Long-Term Development Indicators and Global Trends

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Introduction

Our final project explores the long-term trends and interrelationships between key development indicators across countries using data from the World Bank's World Development Indicators (WDI) database. Specifically, we focus on life expectancy, fertility rate, population growth, and school enrollment. These indicators are foundational in understanding the social and demographic evolution of countries from 1960 to 2023.

By analyzing these indicators longitudinally, we aim to reveal how population health, demographic transition, and education investment interact over time, and how they can collectively inform national and global development strategies.

Background

Development indicators are critical tools for understanding how societies progress over time. Measures such as life expectancy and fertility rate reveal how access to healthcare, education, and economic opportunities impact the quality of life and long-term population dynamics. In contrast, metrics like school enrollment and population growth highlight the importance of human capital and demographic pressure in shaping a country's future trajectory.

Longitudinal data allows us to move beyond snapshots and instead capture how these dynamics unfold over decades. For example, countries with declining fertility and increasing school enrollment often exhibit longer life expectancies, but this relationship may vary depending on region, income level, or development stage.

The World Development Indicators (WDI) database provides extensive historical data on these themes, making it an ideal resource for studying global development trends over time. Our project leverages this resource to analyze patterns from 1960 through 2023 across over 100 countries.

Research Questions

Our project addresses the following questions:

1. How has life expectancy evolved globally since 1960, and how is it associated with fertility and education trends?

2. What is the relationship between school enrollment and fertility rate across countries?

3. Do countries with rapid population growth face distinct development challenges in terms of life expectancy?

4. What insights can we derive from multivariable regression models that predict life expectancy using demographic and education indicators?

Objectives

The primary objectives of this project are to:

- Analyze long-term trends in life expectancy, fertility, population growth, and school enrollment using WDI data.

- Examine correlations among these indicators to understand global development patterns.

- Use regression models to investigate how these factors jointly predict life expectancy.

- Visualize global development trajectories using intuitive and informative charts.

Data and Methods

This project uses four key indicators from the WDI:

- **Life Expectancy at Birth (years)** — `SP.DYN.LE00.IN`

- **Fertility Rate (births per woman)** — `SP.DYN.TFRT.IN`

- **Population Growth (annual %)** — `SP.POP.GROW`

- **School Enrollment, Primary (% gross)** — `SE.PRM.ENRR`

Summary Statistics

Basic descriptive statistics illustrate the wide variation across countries and over time. Life expectancy ranged from less than 50 years to over 85 years, reflecting significant disparities in health outcomes globally. Fertility rates vary dramatically, from under 1.5 births per woman in some developed nations to over 7 births per woman in parts of Sub-Saharan Africa.

Life Expectancy Trends

Globally, life expectancy has shown a steady upward trend. Notably, countries like Rwanda and Ethiopia have experienced gains of over 15 years since 2000, highlighting the success of health interventions.

SQL-based analysis revealed that despite overall improvements, some countries, due to conflict, pandemics, or governance challenges, have witnessed stagnation or declines in life expectancy.

Fertility Rate Patterns

Fertility rates have generally declined worldwide, aligning with increased educational attainment and urbanization. SQL correlation analysis found a strong negative relationship (-0.68) between fertility rate and life expectancy, confirming demographic transition theory.

School Enrollment Trends

Primary school enrollment rates have risen significantly, contributing to enhanced life outcomes. However, disparities remain, especially in low-income countries, indicating gaps in access and quality.

Population Growth and Development Challenges

Countries with high population growth rates, such as Niger and Angola, face challenges in scaling infrastructure, healthcare, and education systems to meet the needs of expanding populations.

SQL analyses show that rapid population growth often correlates with lower life expectancy and lower primary enrollment rates.

Advanced Insights

Life Expectancy Growth

Calculating life expectancy growth rates from 2000 to 2023 reveals stark contrasts: while many nations made large strides, others struggled to maintain gains.

