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Analyzing the Impact of GDP Growth on Health Outcomes

1 Introduction

The relationship between a country's economic growth with the health of its population has been a topic of great importance for a long period of time. This case study aims to examine how economic growth, measured by **Gross Domestic Product (GDP)** per capita, affects the health metrics, such as infant mortality rate and life expectancy of a country.

Economic Growth means an increase in the investment of resources being made available to the people. On paper, a higher GDP should lead to better health outcomes by improving healthcare access and technologies. However, the actual relationship is not so easily defined by these factors alone.

The objective of this research makes use of data analysis and statistical models such as *Linear Regression* and *Ordinary Least Squares* to find the relationship between GDP and health factors across various countries. This will include both cross-sectional analysis (comparing different countries at a specific point in time) and longitudinal analysis (examining changes within UK over time). Moreover, the study will explore causality, investigating whether economic growth drives improvements in health outcomes or vice versa, which remains a critical question in economic and public health research.

2 Literature Survey and Review

Numerous studies and research has been conducted over time to identify the trends between GDP and various health metrics such as tuberculosis rate, spread of epidemics and many more. The widely accepted view suggests a positive correlation between GDP per capita and improved health outcomes. This relationship is often shown in health economics theories such as the Grossman model, which considers health as both a *consumption good* — enhancing the quality of life, and an *investment good* — boosting economic output through better productivity.

Grossman's Model [9] suggests that individuals invest in health capital, which represents the health they possess at any given time. Investments in health can include expenditures on medical care, preventive measures (like exercise or healthy diet), and other health-enhancing activities. According to his model, higher income

enables greater investment in health, thus improving health outcomes. Empirical studies testing Grossman's model have often found that increases in GDP per capita correlate with better health indicators, such as lower infant mortality rates and higher life expectancy [3].

Furthermore, research extending Grossman's model has also considered how public healthcare expenditures, which often increase with GDP, contribute to better population health. A systematic review by Anyanwu and Erhijakpor [1] demonstrated that health spending significantly lowers death rates in both developed and developing African countries. Studies like those by Deaton [5] have used cross-country regression models to illustrate that richer countries tend to have lower mortality rates, suggesting a direct benefit of economic growth on health outcomes. Despite extensive research, significant gaps remain in the studies trying to show how economic growth impacts health and the variability of this impact across different socio-economic contexts.

This study aims to address these gaps by incorporating a detailed analysis of how economic growth correlates with health outcomes across different countries and over time, considering both the aggregate and distributional impacts of economic growth. Additionally, it seeks to explore the causality between economic growth and health improvements using advanced statistical techniques, providing a clearer picture of the interdependencies between these aspects of development.

3 Methodology

This research made use of several statistical models to try and define the relationship between GDP per capita and health metrics. *Ordinary Least Squares (OLS) Regression* [6] is utilized to estimate the linear relationships between GDP per capita and infant mortality rates, and for the Grossman Model implementation. A general euqation has been mentioned below, where β_0 is the intercept term, $\beta_1, \beta_2, \ldots, \beta_n$ are the cooefficients for variables $x_1, x_2, \ldots, x_n$, and ϵ represents the error term.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon$$

The Grossman Model was designed using variables that represent both the consumption and the investment aspect of health. For this case, **Life expectancy** was chosen as the dependent variable while GDP per capita, health expenditure per capita, literacy rate, and Pollution levels were chosen as the independent variables.

4 Analysis and Results

4.1 Data Description

The data for this study was collected from the World Bank's World Development Indicators database, where each variables was pre-processed appropriately to form a dataframe. The data consisted of 5871 *rows* and 17 *columns* of 266 different countries spanning over a time frame of 1960-2021. The variables include :

- **Gross Domestic Product (GDP):** Provides annual GDP figures in both U.S. Dollars and the Local Currency Unit (LCU).
- **Infant Mortality Rates:** Defined as the number of infant deaths per 1,000 live births in a given year.
- **Life Expectancy:** Male and Female Life Expectancy at birth.
- **Literacy Rate:** The percentage of adults (aged 15 and above) that can read and write.
- **Health Expenditure per Capita:** The amount that each country spends on health, for both individual and collective services in U.S. Dollars.
- **Pollution Levels:** Total Greenhouse gases emissions (kilotonnes of Carbon Dioxide emissions).
- Cross-sectional data containing the GDP and Infant Mortality rates of the year 2015.
- Longitudinal data of UK for GDP and Infant Mortality Rates for the years 1960 - 2021.

