasons for this trend may include a diminishing return of technological innovations in agriculture, disease, and a decline in international aid.

Changes in the Relationship between GDP and Life Expectancy over Time

To explore if the relationship between GDP and life expectancy changed over time, I plot life expectancy vs. GDP per capita (logged) with points grouped by decade. I group points by decade rather than year because then only six comparisons need to be made, rather than eleven. I then plot decade specific LOESS smoothers to ascertain patterns in the data. I exclude Kuwait from the analysis because it is an outlier; as an oil rich state with an extremely small population, it heavily influences the LOESS smoothers for the earlier decades even after weighting for population. A plot including Kuwait is included in the Appendix. Figure 4 demonstrates that the relationship between GDP per capita and life expectancy does depend on time. In the 1950's, 1960's, and 1970's, the relationship between logged GDP per capita and life expectancy is flat at lower levels of GDP per capita and then linear at higher levels of logged GDP per capita. In contrast, in the 1980's 1990's, and 2000's, the relationship between logged GDP per capita and life expectancy is linear across the full range of GDP per capita. For the most recent data – the 2000s – the LOESS smoother is nearly linear. To further explore the nuances of this relationship, I now examine this pattern in each continent.

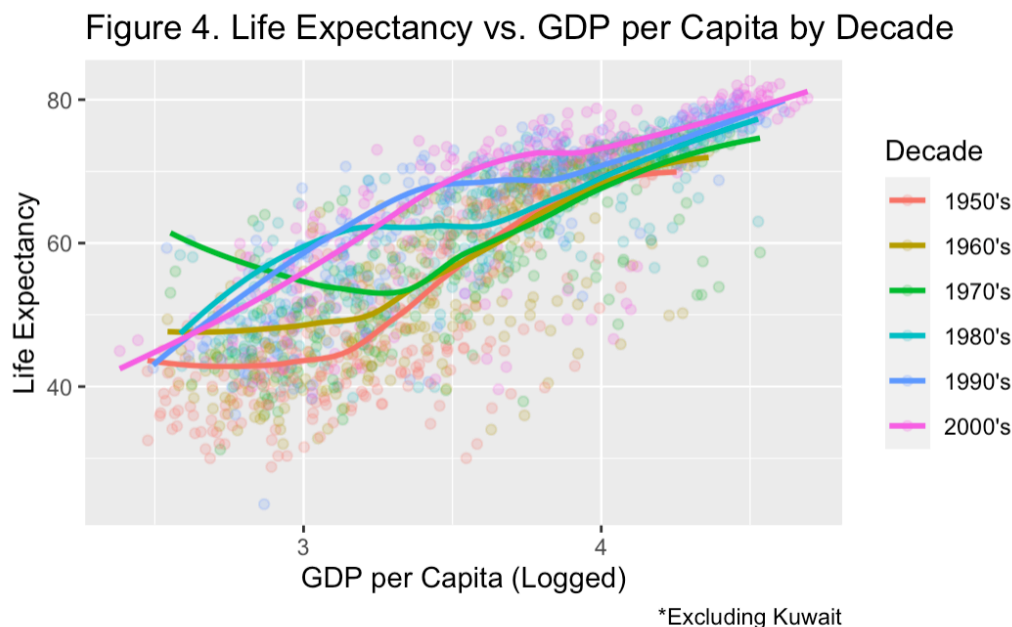Figure 4. Life Expectancy vs. GDP per Capita by Decade

*Excluding Kuwait

Figure 5 plots life expectancy vs. GDP per capita colored by decade (with LOESS smoothers) and faceted out by continent. Figure 5 excludes Kuwait because it is an outlier and Oceania due to sparse data. Thus, Figure 5 contains information on the relationship between life expectancy and each of GDP per capita (logged), year, and continent controlling for the other two. Now, it

can be determined whether the earlier patterns still hold once controlling for all the variables of interest. The plots paint a different picture for Africa than for the other three continents (the Americas, Asia, and Europe). First, the latter continents. In each continent, the relationship between GDP per capita (logged) and life expectancy is constantly positive and linear across each decade. This is evidenced by the LOESS smoothers all having roughly the same pattern. There are exceptions, like Asia in the 1950's. However, this may be caused by one-off events in China as discussed earlier. Additionally, there appears to be a time effect. This is evidenced by the smoothers being roughly parallel and shifting upwards as the decades progress. The effect of time is not as pronounced in Europe, which suggests an interaction between time and continent. Overall, continent doesn't seem to matter as much as it used to (for these three continents) as the 2000's smoother has a similar slope and intercept in each plot. This can't be said for all continents, however.