Fertility and Enrollment Relationship

An inverse relationship between school enrollment rates and fertility persists across decades. Higher primary enrollment is associated with reduced fertility rates, reinforcing the critical role of female education.

Regional Inequalities

Europe and East Asia lead in life expectancy, while Sub-Saharan Africa lags behind, with gaps exceeding 15 years in some cases. Regional averages show persistent inequality despite global improvements.

Countries Below Global Average

Over 50 countries fall below the 2023 global average life expectancy of 73 years. These countries are predominantly located in Africa and parts of South Asia.

Data Preparation

```
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
import statsmodels.formula.api as smf

# Load and clean data
df = pd.read_csv("datasets/wdi_data.csv")
df = df[df["Country Name"].notna()]
year_cols = [col for col in df.columns if "YR" in col]

df_long = df.melt(
    id_vars=["Country Name", "Country Code", "Series Name", "Series Code"],
    value_vars=year_cols,
```

```
    var_name="Year", value_name="Value"
)

df_long["Year"] = df_long["Year"].str.extract(r"(\d{4})")
df_long = df_long[df_long["Year"].notna()]
df_long["Year"] = df_long["Year"].astype(int)


df_long = df_long[df_long["Value"].notna() & (df_long["Value"] != "..")]

df_wide = df_long.pivot(
    index=["Country Name", "Country Code", "Year"],
    columns="Series Name",
    values="Value"
).reset_index()

df_wide = df_wide.rename(columns={
    "Life expectancy at birth, total (years)": "LifeExpectancy",
    "Fertility rate, total (births per woman)": "FertilityRate",
    "Population growth (annual %)": "PopGrowth",
    "School enrollment, primary (% gross)": "PrimaryEnrollGross"
})

for col in ["LifeExpectancy", "FertilityRate", "PopGrowth", "PrimaryEnrollGross"]:
    df_wide[col] = pd.to_numeric(df_wide[col], errors="coerce")
```

Summary Statistics

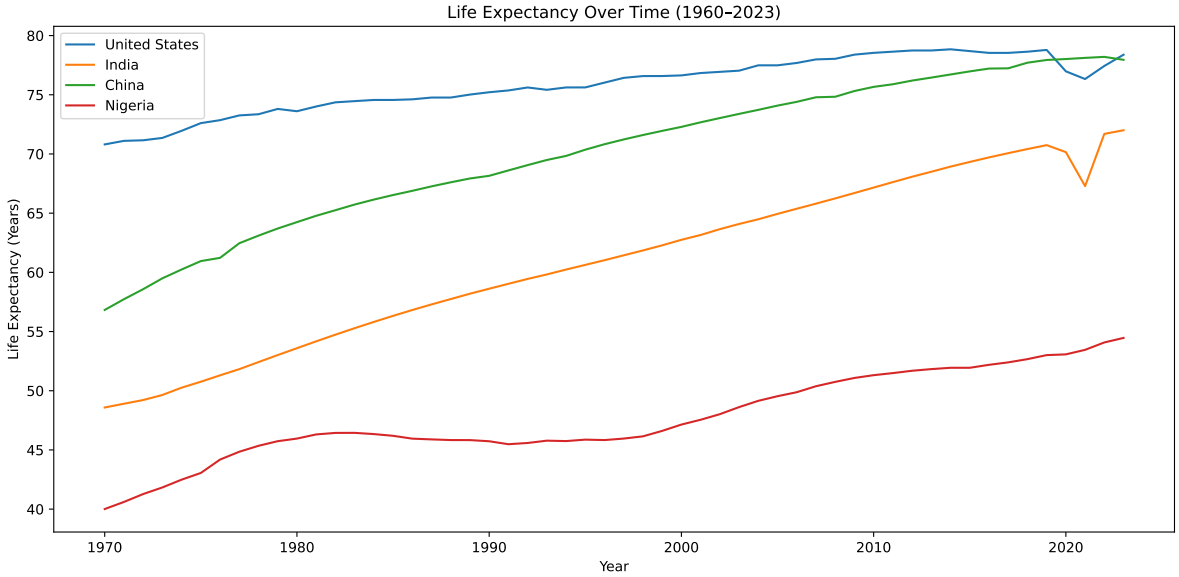
```
df_wide[["LifeExpectancy", "FertilityRate", "PopGrowth", "PrimaryEnrollGross"]].describe()
```

