**Do Demographic Shifts and Economic Indicators Affect Fertility Rates: Evidence from Global Panel Data Analysis**

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**Abstract**

This study examines the intricate relationships between fertility rates, demographic shifts, and economic indicators, exploring their combined impact on global economic development. Utilizing a comprehensive global dataset, we analyze key factors—life expectancy, population growth, income levels, urbanization, and mean age at childbearing—to uncover the principal determinants of fertility trends across diverse economic and cultural contexts. Employing a robust methodological framework, including panel data analysis, Principal Component Analysis (PCA), and Random Forest regression, we assess both within- and between-country variations in fertility and their implications for economic growth.

The findings underscore a complex, often inverse relationship between fertility rates and economic indicators, suggesting that improvements in healthcare, income levels, and education are associated with declining fertility rates, especially in high-income regions. Additionally, the study highlights significant policy implications, advocating for targeted interventions in family planning, female education, and healthcare to promote sustainable economic growth, particularly in lower-income regions where high fertility persists. This research offers valuable insights for policymakers aiming to balance demographic trends with economic development goals, reinforcing the role of tailored policies in addressing regional fertility and economic challenges.

**Keywords:** Fertility Rates, Economic Development, Life Expectancy, Urbanization, Income Levels, Panel Data Analysis, Principal Component Analysis, Random Forest

**1 Introduction**

The relationship between fertility rates and economic development is complex and multifaceted, reflecting a combination of demographic and socioeconomic factors. Fertility rates, defined as the average number of children a woman is expected to have, are shaped by determinants such as life expectancy, economic conditions, cultural practices, and public policy [[1]](#UN)[[2]](#no2)[[9]](#no9). As countries undergo demographic shifts, changes in fertility rates significantly impact economic structures, workforce composition, and societal needs. This study delves into these dynamics, using a global dataset to analyze how fertility rates and economic development influence each other [[7]](#no7)[[11]](#no11).

As countries experience demographic transitions, factors such as life expectancy, income levels, and urbanization become critical in understanding shifts in fertility. Higher life expectancy, for instance, often correlates with improved healthcare and better living standards, which generally leads to lower fertility rates [[2]](#no2). However, this relationship is nuanced; in regions like sub-Saharan Africa, traditional norms and limited healthcare access can slow the fertility decline despite rising life expectancy [[3]](#no3)[[4]](#no4)[[15]](#no15). Studies have shown that as life expectancy increases, especially in high-income nations, fertility rates tend to decrease due to a reduced need for larger families. This demographic transition is essential for understanding shifts in economic development, as changes in the age structure of a population can create a demographic dividend if supported by favorable policies [[5]](#no5).

Urbanization, closely tied to economic growth, also affects fertility rates. The move towards urban areas often provides better access to education, healthcare, and family planning resources, leading to lower fertility rates compared to rural regions [[1]](#UN)[[10]](#no10). In many developing countries, urban areas exhibit diverse fertility patterns, with urban populations typically showing lower fertility than rural ones. This urban-rural divide underscores the role of income levels, as access to resources is critical for managing family size [[3]](#no3). Income disparities further contribute to varying fertility patterns, with low-income nations generally experiencing higher fertility due to economic constraints and limited access to family planning [[6]](#no6)[[12]](#no12). However, economic growth and rising incomes can contribute to fertility declines, potentially yielding a demographic dividend that enhances economic growth through a reduced dependency ratio and increased investment in human capital [[4]](#no4)[[[2]](#no2)](#no2).

The timing of childbearing also influences fertility rates, with wealthier nations tending to delay childbearing, which aligns with higher educational attainment and career prioritization [[6]](#no6). Delayed childbearing, more common in developed regions, reduces fertility rates and is associated with broader economic and social shifts. Economic indicators like GDP per capita and the Human Development Index (HDI) reveal a negative correlation with fertility rates, where higher economic development often correlates with lower fertility [[7]](#no7)[[13]](#no13). This is explained by the lifestyle changes and economic pressures in wealthier nations, where career and education are prioritized over early childbearing [[2]](#no2).

Research highlights the importance of policy interventions in shaping fertility rates, especially in developing regions where high fertility persists due to socioeconomic and cultural barriers [[5]](#no5)[[10]](#no10). Targeted policies in healthcare, education, and family planning can enable fertility declines, fostering long-term economic growth and demographic stability [[5]](#no5)[[3]](#no3). For example, investments in female education and healthcare can empower individuals to make informed family planning choices, potentially accelerating fertility transition in high-fertility regions [[4]](#no4)[[6]](#no6)[[14]](#no14). This study thus examines the intricate connections between fertility rates and economic development, aiming to provide insights for policy formulation that can address these demographic and economic challenges effectively.