Africa is an exception to these general patterns. The association between GDP per capita (logged) and life expectancy is weak to moderately positive in earlier decades. During the more recent decades, the relationship between GDP per capita (logged) and life expectancy is negative at the highest levels of GDP. There appears to be a time effect, but the effect diminishes as the decades progress. Figure 3 showed a leveling off in life expectancy in Africa from 1987 - 2007. Figure 5 suggests that this leveling off might be the result of both time and economic growth no longer having an effect, at least for this case. The unique situation of Africa means that two models should be built: one for Africa and one for the rest of the continents.

Figure 5. Life Expectancy vs. GDP per Capita by Decade, Faceted by Continent

*Excluding Kuwait and Oceania
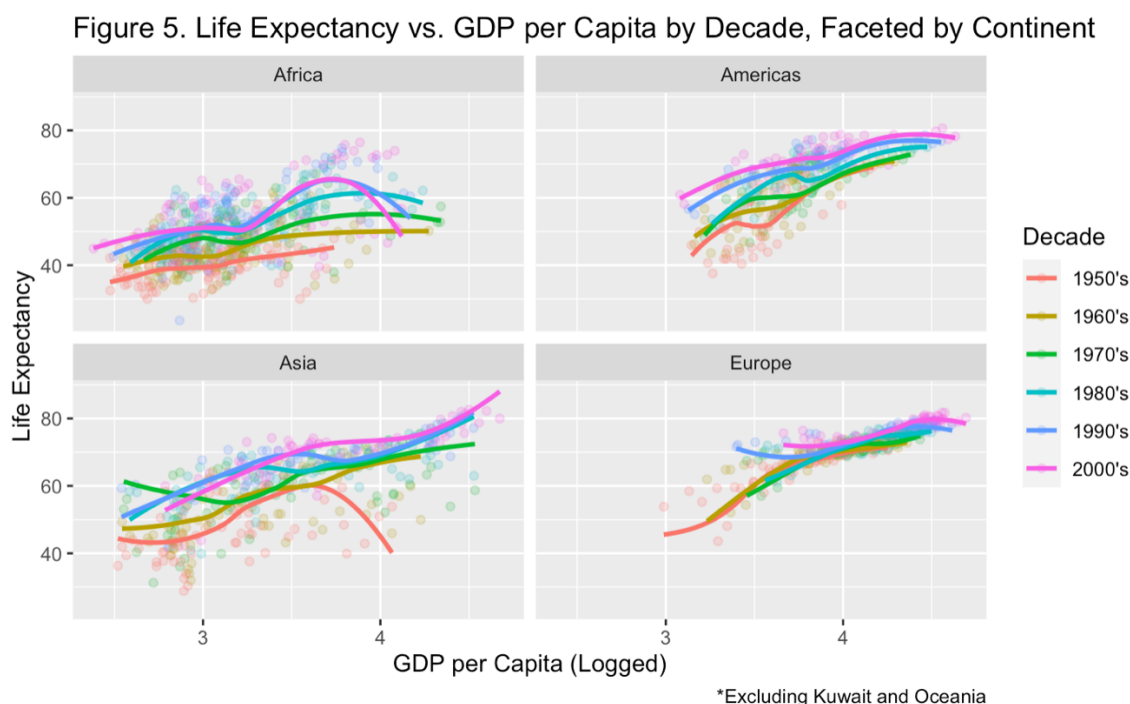
The first model is an ordinary least squares regression predicting life expectancy for Asia, the Americas, Europe, and Oceania (excluding Africa). Based on the exploratory data analysis above, the model contains four regressors (excluding the intercept): a main effect for logged GDP per capita, a main effect for continent, a main effect for year, and an interaction between year and continent. The diagnostics indicate that this model fits well (see Appendix). The plot of

