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Human Capital Development and Migration Patterns in Nigeria: A Ridge and Lasso Regression Analysis Using Python

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Abstract: This study investigates the relationship between human capital development and migration patterns in Nigeria from 1981 to 2021 using ridge and lasso regression techniques implemented in Python. Human capital development is proxied by government expenditure on education, health, social services, and gross fixed capital formation, while net migration serves as the dependent variable. The results indicate that human capital development positively influences net migration, suggesting a higher emigration rate relative to immigration. This highlights the paradox of brain drain, where increased investment in education and health enhances skill acquisition but simultaneously encourages outward migration due to limited domestic opportunities. The ridge regression model, preferred over lasso due to its robustness against multicollinearity, demonstrates a strong explanatory power with an R-squared value of 0.99. Policy recommendations emphasize the need for strategic interventions, including competitive wages, job creation, and entrepreneurship incentives, to retain skilled labor and mitigate the negative effects of migration. Additionally, fostering foreign direct investment and improving domestic economic conditions can enhance productivity and optimize the benefits of human capital development for national growth.

Keywords: human capital, migration, government expenditure, Python

1. Introduction

The migration of human populations across borders and territories has been an integral part of human societies throughout history. Empirical studies have shown that these movements are driven by a plethora of factors, including economic opportunities [1], conflict and political instability, environmental factors [2, 3], social networks [4], demographic factors [5, 6], government policies and legal frameworks [7], and human capital development [8, 9], among others. Particularly, human capital development and migration patterns are deeply related, with each influencing the other in multifaceted ways. For instance, human capital development through education and skills training can increase the likelihood of migration. As people gain skills and qualifications, they become more appealing to employers abroad, increasing their chances of migrating. Conversely, the emigration of highly skilled individuals in search of better opportunities can result in a significant loss of human capital for the origin country. Understanding this relationship is crucial for policymakers aiming to harness the benefits of migration.

In Nigeria, migration patterns have assumed alarming dimensions, creating challenges for public policies. According to a recent estimate, there are over 17 million Nigerians living in the diaspora, with a substantial portion of them residing in Canada, the United States, the United Kingdom, and Europe. The migration pattern of Nigerians over the years has shown widespread coverage, extending to regions such as Africa, the Middle East, Asia, and Oceania. In the extant literature, several studies have examined the nexus between migration and selected macroeconomic variables such as economic growth, unemployment [10], poverty, and inequality, among others. However, empirical studies linking migration patterns and human capital development in Nigeria are rarely found on the shelf. This paper is motivated by the need to fill this literature gap, while leveraging an advanced machine learning technique – lasso and ridge regression – which addresses some of the limitations of ordinary least squares (OLS) regression, particularly when dealing with multicollinearity and high-dimensional data. Hence, this paper investigates the impact of human capital development on migration patterns in Nigeria, covering the period 1981–2021.

In this study, we found that human capital development has a positive impact on net migration, suggesting that the number of emigrants would be more than immigrants, thus heightening the risk of brain drain with a higher level of human capital development in Nigeria. This trend underscores the importance of human capital development in shaping migration patterns in Nigeria. Thus, by exploring the complex relationship between human capital development and migration, this contributes to a deeper understanding of a major driver of migration patterns in Nigeria. This understanding is crucial for informing policies that promote sustainable development and mitigate the adverse effects of migration on the economy.

Following the introduction, Section 2 reviews both theoretical and empirical literature on migration and human capital development. Section 3 covers the materials and methods. Section 4

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describes the results and analysis. Section 5 concludes with policy recommendations.

2. Review of Literature

The literature review in this section presents the theoretical and empirical justifications that underpin the foundation of this paper. In addition, we carefully select the most recent and relevant studies in this area to serve as the basis for our argument. Specifically, this paper investigates the nexus between human capital development and migration patterns using Nigeria as a case study. The study leverages the neoclassical theory to provide a robust analytical foundation. The neoclassical theory offers critical insights into how economic factors, particularly wage differentials and employment prospects, drive migration [10, 11]. Thus, we analyze how government investments in education, health, and other social services influence migration trends using advanced econometric techniques.