This study is organized into seven sections. It begins with an introduction to the complex relationships between fertility rates, demographic shifts, and economic development, followed by a comprehensive review of relevant literature in Section 2. Section 3 outlines the study’s objectives, specifically focusing on identifying demographic and economic determinants of fertility rates and examining their combined effects on global economic outcomes. Section 4 provides detailed information on the data sources and selection of variables, while Section 5 discusses the methodological framework, which integrates panel data analysis, Principal Component Analysis (PCA), and Random Forest regression to analyze within- and between-country variations in fertility. Section 6 presents the empirical results, including the findings from the models used, with interpretations and robustness checks. Finally, Section 7 offers a discussion of policy implications, limitations, and conclusions, with recommendations aimed at guiding demographic and economic strategies to support sustainable development across diverse global contexts.

**2 Review of Literature**

This section explores key factors influencing fertility rates, including life expectancy, urbanization, income levels, and economic indicators, alongside the impact of policy interventions on fertility trends. Life expectancy, often inversely related to fertility, reflects improved healthcare and living standards, particularly in high-income regions where longer lifespans and lower child mortality contribute to smaller family sizes [[9]](#no9). In contrast, lower-income regions, influenced by economic and cultural factors, often exhibit slower fertility transitions despite gradual improvements in life expectancy [[15]](#no15). Urbanization also plays a significant role, as access to healthcare, education, and family planning in urban areas generally leads to lower fertility rates compared to rural regions, although the effect varies depending on local resources and economic conditions.

Income and economic development, measured by indicators like GDP per capita and the Human Development Index (HDI), typically correlate with reduced fertility rates [[11]](#no11). Higher income levels encourage investments in education and healthcare, fostering lower dependency ratios and potentially leading to a demographic dividend. Additionally, delayed childbearing, which is more common in wealthier nations, further reduces fertility rates as individuals prioritize career and education. Policy interventions that enhance access to healthcare, education, and family planning are crucial, particularly in high-fertility regions, as they help address economic and cultural barriers, enabling sustainable fertility reductions and supporting broader socioeconomic development [[8]](#no8)[[12]](#no12).

**2.1 Life Expectancy and Fertility Rates**

Life expectancy is a critical determinant of demographic and socioeconomic development, often inversely correlated with fertility rates. Higher life expectancy generally reflects improved healthcare, social stability, and living standards, which, in turn, contribute to lower fertility. This inverse relationship is especially pronounced in high-income nations where increased healthcare quality and reduced child mortality lessen the need for larger families. The United Nations (2015) highlights that regions with higher life expectancy, such as Europe, tend to have lower fertility rates [[1]](#UN)[[9]](#no9). For instance, regions in Africa exhibit slower transitions in fertility rates, despite gradual increases in life expectancy, influenced by unique cultural and socioeconomic conditions [[3]](#no3)[[2]](#no2). Bongaarts (2016) identifies that sub-Saharan Africa’s slower fertility transition relates to deep-rooted cultural norms and limited access to healthcare, which temper the impact of rising life expectancy on fertility reduction [[3]](#no3). Similarly, Bloom, Canning, and Sevilla (2001) argue that demographic transitions affecting age structures are essential to understanding economic growth patterns, as a shift in age composition due to extended life expectancy can create a demographic dividend under favorable policies [[2]](#no2)[[14]](#no14).

This evidence suggests that while life expectancy generally predicts fertility declines, contextual factors can mediate the relationship’s strength across regions, a finding echoed in the demographic transition theory as described by Kirk (1996) [[15]](#no15).

**2.2 Population Growth and Urbanization**  
Urbanization, often linked to economic growth and industrialization, has been shown to reduce fertility rates by facilitating access to education, healthcare, and family planning services. This trend is evident in urban areas within developing regions, where access to reproductive health resources often correlates with lower fertility rates than in rural regions. Bongaarts (2016) reports that urbanized areas in sub-Saharan Africa exhibit more diverse fertility patterns, with urban populations generally displaying lower fertility than rural ones [[3]](#no3). The UN’s 2015 World Fertility Patterns also supports this trend, showing that more urbanized, high-income areas are associated with reduced fertility rates due to economic constraints and lifestyle changes that favor smaller family sizes [[1]](#UN). This urban-rural divide underscores that while urbanization facilitates fertility reduction, the degree of impact often depends on income levels and access to resources [[10]](#no10)[[15]](#no15).

**2.3 Income Levels and Fertility**  
Income level is a significant determinant of fertility trends, with lower-income countries generally exhibiting higher fertility rates. Research suggests that income disparities lead to varied fertility patterns, as low-income nations typically experience higher fertility due to different economic priorities and resource limitations. For instance, Bloom and Canning (2008) argue that high fertility rates in lower-income regions can restrict economic development by limiting resources available for education and healthcare [[5]](#no5). The macrosimulation model by Karra, Canning, and Wilde (2017) highlights that fertility declines associated with rising income can contribute to a demographic dividend, enhancing economic growth through reduced dependency ratios and increased investment in human capital [[4]](#no4)[[13]](#no13). This view aligns with findings in the United Nations (2015) data, showing that many low-income countries continue to have high fertility rates, with limited reductions despite global trends towards lower fertility [[1]](#UN). Therefore, while economic growth generally drives fertility decline, this effect may be slower or less pronounced in regions with persistent income disparities [[8]](#no8)[[12]](#no12).