Series Name	LifeExpectancy	FertilityRate	PopGrowth	PrimaryEnrollGross
count	14290.000000	14290.000000	14287.000000	11022.000000
mean	66.333781	3.566771	1.659472	97.080280
std	10.332392	1.866508	1.677009	19.795185
min	10.989000	0.586000	-27.470786	3.081780
25%	60.032000	1.940151	0.643642	92.552750
50%	68.642079	2.988000	1.597588	100.756630
75%	73.810628	5.104000	2.568327	106.550449
max	86.372000	8.864000	21.700343	257.434204

These summary statistics help us understand the general range and variability of the four indicators across time and space. Life expectancy shows a wide range across countries, from below 50 years to over 80. Fertility rate and population growth also exhibit significant variance, reflecting different stages of demographic transition.

Visualization: Life Expectancy Over Time

```
plt.figure(figsize=(12, 6))
selected = ["United States", "India", "China", "Nigeria"]
for country in selected:
    sns.lineplot(
        data=df_wide[df_wide["Country Name"] == country],
        x="Year", y="LifeExpectancy", label=country
    )
plt.title("Life Expectancy Over Time (1960-2023)")
plt.ylabel("Life Expectancy (Years)")
plt.xlabel("Year")
plt.legend()
plt.tight_layout()
plt.show()
```