the residuals vs. the fitted values and the plot of the squared residuals vs. the fitted values are both null, indicating that the assumptions of linearity and constant variance are met[1]. Additionally, a plot of the standardized residuals vs. the leverage does not reveal any outliers with high leverage. While some points do have a high standardized residual, they also have a small leverage value and thus do not affect the regression line. The second model is a LOESS model predicting life expectancy in Africa. Again, a LOESS model is a highly flexible model that fits a multitude of local regressions that trace the data. A LOESS model is used due to the unclear, non-parametric relationships in the Africa data. After decreasing the span to 0.35 (which makes the local regressions even more local), the plot of the residuals vs. the fitted values is null and the points in a Q-Normal plot of the residuals fall on the identity line (see Appendix). The LOESS model fits the Africa data well. Both models are weighted by population so that a small country like Jamaica does not have the same impact as a more populous country like India.

Interpretation and Conclusion

In the context of a new debate regarding the benefits of economic growth, is economic growth associated with increased life expectancy? To answer this question, this analysis examined the *gapminder* dataset. Bivariate, trivariate, and hypervariate plots were constructed to explore the relationships between life expectancy, GDP per capita, time, and continent. Two models were constructed: one predicting life expectancy for Asia, the Americas, Europe, and Oceania, and one predicting life expectancy for Africa. The models reveal that *economic growth is indeed associated with higher life expectancy*. In the first model (excluding Africa), each inflation-adjusted dollar increase in GDP per capita is associated with a 0.12% increase in life expectancy, controlling for year and continent. In the second model (only including Africa), inference is not possible. However, as GDP increases, the model generally predicts higher life expectancy (see Appendix Figure A9), although this relationship is more complicated than the linear relationship in the other model. The models reveal that time and continent matter as well. In the model excluding Africa, the regressors (logged GDP per capita, year, continent, and an interaction between year and continent) explain 79.55% of the variation in life expectancy adjusted for the number of regressors. This speaks to the relevance of all four variables. While this research cannot proclaim causality, it still uncovers a strong association between economic growth and life expectancy. Degrowth activists should best be aware of this association before giving up on economic growth entirely.

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[1] A Q-Normal plot of the residuals deviates drastically from the identity line towards the tails of the theoretical quantiles. Thus, the assumption of Normality is not met. However, this dataset contains observations for the same countries over time, so the residuals are correlated and not independent and identically distributed. An ordinary least squares model is fit due to the constraints of the assignment. More advanced methods in time series analysis would be more accurate.

Appendix

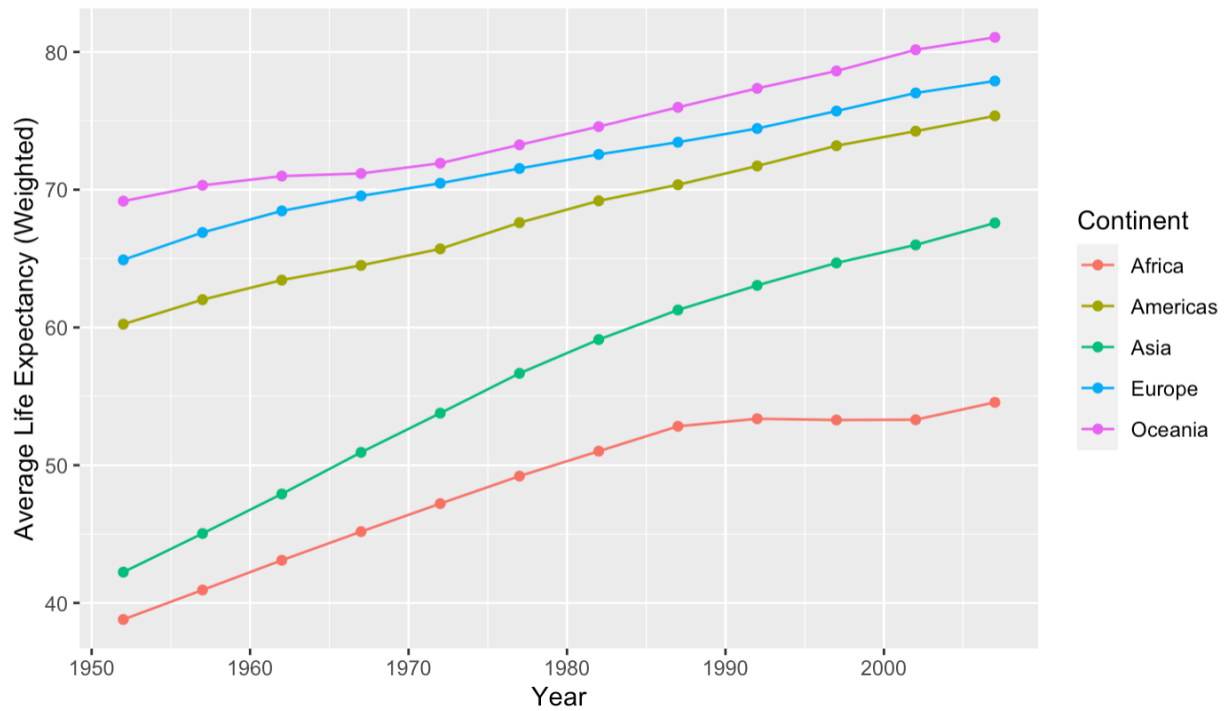Figure A1. Average Life Expectancy vs. Year (Omitting China)