4.2 Exploratory Data Analysis

The data preparation process involved several steps to ensure the integrity and usability of the dataset for statistical analysis. The data had to be formatted to a standard format with normalised and log based values for easier interpretation. The skewed distribution of the data as is seen in Fig 1 makes it difficult to gain actionable insights, thereby, using a log based transformative approach made them more suitable for linear modeling techniques.

Missing data posed a significant challenge, as a lot of the countries did not have data for the years 1960-1990. Moreover, several variables had rows Missing at

Random, since the World Bank included data for certain countries much later. Where possible, missing values were imputed using mean based interpolation method by making use of the country's trend lines or regional averages, ensuring a comprehensive dataset. Countries having large number of NULL values were completely excluded from the dataset to prevent uncertainities in the regression analysis.

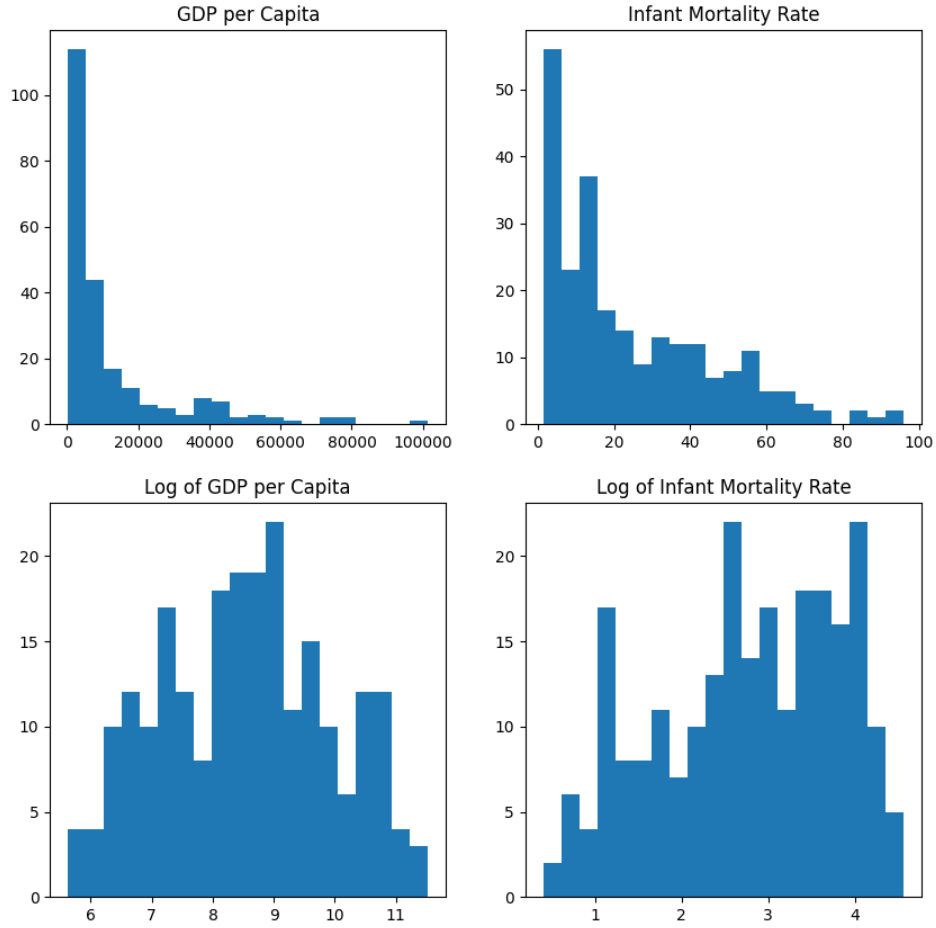

Figure 1: Histograms showing the skewed Distribution of the GDP per Capita and the Infant Mortality Rate (top) and the log transformed distribution of the same (bottom).

4.3 Relationship between GDP and Infant Mortality

The analysis of the Cross Sectional Data between the GDP and Infant Mortality Rate of several countries in the year 2015 reveals a clear downward trend. From Fig 1 (a),it is evident that as GDP per capita increases, there is a noticable decrease in the infant mortality rates, suggesting that countries having sustained economic growth has resulted in reducing the infant mortality rate by 46% from the year

2000 to 2020. Conducting a similar study on the Longitudinal Analysis for UK over the years 1960 to 2015 reveals a similar trend as seen in Fig 2 (b).