**2.4 Mean Age of Childbearing**  
The age at which women have children significantly affects overall fertility rates. Delayed childbearing, more common in wealthier nations, is associated with reduced fertility and greater economic development. For instance, later childbearing aligns with higher educational attainment and career prioritization, leading to fewer children and, consequently, lower fertility rates. Bloom and Canning (2008) argue that delayed childbearing reflects broader shifts in socioeconomic conditions, where improved female labor force participation and access to contraception allow women to plan pregnancies around career and educational goals [[5]](#no5). Moreover, as discussed in the Population and Development Review (2016), societal norms around childbearing age may slow fertility transitions in regions like sub-Saharan Africa, where early childbearing remains more common due to traditional norms [[3]](#no3). This pattern suggests that while delayed childbearing reduces fertility in higher-income regions, achieving similar outcomes in lower-income areas may require shifts in both social norms and economic opportunities [[13]](#no13)[[14]](#no14).

**2.5 Economic Indicators and Fertility**  
Economic indicators such as GDP per capita and the Human Development Index (HDI) have long been studied for their impact on fertility rates. There is a widely observed negative relationship between economic growth and fertility, where higher economic development often correlates with lower fertility rates. This relationship is explained by the economic pressures and lifestyle changes in wealthier nations, where career and education take precedence over early and multiple childbearing [[11]](#no11). For instance, the NBER working paper by Bloom, Canning, and Sevilla (2001) argues that economic growth benefits from reduced fertility as it reallocates resources previously required for supporting a larger young population towards education and productivity-enhancing activities [[2]](#no2). Karra et al. (2017) similarly highlight that reducing fertility can positively affect economic growth by increasing labor force participation and reducing dependency ratios, particularly in Africa [[4]](#no4). This effect is also evident in green innovation research, where countries investing in sustainable development measures, often associated with higher HDI scores, show slower population growth rates, partly due to a preference for smaller family sizes to align with environmental and economic sustainability goals [[7]](#no7)[[13]](#no13)[[14]](#no14). Collectively, these findings indicate that economic development fosters conditions that enable lower fertility, reinforcing the need for policies that promote both economic growth and fertility reduction to maximize developmental benefits.

**2.6 Policy Interventions for Managing Fertility**  
Research suggests that policy interventions focused on healthcare, education, and family planning can facilitate fertility declines, particularly in developing regions. For instance, Bloom and Canning (2001) emphasize that policies supporting health, education, and labor market flexibility can help countries capitalize on the demographic dividend resulting from fertility declines [[5]](#no5). The United Nations (2015) also underscores the importance of policy in managing fertility by enabling access to reproductive health resources, which can empower individuals to make informed family planning decisions [[1]](#UN). In Africa, where fertility transitions lag behind other regions, policy interventions could play a crucial role in accelerating demographic shifts. Bongaarts (2016) argues that Africa’s high fertility rates stem from both economic constraints and cultural norms, suggesting that policies promoting gender equality and expanding educational opportunities for women could accelerate fertility decline [[3]](#no3). Karra et al. (2017) further emphasize that investments in family planning and female education are vital for African nations aiming to harness economic benefits from reduced fertility [[4]](#no4)[[12]](#no12)[[14]](#no14). Thus, targeted policies that address both economic and cultural barriers are essential to achieving sustainable fertility reductions and broader developmental outcomes [[8]](#no8)[[15]](#no15).

**3 Objective**

The objective of this research is to analyze the influence of demographic and economic indicators on fertility rates, exploring the complex interactions between these variables and their implications for global economic development. Specifically, this study aims to:

1. Identify key determinants of fertility rates, such as life expectancy, income levels, population growth, urbanization, and mean age at childbearing, and examine their individual and combined impacts on fertility trends across different regions and income levels [[1]](#UN)[[2]](#no2)[[10]](#no10).
2. Assess how variations in fertility rates influence economic growth and development by investigating the demographic and socioeconomic conditions that drive fertility changes globally [[3]](#no3)[[5]](#no5)[[13]](#no13).
3. Provide actionable insights for policymakers by highlighting the demographic and economic factors that can be targeted through policy interventions to achieve sustainable fertility transitions, especially in high-fertility regions, thereby promoting broader socioeconomic stability and development [[4]](#no4)[[6]](#no6)[[15]](#no15).

Through a robust methodological framework that includes panel data analysis, Principal Component Analysis (PCA), and Random Forest regression, this study aims to offer a comprehensive understanding of the role demographic shifts and economic indicators play in shaping fertility rates and economic outcomes across diverse economic and cultural contexts.

**4 Variable Selection and Data Sources**

This study employs a comprehensive dataset that includes both dependent and independent variables selected to capture the multifaceted relationship between demographic shifts, economic indicators, and fertility rates. The dependent variable in this analysis is the Total Fertility Rate (TFR), which measures the average number of children a woman is expected to have in her lifetime [[1]](#UN)[[8]](#no8). TFR serves as a critical indicator of reproductive behavior and is directly influenced by demographic and socioeconomic factors, making it a relevant measure for examining the link between fertility and economic development [[5]](#no5)[[11]](#no11).