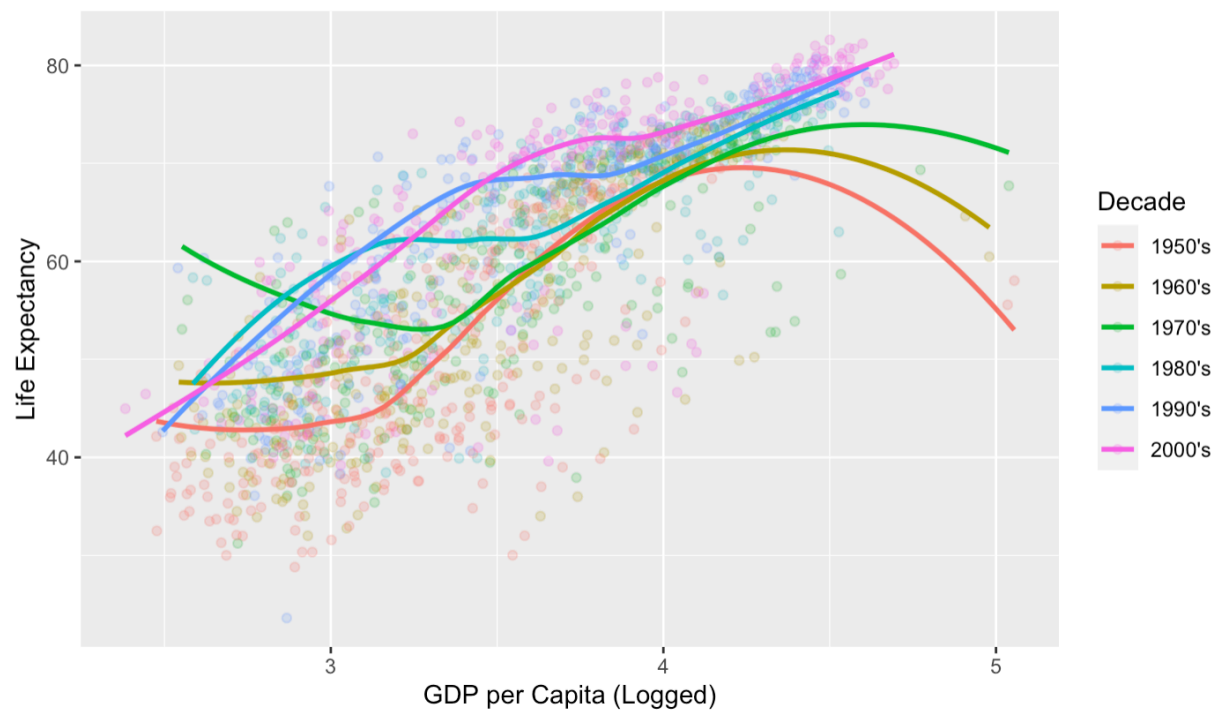Figure A2. Life Expectancy vs. GDP per Capita by Decade (Including Kuwait)