The observed negative correlation between GDP per capita and infant mortality rates supports the hypothesis that economic prosperity plays a crucial role in enhancing infant health outcomes. Economically stable countries are likely to have better healthcare infrastructure, more accessible medical services, and higher overall health education, which contribute to lower infant mortality rates. However, during periods of economic instability, such as recessions or financial crises, this relationship can become less predictable. For example, the economic downturns witnessed globally in 2008 disrupted healthcare funding and services, temporarily reversing the gains, although mildly, in infant mortality reductions in UK. But, the advanced investments in healthcare have also helped stabilize the health issues like Infant Mortality Rate, preventing a sudden increase during times of recessions.

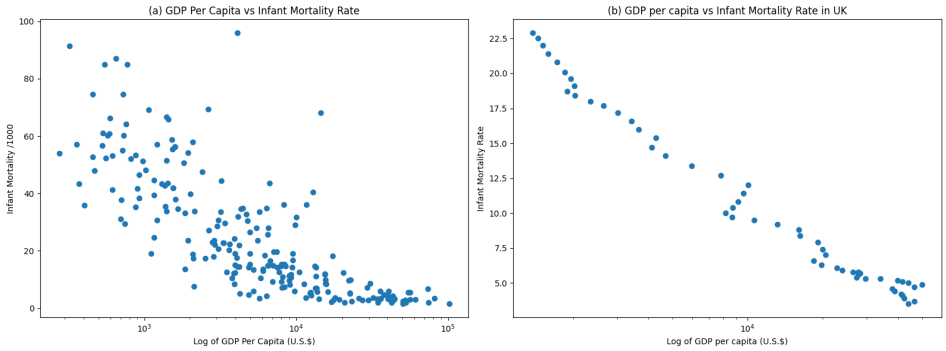

Figure 2: Scatterplots showing the negative correlation between the GDP per capita and Infant Mortality Rate for Cross-sectional Data in 2015 (a) and Longitudinal Data for UK (b)

Further research was done to check if this trend remains unchanged for both developed and developing countries. United States, United Kingdom and Canada were chosen as developed countries while India and China were selected as the developing nations for this study. The relationship between GDP and infant mortality varies significantly due to different political, social, and healthcare contexts. The United States, United Kingdom and Canada show a steady increase in GDP along with a consistent decline in infant mortality rates. The United States, despite its higher GDP growth, has infant mortality rates that decrease in parallel with Canada's. This similarity suggests that both countries have effectively utilized their economic growth in enhancing healthcare systems and policies aimed at reducing infant mortality. Fig 3 (a) highlights more rapid economic growth in both India and China starting from the late 20th century, which correlates with steep declines in infant mortality rates. This suggests a direct relationship between economic growth and healthcare outcomes in rapidly developing economies.

The steep decrease in the Infant Moratlity rates in China when compared to India could be due to the significant economic reforms in the late 1970s and early 1980s implemented in China.These reforms, which opened China to foreign investment and boosted economic productivity, likely also led to increased healthcare funding and infrastructure development. Similarly, the steady decline in infant mortality rates in developed countries like Canada and the UK during periods of low economic growth could be due to advancements in medical technology and improved healthcare practices.

Moreover, The impact of the 2008 global financial crisis can be inferred from slight disruptions in GDP growth rates, particularly in the United States and the United Kingdom. Although not dramatically affecting the downward trend in infant mortality, economic instability during this period might have temporarily slowed the pace of healthcare improvements.

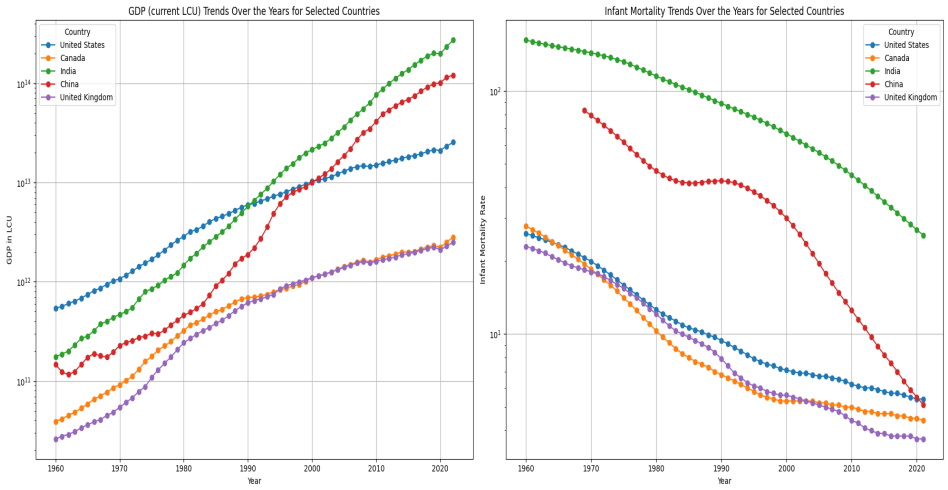

Figure 3: Trends illustrating the economic growth (GDP in LCU) and infant mortality rates over the years for selected countries