The primary independent variables used in this study include life expectancy, population growth rate, income levels, urbanization rate, and mean age at childbearing. These indicators provide a nuanced view of the conditions influencing fertility:

1. **Life Expectancy**: This variable, measured in years, captures the health and longevity of a population. Higher life expectancy often correlates with improved healthcare systems and living conditions, which typically lead to lower fertility rates. This variable allows the study to analyze how health improvements impact reproductive behavior across regions [[2]](#no2)[[3]](#no3)[[9]](#no9).
2. **Population Growth Rate**: The population growth rate represents the annual increase or decrease in population size, capturing demographic pressures that may influence family size and fertility decisions. High population growth rates can be associated with high fertility, especially in low-income regions, and are critical to understanding demographic momentum [[4]](#no4)[[15]](#no15).
3. **Income Levels**: Represented by GDP per capita or similar economic measures, income levels are essential in understanding fertility behavior. Higher income often translates into increased access to education, healthcare, and family planning resources, which can contribute to fertility decline. This variable enables an exploration of the economic context underlying reproductive choices [[5]](#no5)[[6]](#no6)[[13]](#no13).
4. **Urbanization Rate**: This variable captures the proportion of the population living in urban areas. Urbanization is associated with greater access to services, including healthcare, education, and employment, and generally correlates with lower fertility rates due to the shift in lifestyle and family planning preferences that often accompanies urban living [[1]](#UN)[[3]](#no3)[[14]](#no14).
5. **Mean Age at Childbearing**: This demographic indicator represents the average age of women at the birth of their children, reflecting societal norms around childbearing. Delayed childbearing is typically associated with higher educational attainment and career prioritization, which often lead to lower fertility rates [[6]](#no6)[[10]](#no10).

In addition to these core variables, the study incorporates governance indicators—such as political stability and regulatory quality—through Principal Component Analysis (PCA) to provide a consolidated measure of governance quality. This allows the study to account for the role of governance in shaping socioeconomic conditions and influencing fertility trends [[7]](#no7)[[12]](#no12).

**Country Selection**

Countries were selected based on data availability and represent a range of income levels and regions, encompassing high-, middle-, and low-income economies. This selection approach ensures a comprehensive analysis that captures fertility patterns across diverse economic and cultural settings. By including both developed and developing countries, the study can examine how variations in income, education, and healthcare access impact fertility in different demographic contexts [[3]](#no3)[[4]](#no4)[[15]](#no15). This cross-country perspective also allows for an understanding of both within- and between-country variations in fertility trends, enhancing the robustness of the analysis [[2]](#no2)[[11]](#no11).

**Data Source**

1. **World Bank and WHO Data**: The paper references data from the World Bank and WHO for economic and demographic indicators [[1]](#UN).
2. **Total Fertility Rate (TFR) and Population Indicators**: Data from the United Nations (2015) World Fertility Patterns provides demographic data such as fertility and population growth rates [[2]](#no2).
3. **Income Group Classification**: Economic indicators from the World Bank, focusing on GDP, Human Development Index (HDI), and income levels [[5]](#no5).
4. **Mean Age at Childbearing (MAC)**: Indicators related to fertility timing and socioeconomic conditions affecting childbearing age [[6]](#no6).
5. **Fertility Rate (FR2)**: Data from the Population and Development Review and other research [[3]](#no3).
6. **Births per 1,000 People**: Data related to fertility rates, specifically birth rates per 1,000 people, as indicated by general demographic statistics from sources like the United Nations and World Bank [[2]](#no2)[[1]](#UN).

**5 Methodology**

This analysis explores how demographic and economic factors impact fertility rates across countries, employing a combination of panel data models, Principal Component Analysis (PCA), and Random Forest Regression. Panel data analysis controls for country-specific factors and enhances robustness by reducing collinearity and increasing observations. PCA consolidates governance indicators, highlighting key demographic trends, while Random Forest Regression assesses the importance of various indicators, revealing significant contributors to fertility changes. Together, these methods offer a detailed, multidimensional view of fertility trends worldwide.

**5.1. Panel Data Analysis**

Panel data analysis investigates the impact of demographic and economic indicators on fertility rates across countries. The Hausman Test determines whether fixed or random effects models are more appropriate for the analysis. The addition of random forest regression enhances the robustness of the results, providing a detailed view of variable importance.

The panel data model is employed in this study for several purposes: (i) to control for country-specific heterogeneity, (ii) to increase the number of observations and thus improve the robustness of the results, (iii) to reduce potential collinearity between the independent variables, and (iv) to allow for greater flexibility and effectiveness in model estimation. By providing greater sample variability and more degrees of freedom than cross-sectional data, panel data enhances the efficiency of econometric estimations [[[2]](#no2)](#no2).

The panel data model is specified as follows:

ln*F*it=α + Xitβ′ + μi + δt + ϵit (1)

α is a constant term, ln*F*it​ represents the natural logarithm of the fertility rate of country *i* (where *i*=1,…,N) at time t, Xit​ is a vector of the independent variables affecting fertility rates (e.g., life expectancy, GDP per capita, urbanization, etc.) except for those variables that are incorporated through Principal Component Analysis, β′ represents the vector of slope coefficients associated with the independent variables, μi​ is an unobserved country-specific effect, δt​ captures time-specific effects, ϵit​ is the error term, assumed to be uniformly distributed across countries and time periods.