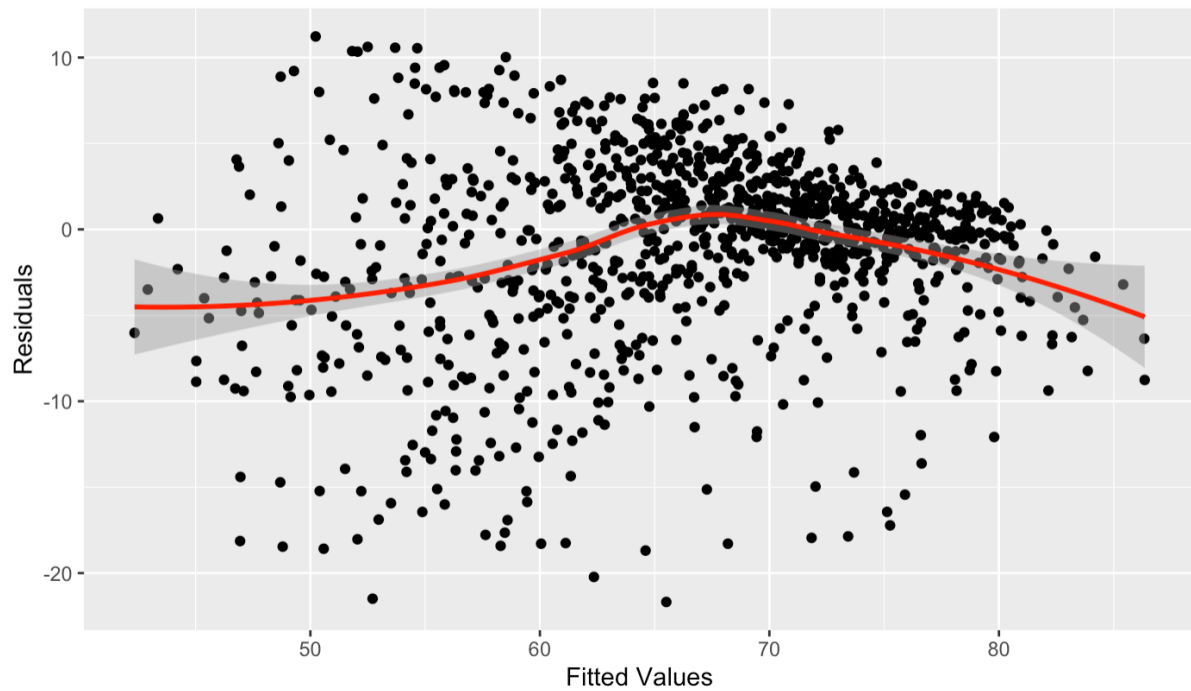Figure A3. Linear Model (No Africa) Linearity Check

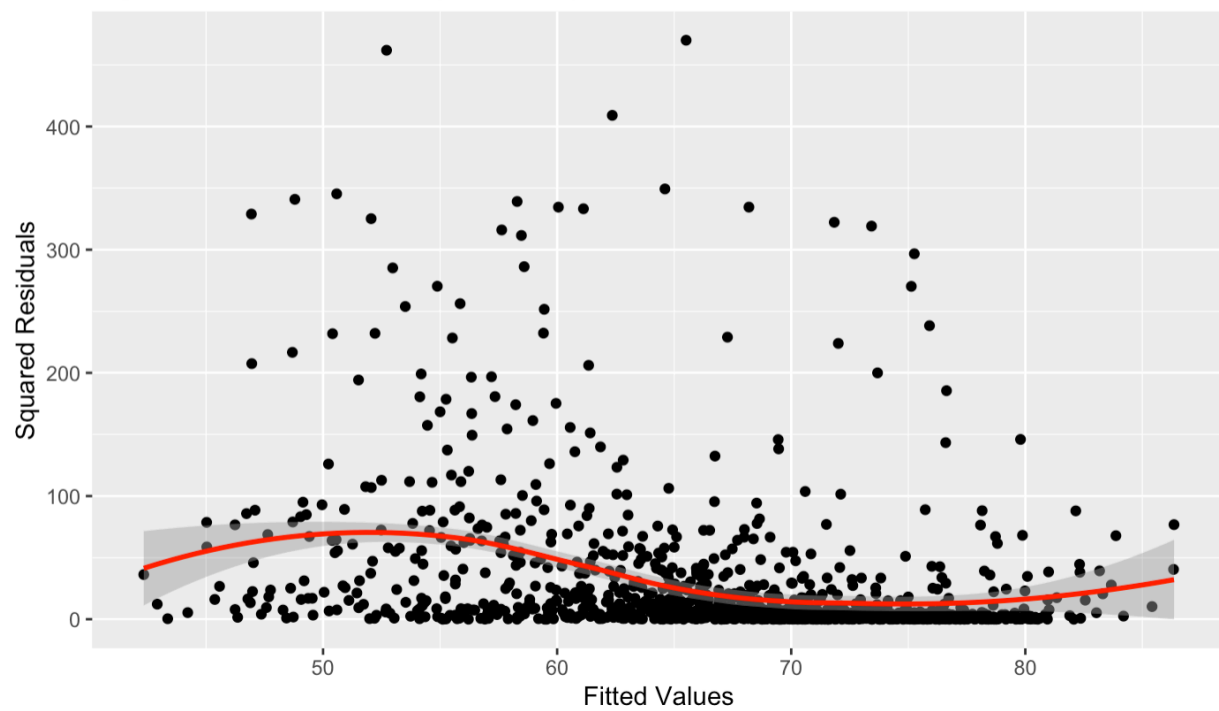Figure A4. Linear Model (No Africa) Constant Variance Check