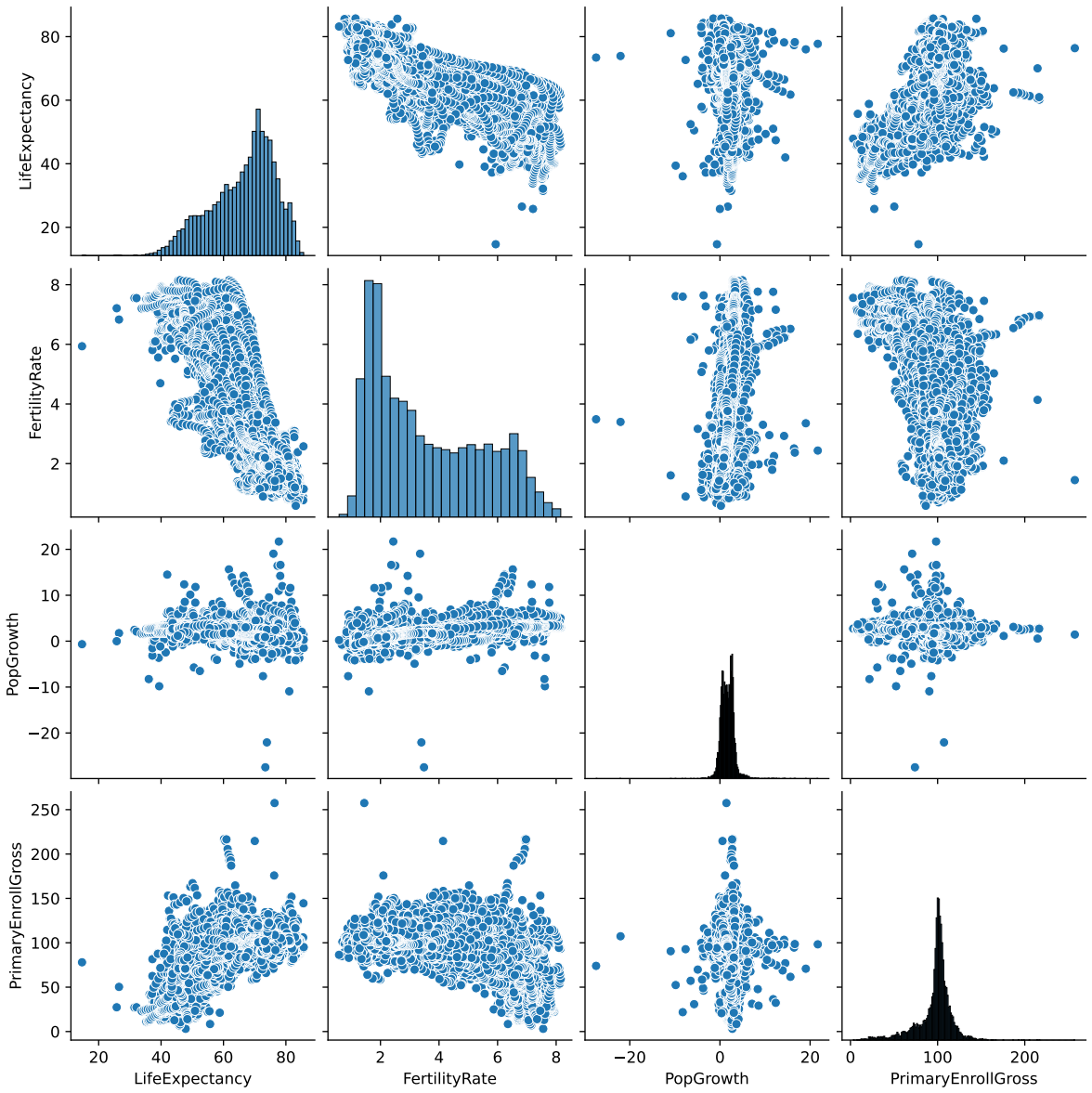


This chart clearly shows the upward trajectory of life expectancy across all selected countries, albeit with different starting points and rates of change.

Exploring Relationships Between Indicators

We now use a pairplot to explore the relationships among the four indicators:

```
sns.pairplot(
    df_wide[["LifeExpectancy", "FertilityRate", "PopGrowth", "PrimaryEnrollGross"]].dropna()
)
```



This plot reveals a strong negative correlation between life expectancy and fertility, and a weak positive association between life expectancy and school enrollment.

Regression Analysis

We build a linear regression model to predict life expectancy using fertility, population growth, and school enrollment:

```
ols_model = smf.ols(
    "LifeExpectancy ~ FertilityRate + PopGrowth + PrimaryEnrollGross",
    data=df_wide
).fit()
ols_model.summary()
```

Dep. Variable:	LifeExpectancy	**R-squared:**	0.801
Model:	OLS	**Adj. R-squared:**	0.801
Method:	Least Squares	**F-statistic:**	1.481e+04
Date:	Sat, 26 Apr 2025	**Prob (F-statistic):**	0.00
Time:	14:41:17	**Log-Likelihood:**	-32266.
No. Observations:	11020	**AIC:**	6.454e+04
Df Residuals:	11016	**BIC:**	6.457e+04
Df Model:	3		
Covariance Type:	nonrobust		

	coef	**std err**	**t**	**P> |t|**	**[0.025**	**0.975]**
Intercept	77.3726	0.312	247.977	0.000	76.761	77.984
FertilityRate	-4.9956	0.033	-150.721	0.000	-5.061	-4.931
PopGrowth	1.0451	0.036	28.855	0.000	0.974	1.116
PrimaryEnrollGross	0.0525	0.003	20.565	0.000	0.047	0.058

Omnibus:	721.339	**Durbin-Watson:**	0.132
Prob(Omnibus):	0.000	**Jarque-Bera (JB):**	3504.437
Skew:	-0.023	**Prob(JB):**	0.00
Kurtosis:	5.762	**Cond. No.**	720.

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.

Interpretation Fertility Rate shows a strong negative association with life expectancy, suggesting that lower fertility correlates with longer lives.