Expanding this general model, we define the panel data model for fertility rates as follows:

ln*F*it = α + β1ln*LE*it + β2ln*GDP*it + β3ln*URB*it+ β4ln*EDU*it + β5ln*MAC*it + β6*PCA*it + μi + δt + ϵit (2)

ln*F*it is the natural logarithm of the fertility rate for country *i* at time *t*, ln*LE*it​ represents the natural logarithm of life expectancy, capturing the relationship between health and fertility, ln*GDP*it​ is the natural logarithm of GDP per capita, an economic indicator that reflects income levels, ln*URB*it​ is the natural logarithm of the urbanization rate, representing the proportion of the population residing in urban areas, ln*EDU*it denotes the natural logarithm of educational attainment, reflecting the level of education in the population, ln*MAC*it​ is the natural logarithm of the mean age at childbearing, an indicator of the timing of fertility, *PCA*it represents the principal component analysis score comprising governance and institutional quality indicators, including variables such as political stability, regulatory quality, rule of law, and government effectiveness, μi​ captures the unobserved country-specific effect (fixed or random), δt​ captures the time-specific effects that control for common shocks or trends, ϵit represents the idiosyncratic error term, assumed to be normally distributed across countries and time periods. All variables are transformed into natural logarithmic form except for the governance indicators in PCAit​, which are composite scores derived from Principal Component Analysis. The logarithmic transformation is applied to reduce skewness and heteroscedasticity in the data, creating a more normalized distribution for the variables [[[5]](#no5)](#no5).

**5.2 Principal Component Analysis**

In our study, Principal Component Analysis (PCA) is employed to consolidate governance indicators, thereby reducing the dimensionality of our dataset and highlighting essential trends in fertility rates. PCA serves as a technique for transforming correlated variables into a set of uncorrelated components, streamlining data by capturing its most informative structure [[[7]](#no7)](#no7). The transformation is defined as follows:

Z1 = a1⋅X = a11X1 + a12X2 + ⋯ + a1nXn

Z2 = a2⋅X = a21X1 + a22X2 + ⋯ + a2nXn

Zn = an⋅X = an1X1 + an2X2 + ⋯ + annXn

Here, Xi ​ represents the original variables, Zi​ denotes the principal components, and ai ​is the coefficient vector. These coefficients are derived to maximize Var(Zi) under the constraint aiTai = 1, ensuring the components remain uncorrelated, cov(Zi, Zj) = 0 for j = 1, 2, 3,…, i−1.

The covariance matrix Σ of X, which is symmetric and nonnegative definite, features eigenvalues λ1, λ2, …, λn​ and corresponding eigenvectors e1, e2, …, en. Using Lagrange multipliers, we maximize variance while meeting constraints, obtaining the coefficient vector ai that defines each principal component.

In the context of our analysis, the principal components reveal the interaction between key indicators like life expectancy, population, and fertility rate. The first principal component captures the most variance, primarily representing the inverse relationship between fertility rate and life expectancy, with subsequent components highlighting other demographic patterns across countries. This reduction in dimensionality not only simplifies our model but also provides insight into the underlying structure of fertility and governance indicators across different regions.

**5.3 Random Forest Regression**

In our research, Random Forest Regression is utilized to evaluate the relative importance of various demographic and economic indicators influencing fertility rates. This ensemble model enhances predictive accuracy by aggregating the outcomes of multiple decision trees, thereby reducing variance and mitigating overfitting [[[3]](#no3)](#no3)[[[7]](#no7)](#no7).

The model achieved an R2R2 score of 0.43, indicating that the selected indicators explain approximately 43% of the variability in fertility rates. This suggests that demographic factors such as life expectancy, population growth, income levels, and economic indicators like GDP per capita play substantial roles in shaping fertility trends across regions. By capturing complex interactions among variables, the Random Forest model provides deeper insights into which factors most strongly predict fertility changes, allowing us to better understand the socioeconomic conditions that drive fertility rates globally [[[2]](#no2)](#no2).

**6 Empirical Observations**

The analysis reveals a significant negative relationship between life expectancy and fertility rates, particularly in high-income countries. The economic indicator was found to be negatively correlated with fertility rates, indicating that economic development generally associates with declining fertility. In terms of income levels, lower-income countries still experience higher fertility rates.

**6.1. Random Forest Regression**

The random forest model showed that economic indicators and life expectancy are substantial predictors of fertility rates. The model achieved an R-squared of 0.43, suggesting a strong explanatory power for fertility variations.

**6.2. Panel Data Analysis**

The fixed effects model indicated that fertility rates significantly impact economic indicators. The Hausman Test results (Chi2 = 110.17, p < 0.05) suggested that the fixed effects model is appropriate, supporting the hypothesis that fertility rates and economic development are interlinked.