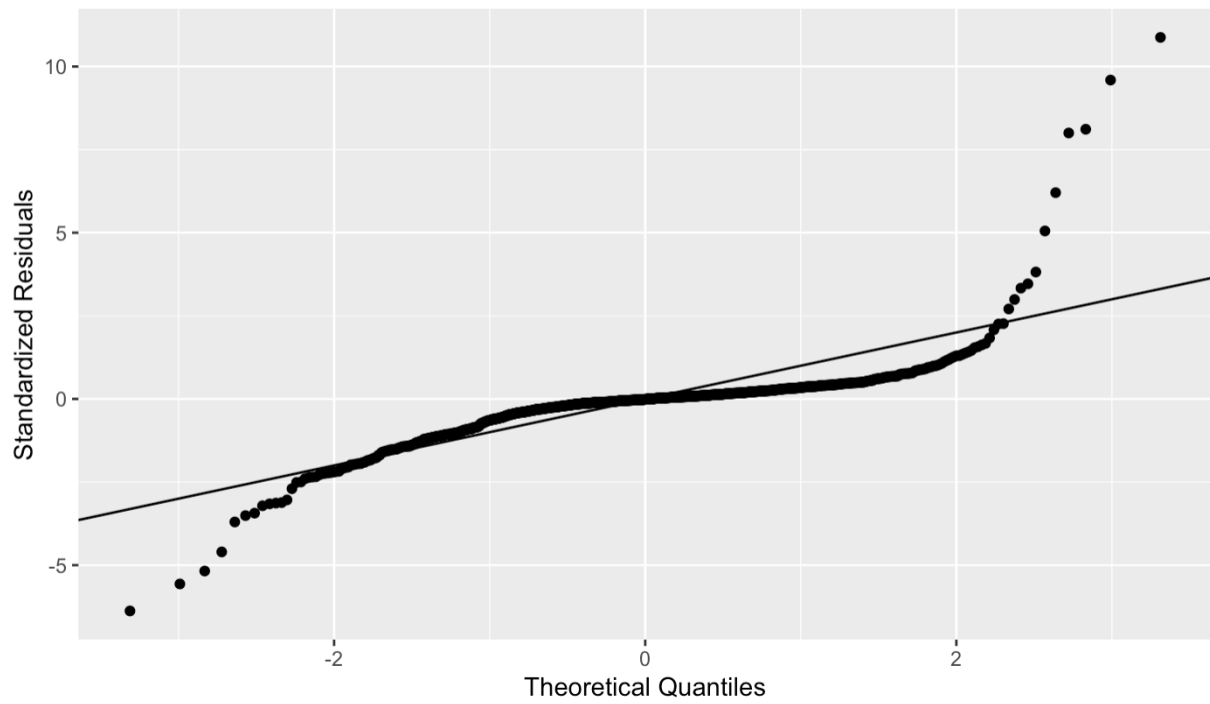## Figure A5. Linear Model (No Africa) Normality Check
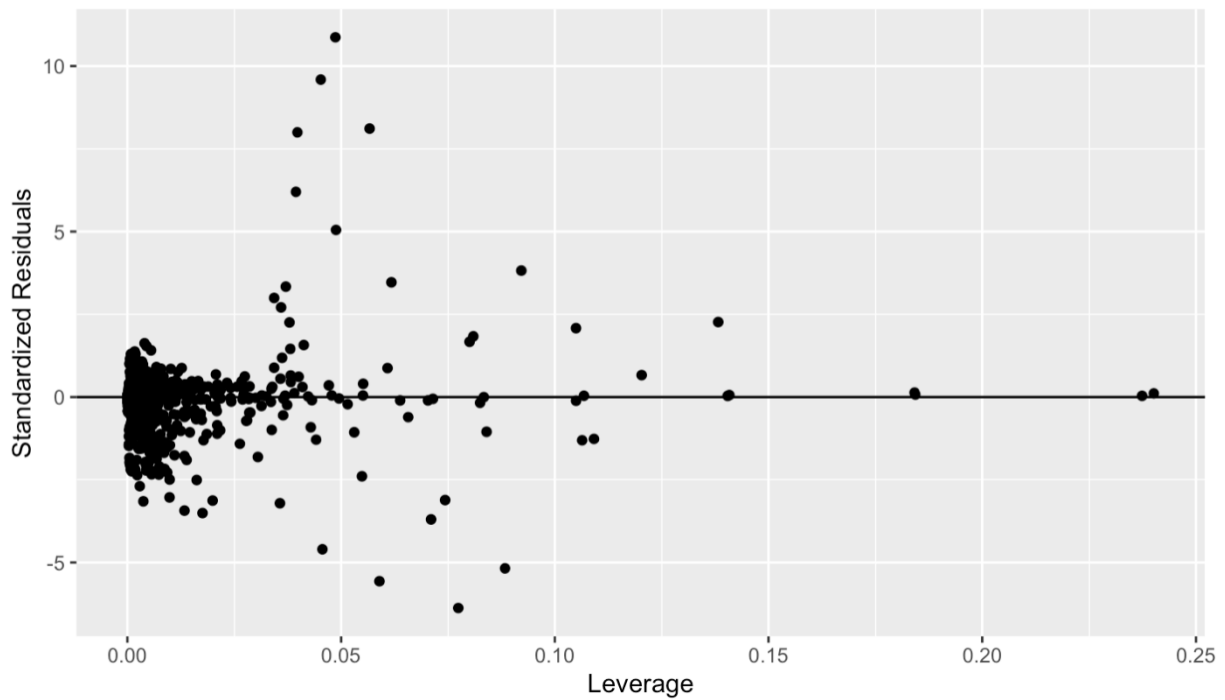