The above results of analysis could imply that the relationship between GDP per capita and infant mortality does vary across different countries and is influenced by specific historical events. However, it is to be noted that almost all countries do follow the similar trend of the decrease in infant mortality rates and increase in GDP over the years. In developing countries like India and China, rapid economic growth has a more immediate impact on reducing infant mortality rates, reflecting significant improvements in access to healthcare services. In contrast, in developed countries with already low infant mortality rates, the relationship is more stable and less sensitive to economic fluctuations, stating the importance of implementing consistent healthcare policies and advanced medical practices.

4.4 Relationship between GDP and other Health Metrics in UK

In this section, the effect GDP of a country has on health metrics, primarily *Life Expectancy* in the United Kingdom will be analysed. The graphs in Fig 4 depicts the increasing trend of GDP in the UK especially noticeable from the early 1980s onward, as seen in the previous section. Alongside the decline in Infant Mortality Rates in the UK, the country witnessed a substantial increase in the life expectancy of the populace that aligns with the increase in GDP. This increase in life expectancy could be directly correlated with enhancements in medical technology, better healthcare policies, and overall improvement in the standard of living, all of which are often by-products of economic growth.

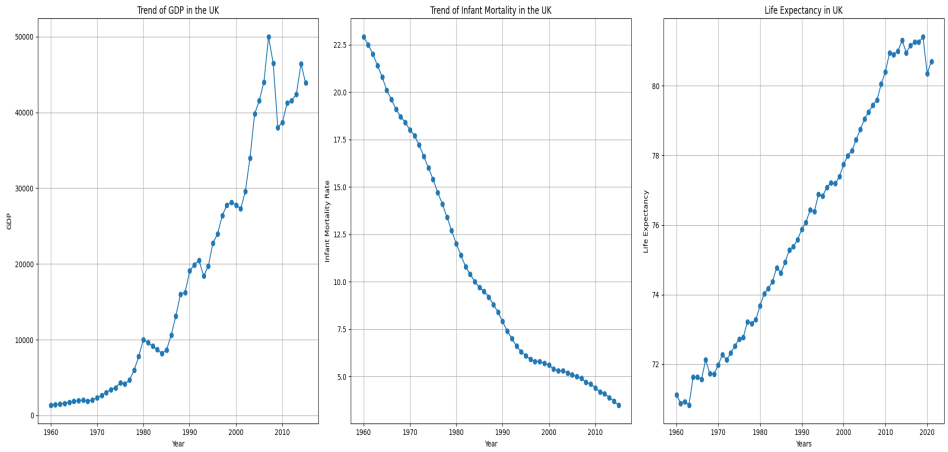

Figure 4: Longitudinal trends in the UK (1960-2020). The first panel shows the increase in GDP over time, the second panel depicts the decreasing trend in infant mortality rate, and the third panel shows the rise in life expectancy.

A regression analysis was conducted by making use of the OLS Regression to explore the impact GDP has on health metrics such as Infant Mortality Rate, Life Expectancy and the Health Expenditure per Capita. The regression results indicate a strong negative correlation between GDP and Infant Mortality Rate. This result aligns with our previous findings, suggesting that as economic situations of a country improves, it contributes to lower infant mortality. For instance, in our regression analysis, a 10% increase in GDP per capita was associated with a statistically significant decrease in infant mortality rates, on average, by 2 deaths per 1,000 live births, holding other factors constant.

Additionally, the relationship between GDP per capita and health expenditure is shown to be positive, indicating that as GDP per capita increases, health expenditures also rise, although the rise is not very significant. This trend suggests that economically developed countries have the capacity to spend more on health

per capita, potentially leading to better health outcomes through more accessible and higher quality healthcare services. For life expectancy, the regression analysis indicates a positive relationship with GDP per capita as well, supporting the hypothesis that higher GDP is associated with longer life.