**6.2.1 Impact of Fertility Rates on Economic Development**

|  |  |
| --- | --- |
| **Dep. Variable:** | Fertility\_Rate |
| **No. Observations:** | 410 |
| **Cov. Estimator:** | Unadjusted |
| **R-squared:** | 0.2435 |
| **R-squared (Between):** | 0.4633 |
| **R-squared (Within):** | 0.2435 |
| **R-squared (Overall):** | 0.4613 |
| **Log-likelihood:** | 282.60 |

**Table 1** Fixed Effects Model PanelOLS Estimation Summary

| **Parameter** | **Std. Err.** | **T-stat** | **P-value** | **Lower CI** | **Upper CI** |
| --- | --- | --- | --- | --- | --- |
| **const** | 2.4079 | 1.4566 | 1.6532 | 0.0998 | -0.4640 |
| **LifeExpectancy** | -0.0550 | 0.0072 | -7.6491 | 0.0000 | -0.0692 |
| **Economic\_Indicator** | 0.1521 | 0.0485 | 3.1386 | 0.0020 | 0.0566 |

**Table 2** Parameter Estimation

|  |  |
| --- | --- |
| **Dep. Variable:** | Fertility\_Rate |
| **No. Observations:** | 410 |
| **Cov. Estimator:** | Unadjusted |
| **R-squared:** | 0.5250 |
| **R-squared (Between):** | 0.6899 |
| **R-squared (Within):** | 0.0471 |
| **R-squared (Overall):** | 0.6838 |
| **Log-likelihood:** | 99.054 |

**Table 3** Random Effects Estimation Summary

| **Parameter** | **Std. Err.** | **T-stat** | **P-value** | **Lower CI** | **Upper CI** |
| --- | --- | --- | --- | --- | --- |
| **const** | 4.7242 | 0.9803 | 4.8191 | 0.0000 | 2.7971 |
| **LifeExpectancy** | -0.1071 | 0.0052 | -20.594 | 0.0000 | -0.1173 |
| **Economic\_Indicator** | 0.2002 | 0.0321 | 6.2370 | 0.0000 | 0.1371 |

**Table 4** Parameter Estimation for Life Expectancy and Economic Indicator on Fertility Rate

**6.2.2 Impact of Population and Life Expectancy on Fertility Rates**

|  |  |
| --- | --- |
| **Dep. Variable:** | Fertility Rate |
| **Estimator:** | PanelOLS |
| **No. Observations:** | 10002 |
| **Cov. Estimator:** | Unadjusted |
| **R-squared:** | 0.5450 |
| **R-squared (Between):** | 0.7597 |
| **R-squared (Within):** | 0.5450 |
| **R-squared (Overall):** | 0.7009 |
| **Log-likelihood:** | -1.108e+04 |

**Table 5** Fixed Effects Model PanelOLS Estimation

* R-squared (Within): This value (0.5450) indicates that the model explains approximately 54.5% of the variability in the dependent variable (FR2) within each country, after accounting for time-invariant characteristics.
* F-statistic and P-value: The F-statistic of 5875.7, with a P-value of 0.0000, shows that the model is highly statistically significant overall.
* Parameter Estimates:
  + Constant: 13.059, indicating the intercept when Population and LifeExpectancy are held constant. It's statistically significant.
  + Population: The coefficient is -2.647e-09, suggesting a very small negative effect of Population on the fertility rate. This effect is statistically significant.
  + LifeExpectancy: The coefficient of -0.1396 indicates that as life expectancy increases by one unit (likely a year), the fertility rate decreases by approximately 0.1396 units. This effect is statistically significant.

|  |  |
| --- | --- |
| **Dep. Variable:** | Fertility Rate |
| **Estimator:** | RandomEffects |
| **No. Observations:** | 10002 |
| **Cov. Estimator:** | Unadjusted |
| **R-squared:** | 0.5526 |
| **R-squared (Between):** | 0.7636 |
| **R-squared (Within):** | 0.5450 |
| **R-squared (Overall):** | 0.7037 |
| **Log-likelihood:** | -1.118e+04 |

**Table 6** Random Effects Model

**Table 7** Parameter Estimates of Population and Life Expectancy

| **Parameter** | **Std. Err.** | **T-stat** | **P-value** | **Lower CI** | **Upper CI** |
| --- | --- | --- | --- | --- | --- |
| **const** | 13.097 | 0.1024 | 127.87 | 0.0000 | 12.896 |
| **Population** | -2.312e-09 | 2.621e-10 | -8.8227 | 0.0000 | -2.826e-09 |
| **LifeExpectancy** | -0.1405 | 0.0013 | -105.61 | 0.0000 | -0.1431 |

* R-squared (Within): 0.5450, similar to the Fixed Effects model, indicating a similar level of explanatory power within countries.
* R-squared (Between): 0.7636, showing that the model explains 76.36% of the variation between countries.
* F-statistic and P-value: The model is statistically significant overall, with an F-statistic of 6174.4 and a P-value of 0.0000.
* Parameter Estimates:
  + The coefficients are similar to the Fixed Effects model, with a slightly less negative coefficient for Population (-2.312e-09).
  + The LifeExpectancy effect is similar (-0.1405), indicating a consistent negative relationship between life expectancy and fertility rate.
  + Hausman Test: Chi2 = 8.354894765223571, p-value = 0.03921919711261574
* Chi2 Statistic: 8.35, with a P-value of 0.0392.
* The low P-value (< 0.05) suggests that the Fixed Effects model is more appropriate than the Random Effects model. This result indicates that there are significant differences between countries that are better captured by the Fixed Effects model, which controls for these time-invariant characteristics.