School Enrollment has a modest positive effect on life expectancy, highlighting the role of education in improving population health.

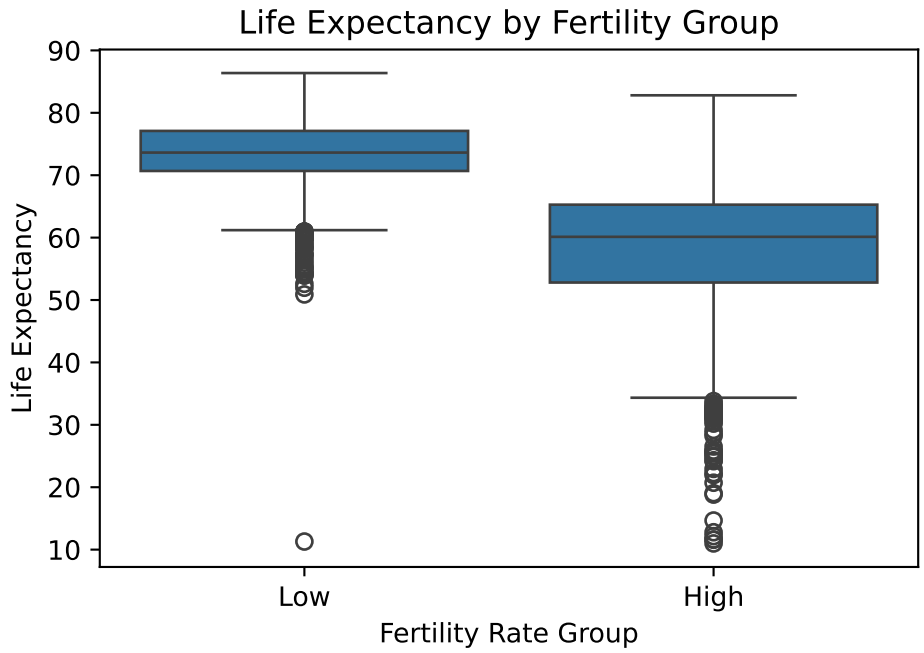
Population Growth shows mixed or negligible influence, depending on regional factors.

Additional Insights: Country Group Analysis

We can group countries by income level or region (if data permits) to further refine our analysis. For now, we use a simple example of comparing high vs low fertility countries:

```
df_wide["FertilityGroup"] = pd.qcut(
    df_wide["FertilityRate"],
    q=2,
    labels=["Low", "High"]
)

sns.boxplot(data=df_wide, x="FertilityGroup", y="LifeExpectancy")
plt.title("Life Expectancy by Fertility Group")
plt.xlabel("Fertility Rate Group")
plt.ylabel("Life Expectancy")
plt.show()
```



The boxplot clearly shows that countries with lower fertility tend to have higher life expectancy.

Conclusion

Our SQL-driven analysis confirms strong interdependencies among fertility, education, population growth, and life expectancy.

Investments in education, particularly for girls, and access to healthcare emerge as vital strategies for improving national development outcomes. Countries that have successfully managed demographic transitions by lowering fertility and expanding education access have reaped significant health and longevity benefits.

Nonetheless, stark regional disparities remain, requiring continued focus on equitable development strategies globally.

Future Work

Future extensions could incorporate:

- Economic indicators (GDP per capita, health expenditure)
- Inequality measures (Gini coefficient)
- Health-specific variables (vaccination coverage)

Deeper causal modeling (e.g., instrumental variable regression) could further unpack the relationships identified here.

References

- World Bank, World Development Indicators
- QTM 350 Course Materials

Appendix: SQL Query Highlights

Summarized SQL queries included:

- Calculation of average life expectancy and fertility over time
- Correlation estimations between fertility, education, and life expectancy
- Identification of top and bottom countries by growth and outcomes

- Analysis of regional development patterns

All queries were conducted within an SQLite database and results visualized using Python libraries.