Metrics	Infant Mortality Rate	Health Expenditure	Life Expectancy
R-squared	0.012	0.004	0.004
Prob (F-statistic)	1.11×10^{-16}	7.24×10^{-07}	2.57×10^{-06}
AIC	54130	22860	41680
Constants (coef.)	9.2105	6.4542	73.9696
Log GDP (coef.)	-0.7316	0.0302	0.1429

Table 1: Regression Results for Health Metrics vs. GDP

These findings support the conventional understanding that economic growth generally correlates positively with health improvements and that economic development can be a powerful tool for enhancing public health. However, the moderate size of the coefficients, especially in health expenditure, suggests that simply increasing GDP may not automatically translate into proportionate health gains and several other factors also come into play, which could include the political standings in the country, the environmental factors such as pollution and global warming and economic and financial recession in the markets. For further research, analyzing the effects of specific health policies on the observed relationships could clarify how policy interventions impact economic growth on health outcomes.

5 Assessing Causality using the Grossman Model

The Grossman model [7] is often used to analyze the impact of economy (or GDP) on health outcomes. It suggests that higher income levels can lead to increased investments in health capital, as individuals have more resources to allocate toward healthcare and health-enhancing activities. Additionally, higher income levels may also be associated with better access to healthcare services and healthier living conditions. The statistical model employed here uses an Ordinary Least Squares (OLS) regression to estimate the relationship between life expectancy and several independent variables: GDP, Health Expenditure, Rate, and Pollution. The regression formula can be expressed as:

$$\begin{aligned}\text{Life Expectancy} = \beta_0 + \beta_1(\text{Log\_GDP})\beta_2(\text{Log\_Health\_Expenditure}) + \\ \beta_3(\text{Literacy\_Rate}) + \beta_4(\text{Log\_Pollution}) + \epsilon\end{aligned}$$

β_0 is the intercept of the model, $\beta_1, \beta_2, \beta_3, \beta_4$ are the coefficients for Log_GDP, Log_Health_Expenditure, Literacy Rate, and Log_Pollution, respectively and ϵ is the error term, accounting for the variation in life expectancy not explained by the model.

The results tabuated in Table 2 imply that health investments significantly influence life expectancy, supporting the Grossman's theory that health can be "produced" through targeted investments. The model explains about 53% of the variability in life expectancy, as shown by the R-squared value, indicating a moderate fit to the data. The regression results state that an increase in GDP accounts to a slight decrease in Life Expectancy. Although this does not fully support the initial hypothesis, this further states that external factors other than GDP play a more crucial role in improving the life expectancy. Health Expenditure shows a highly positive correlation, supporting the idea that investing more on health resources is directly impacting the health situation of a country's populace.

Metric	**Value**
Dependent Variable	Life Expectancy
R-squared	0.530
Prob (F-statistic)	0.0001
AIC	37760
Variable	**Coefficient (Std. Error) [95% Conf. Interval]**
Intercept	48.3114 (0.745) [46.852, 49.771]
GDP	-0.0857 (0.025) [-0.137, -0.032]
Health Expenditure	3.1990 (0.049) [3.103, 3.295]
Literacy Rate	0.0577 (0.006) [0.047, 0.068]
Log Pollution	0.2731 (0.033) [0.208, 0.338]

Table 2: OLS Regression Results for Life Expectancy

Other variables such as Literacy Rate and Pollution Levels did not have as big of an impact as expected, however, the model predicted a positive correlation of life expectancy with pollution levels. This counter-intuitive result could be due to the limited data collected with regards pollution levels, or it could be due to the higher pollution levels being a by-product of industrial activity, which is associated with economic development. These statistical anomalies could also be driven by outliers, thereby necessitating the need for further analysis with regards to this variable.

6 Discussion

The findings from our analysis reveal a subtle relationship between GDP and health outcomes, particularly focusing on indicators such as infant mortality rates, health expenditure, and life expectancy. The results generally support the hypothesis that higher GDP per capita is associated with better health outcomes, a finding

consistent with Grossman's model which views health as both a consumption and investment good. However, our study also highlights complexities not fully captured by traditional models, such as the slight negative impacts of rising GDP on certain health metrics, which suggests the influence of additional socioeconomic or environmental factors [4].

Our study also aligns with the previous literature studies suggesting a positive correlation between economic prosperity and improved health outcomes. For example, studies referenced in the literature review, such as those by Anyanwu and Erhijakpor [1], Deaton [5], and Rahman [8] identify a clear trend where higher GDP levels correlate with reduced mortality rates and enhanced overall health. However, our findings differ slightly by stating that the relationship is not always linear, as shown by the variations in coefficients and the occasional negative impacts of increased GDP on health metrics. This discrepancy could be due to different methodological approaches, political situations of the country, the range of health metrics analyzed, or the periods and datasets examined.