**6.2.3 Fertility Rates and Life Expectancy Across Income Groups**

|  |  |
| --- | --- |
| **Dep. Variable:** | Total\_fertility\_rate |
| **Estimator:** | PanelOLS |
| **No. Observations:** | 1004 |
| **Date:** | Thu, Oct 17 2024 |
| **Time:** | 19:29:45 |
| **Cov. Estimator:** | Unadjusted |
| **R-squared:** | 0.2684 |
| **R-squared (Between):** | 0.6012 |
| **R-squared (Within):** | 0.2684 |
| **R-squared (Overall):** | 0.5941 |
| **Log-likelihood:** | 226.65 |

**Table 8** Fixed Effects Model

| **Parameter** | **Std. Err.** | **T-stat** | **P-value** | **Lower CI** | **Upper CI** |
| --- | --- | --- | --- | --- | --- |
| **const** | 8.6276 | 0.3805 | 22.677 | 0.0000 | 7.8807 |
| **Life\_expectancy** | -0.0836 | 0.0053 | -15.803 | 0.0000 | -0.0940 |
| **Population** | 0.0368 | 0.0067 | 5.5117 | 0.0000 | 0.0237 |

**Table 9** Parameter Estimates for Life Expectancy and Population Growth

* The coefficient for life expectancy is −0.0836, indicating a statistically significant negative relationship between life expectancy and fertility rate. This suggests that as life expectancy increases, fertility rates tend to decrease.
* Population growth rate has a positive coefficient (0.0368), suggesting that higher population growth rates are associated with slightly higher fertility rates.
* The model’s R2 value (0.2684) suggests that while the model explains some variance in fertility rates within countries over time, a large portion remains unexplained, potentially due to other factors not included in this analysis.
* The life expectancy coefficient is more negative (−0.1099) compared to the Fixed Effects model, with a similar level of statistical significance. This reinforces the inverse relationship between life expectancy and fertility rates across different income groups.

|  |  |
| --- | --- |
| **Dep. Variable:** | Total\_fertility\_rate |
| **Estimator:** | RandomEffects |
| **No. Observations:** | 1004 |
| **Date:** | Thu, Oct 17 2024 |
| **Time:** | 19:29:45 |
| **Cov. Estimator:** | Unadjusted |
| **R-squared:** | 0.4659 |
| **R-squared (Between):** | 0.6795 |
| **R-squared (Within):** | 0.2393 |
| **R-squared (Overall):** | 0.6714 |
| **Log-likelihood:** | 8.6004 |

**Table 10** Random Effect Model for Total Fertility Rate

| **Parameter** | **Std. Err.** | **T-stat** | **P-value** | **Lower CI** | **Upper CI** |
| --- | --- | --- | --- | --- | --- |
| **const** | 10.498 | 0.2790 | 37.628 | 0.0000 | 9.9502 |
| **Life\_expectancy** | -0.1099 | 0.0038 | -28.769 | 0.0000 | -0.1174 |
| **Population** | 0.0531 | 0.0070 | 7.6058 | 0.0000 | 0.0394 |

**Table 11** Parameter Estimation for Life Expectancy and Population

| **Model Comparison** | **Fixed Effects** | **Random Effects** |
| --- | --- | --- |
| **Dep. Variable** | Total fertility rate | Total fertility rate |
| **Estimator** | PanelOLS | RandomEffects |
| **No. Observations** | 1004 | 1004 |
| **Cov. Est.** | Unadjusted | Unadjusted |
| **R-squared** | 0.2684 | 0.4659 |
| **R-Squared (Within)** | 0.2684 | 0.2393 |
| **R-Squared (Between)** | 0.6012 | 0.6795 |
| **R-Squared (Overall)** | 0.5941 | 0.6714 |
| **F-statistic** | 135.53 | 436.53 |
| **P-value (F-stat)** | 0.0000 | 0.0000 |
| **const** | 8.6276 (22.677) | 10.498 (37.628) |
| **Life expectancy** | -0.0836 (-15.803) | -0.1099 (-28.769) |
| **Population** | 0.0368 (5.5117) | 0.0531 (7.6058) |
| **Effects** | Entity |  |

**Table 12** Comparison between Fixed and Random Effects

* The population growth rate coefficient (0.0531) is again positive and slightly larger than in the Fixed Effects model, reinforcing the idea that higher population growth correlates with higher fertility rates.
* With a higher R2 (0.4659), the Random Effects model captures a bit more of the variance in fertility rates overall, which could suggest that both within-country and between-country differences are relevant to understanding fertility trends.
* The Hausman test results in a chi-squared statistic of 30.68 (p-value close to zero), suggesting that the Fixed Effects model is more appropriate. This indicates that unique characteristics within countries are essential in explaining fertility rates, potentially linked to cultural or policy differences.