Figure A6. Linear Model (No Africa) Outlier Check

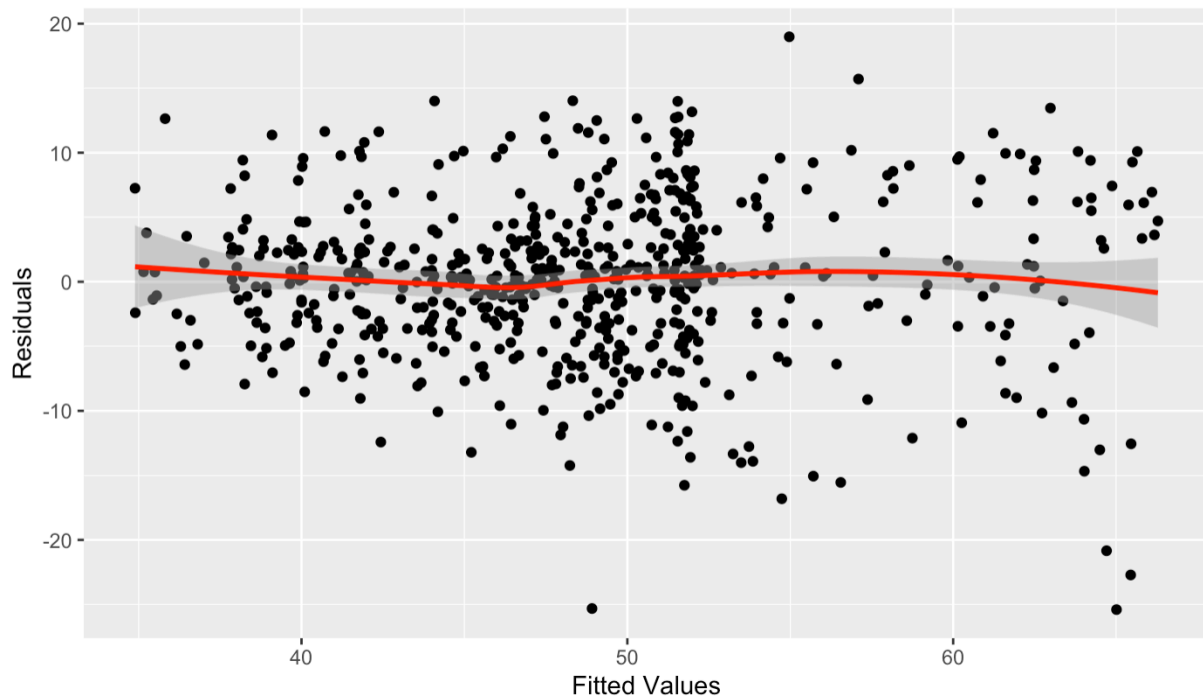Figure A7. LOESS Model (Africa Only) Residual Plot