The analysis also highlighted periods where the expected relationship between GDP and health outcomes varied significantly. During the global financial crisis of 2008-2009, countries like the United States and the United Kingdom saw a decline in health outcome improvements [2]. In contrast, countries like China and India, which have undergone rapid industrialization and economic transformation since the late 20th century, showed accelerated improvements in health outcomes. The introduction of significant health policies such as the *Affordable Care Act* in the United States in 2010 can also be correlated with periods of noticeable improvement in health outcomes.

7 Conclusion

This case study provides a comprehensive analysis of the relationship between Gross Domestic Product (GDP) and key health outcomes, focusing on infant mortality rates, health expenditure, and life expectancy across various countries. Our findings support the existing ideas in economic literature that higher GDP per capita typically correlates with better health outcomes, as shown by various metrics. However, our research also brings to light the discrepancies of this relationship, suggesting that increases in GDP do not always uniformly translate into health improvements, but rather depends on various other factors as well.

The positive impact of GDP on health outcomes, such as lower infant mortality and higher life expectancy, is evident but not consistent across all metrics, and depends on various other health factors such as health expenditure, pollution levels,

disease prevalence and many more. The impact of GDP on health also varies across countries, depending on their economic, social, and political situations. Moreover, the expected positive relationship between GDP and health outcomes was disrupted during economic crisis such as recessions or wars, which had its impact on the health of the citizens as well.

The causailty relationship between GDP and health could be seen as a bidirectional relationship. Countries with sustained economic growth have better resources to invest in healthcare, leading to improved public health metrics, while healthier populations in turn enhance productivity, which in turn impacts economic growth. Based on factors such as education levels, infrastructure and environment decides whether Health causes Wealth or Wealth causes Health over a certain period of time, and this causality will keep fluctuating as seen in Section 5.

To improve both health factor and the economy, the country could implement targeted policies such as investing in medical technology and research, develop environmental regulations that reduce pollution, promote public health education to raise awareness about health issues and encourage healthier lifestyles and improve readiness for health crises such as pandemics or natural disasters. By implementing these policies, governments can create an event cycle where improvements in economic conditions directly contribute to better health outcomes, which in turn can drive further economic growth.

7.1 Further Research

While this study has provided good insights into the relationship between GDP growth and health outcomes, several discrepancies were observed as well. It will be crucial to take care of these for future research purposes to gain even better actionable insights. Conducting longitudinal studies for several countries and not just the UK could help in understanding the long-term effects of economic growth on health, including generational changes. Comparing countries with similar GDP's to check how each country uses it to leverage health outcomes would provide good insights as well. Further research could also be conducted on a more granular level, focusing on the population of smaller regions in a country, which could tell how different regions affect the health of an individual.

References

[1] J. C. Anyanwu and A. E. Erhijakpor. Health expenditures and health outcomes in africa. *African Development Review*, 21(2):400–433, 2009.

[2] J. Appleby, J.-K. Helderman, and S. Gregory. The global financial crisis, health and health care. *Health Economics, Policy and Law*, 10(1):1–6, 2015.

[3] G. S. Becker, T. J. Philipson, and R. R. Soares. The quantity and quality of life and the evolution of world inequality. *American Economic Review*, 95(1):277–291, March 2005.

[4] D. Cutler, A. Deaton, and A. Lleras-Muney. The determinants of mortality. *Journal of Economic Perspectives*, 20(3):97–120, September 2006.

[5] A. Deaton. Health, inequality, and economic development. *Journal of Economic Literature*, 41(1):113–158, March 2003.

[6] S. Lago-Peñas, D. Cantarero-Prieto, and C. Blázquez-Fernández. On the relationship between gdp and health care expenditure: A new look. *Economic Modelling*, 32:124–129, 2013.

[7] J.-M. Muurinen. Demand for health: A generalised grossman model. *Journal of Health Economics*, 1(1):5–28, 1982.

[8] M. M. Rahman, R. Khanam, and M. Rahman. Health care expenditure and health outcome nexus: new evidence from the saarc-asean region. *Globalization and health*, 14:1–11, 2018.

[9] A. Wagstaff. The demand for health: An empirical reformulation of the grossman model. *Health Economics*, 2(2):189–198, 1993.