Overall, the analysis shows a robust negative relationship between life expectancy and fertility rates, suggesting that improvements in life expectancy can contribute to fertility decline, which aligns with broader socio-economic development trends. The positive association with population growth indicates that in settings where population grows rapidly, fertility rates may not decline as fast. ​​

**6.2.4 Principle Component Analysis**

|  |  |  |  |
| --- | --- | --- | --- |
| **Population** | **LifeExpectancy** | **FertilityRate** | **Explained Variance** |
| -0.103811 | -0.701935 | 0.704635 | 0.607847 |
| 0.993904 | -0.099650 | 0.047160 | 0.330718 |
| -0.037114 | -0.705235 | -0.708001 | 0.061435 |

**Table 13** Correlation Matrix

The components are ranked in order of the variance they explain in the data:

* PC1 explains the most variance.
* PC2 explains the second most, and so on.

 The "Explained Variance" column tells us the proportion of the dataset's total variance captured by each principal component. For example:

* The first component (PC1) explains approximately 60.78% of the variance, suggesting it captures a significant portion of the overall patterns in the data.
* The second component (PC2) explains about 33.07% of the variance, which is also substantial.

 The values in each cell of the PCA component matrix show how much each original feature contributes to each principal component

* PC1 has high contributions from both Life Expectancy (negative) and Fertility Rate (positive), which means it primarily reflects the relationship between these two features. A high positive loading on Fertility Rate and a high negative loading on Life Expectancy suggests that these two features have an inverse relationship within this component.
* PC2 is dominated by Population, meaning that Population largely drives the patterns represented by this component. This could imply that variations in Population are largely independent of the variations captured by Life Expectancy and Fertility Rate

**7 Conclusion and Policy Implications**

The study provides a comprehensive analysis of the connections between fertility rates, demographic shifts, and economic indicators, offering new insights into how these factors collectively shape socioeconomic outcomes across various regions. By examining global panel data, this research identifies key determinants of fertility trends, including life expectancy, income levels, urbanization, and mean age at childbearing, which vary in their impact across different economic and cultural contexts.

The literature review elucidates the significance of factors like life expectancy, population growth, and urbanization in influencing fertility rates. Life expectancy, for example, often inversely correlates with fertility, particularly in high-income regions, where longer lifespans and improved healthcare reduce the need for larger families. Conversely, in regions with high fertility, such as parts of sub-Saharan Africa, the relationship between life expectancy and fertility is moderated by cultural norms and limited access to healthcare. Urbanization, too, is shown to influence fertility patterns by increasing access to education, healthcare, and family planning, particularly in developing regions. Economic indicators such as GDP per capita and Human Development Index (HDI) further contribute to fertility decline by improving educational and healthcare investments, particularly when accompanied by delayed childbearing associated with career and education priorities.

The methodology section employs advanced econometric techniques to analyze these relationships, utilizing panel data analysis, Principal Component Analysis (PCA), and Random Forest regression. The panel data model offers a robust framework to control for country-specific effects and examine within- and between-country variations in fertility rates, capturing nuanced interactions between demographic and economic variables over time. PCA is used to condense governance and institutional quality indicators, reducing data dimensionality while retaining the most significant trends. Random Forest regression further enriches the analysis by revealing the relative importance of each factor, with life expectancy and economic indicators emerging as primary predictors of fertility.

Empirical results reinforce the inverse relationship between life expectancy and fertility, as well as the negative correlation between economic indicators and fertility rates, particularly in higher-income nations. The Random Forest model, achieving an R-squared of 0.43, indicates that demographic factors explain a substantial portion of fertility rate variability, underscoring the importance of life expectancy and income levels. Additionally, fixed and random effects models reveal that fertility influences economic development, with higher fertility rates associated with lower economic growth. The Hausman test further validates the fixed-effects model as the more appropriate choice, highlighting the significance of within-country effects over time.

The policy implications drawn from these findings emphasize the need for region-specific interventions to address high fertility rates in developing areas, where economic constraints and limited access to healthcare and family planning resources hinder fertility decline. Enhancing healthcare systems, particularly maternal and child health services, can reduce mortality and indirectly affect fertility rates, fostering broader socioeconomic development. Likewise, improving education, particularly for women, and expanding family planning programs can empower individuals to make informed reproductive choices, contributing to sustainable fertility reductions. In higher-income regions, where low fertility rates may impact labor force composition, policies that balance work and family life could help maintain population stability.

In summary, this study not only advances our understanding of the relationship between demographic factors, fertility, and economic development but also provides actionable insights for policymakers. By recognizing the unique socioeconomic and cultural factors that influence fertility across regions, targeted policies can help manage demographic transitions in a way that promotes long-term economic stability and growth, addressing the distinct needs of both high- and low-income countries. These findings offer a valuable framework for future research and policy interventions aimed at achieving sustainable development goals through balanced demographic and economic strategies.

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