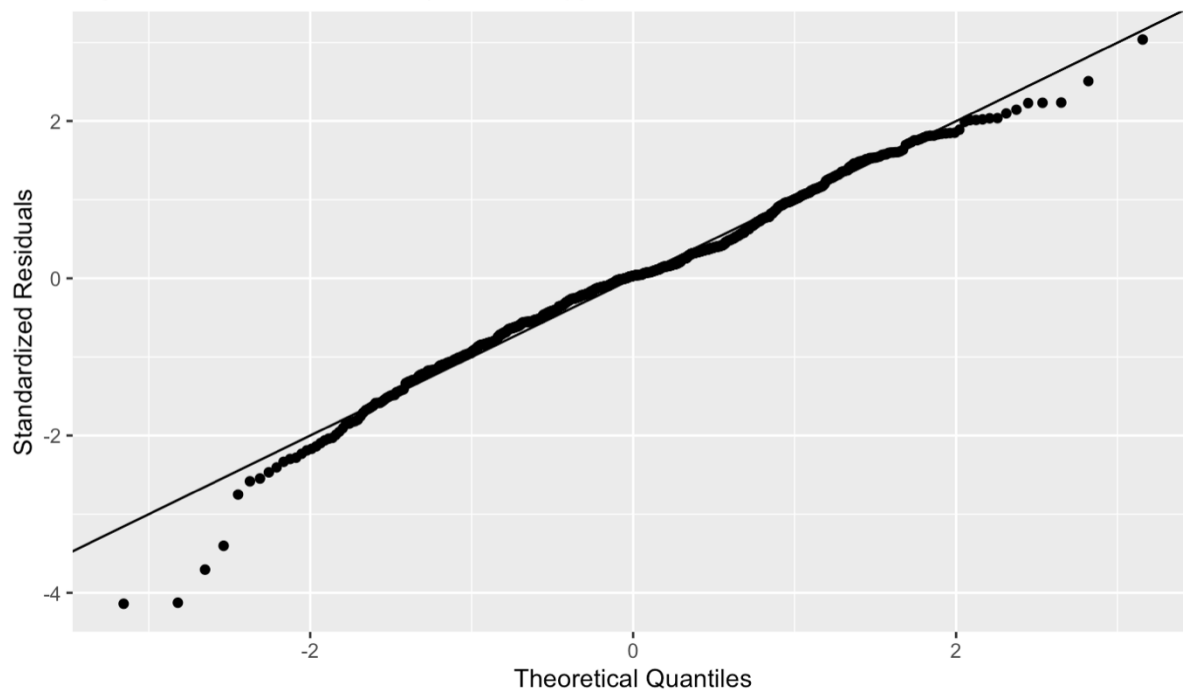Figure A8. LOESS Model (Africa Only) Residual Q-Normal Plot

Figure A9. LOESS Model (Africa Only) Fitted Values vs. GDP