2.1. Theoretical literature

This study is built on the theoretical framework based on the most recent studies relevant to this paper. These include the works of Nnoruga and Osigwe [12], Olsson [13], Ezeudu and Tukur [10], and Nwachukwu [11], among others. Thus, the study relies on the neoclassical theory that provides a robust framework to examine how migration patterns relate to human capital development in an economy (as originally in [14]). The theory offers a basis for examining the time-varying impact of migration on an economy. Also, it provides a background on the economy-wide implications of a continuous increase in the level of migration and key productive sectors such as education and health.

Most importantly, the neoclassical theory has been used in several studies as it provides a comprehensive analysis that underscores the importance of strategic investments in human capital to leverage economic opportunities and address migration challenges (see [15–18, 12], among others). Thus, the neoclassical theory posits that individuals make rational decisions to migrate based on economic incentives, seeking to maximize their utility.

This theory also highlights the importance of wage differentials and employment opportunities between countries as primary motivators for migration. In the context of Nigeria, the theory provides a lens through which we can investigate how human capital development interrelates with migration patterns in Nigeria. While emphasizing economic agents' decision to explore opportunities in advanced economies, this has been consistently affecting the domestic economy. In addition, several factors have been contributing to the high level of migration to advanced countries. These include higher wages, flexible employment opportunities, and a level of economic development [10, 11].

The theory could be modified to examine the cause and effect of the continuous increase in the rate of migration from Nigeria, vis-à-vis the level of human capital development. There is also a finding that countries with abundant resources and a higher level of economic development tend to be more attractive in terms of wage differentials and higher opportunities. Additionally, the theory argues that migration leads to a steady-state equilibrium in the long run, assuming perfect substitution of labor internationally [19].

Linking this to Nigeria, where migration has significantly increased over the past decade, policymakers, particularly fiscal and monetary authorities, have raised concerns [11]. Finally, this study combines both micro and macro understanding of the neoclassical theory in synthesizing how human capital development is related to Nigeria's migration level. To strengthen the link between the neoclassical theory and the empirical findings, migration decisions in Nigeria are largely driven by economic incentives, particularly wage differentials and employment opportunities, as posited by the neoclassical framework. The empirical results show that human capital development positively impacts net migration, suggesting that as education and healthcare improve, more individuals seek opportunities abroad where their skills are better rewarded. This aligns with the theory's assertion that rational individuals migrate to maximize their economic utility. Furthermore, the findings highlight that a lack of domestic opportunities intensifies brain drain, reinforcing the need for policies that enhance local job creation and economic competitiveness.

2.1.1. Human capital as a migration driver

According to the neoclassical theory, the need to invest in the key sectors of human capital development (e.g., health and education sectors) to enhance individuals' productivity and potential earnings is becoming increasingly important. Thus, when the domestic labor market cannot fully absorb this enhanced human capital, skilled individuals are likely to seek better opportunities abroad, where their skills are in higher demand and better rewarded. This phenomenon aligns with the study's finding that human capital development positively impacts net migration, indicating that a well-educated and healthy workforce is more likely to emigrate if domestic opportunities are limited [11].

2.1.2. Economic disparities and migration patterns

Cattaneo et al. [20] examined the impact of climate variability on global migration. The researchers estimated a bilateral gravity equation for emigration rates, controlling for decadal weather averages such as temperature, precipitation, droughts, and extreme precipitation in origin countries. Kan et al. [21] analyzed changes in US migration during the pandemic, revealing that many individuals moved from larger cities to less populated areas. The research highlighted the role of extended family as a crucial yet often overlooked factor in migration decisions during crises. The study utilized census microdata and mobile phone GPS relocation data to demonstrate that people migrated closer to family at higher rates after the pandemic began. Even after controlling for factors such as population density and cost of living, changes in net in-migration tended to be larger and positive in cities with larger proportions of people who can be parents to adult children, serving as a proxy for parental family availability. Arcila-Calderón et al. [22] combined Twitter and mobile phone data to observe these "border-rush" events, highlighting the potential of big data to provide quantitative metrics and qualitative understanding of sudden migration movements. The research underscored the ethical implications of using such data, especially considering the vulnerability of the populations involved. The theory suggests that economic disparities between countries drive migration. In Nigeria, despite improvements in human capital, the local economy may not provide sufficient high-paying jobs, creating a push factor for migration [17]. In this paper, gross fixed capital formation is used to proxy economic investment highlights, and this highlights the role of broader economic conditions in shaping migration patterns. Moreover, as human capital develops, the lack of corresponding domestic opportunities can lead to increased emigration, as predicted by the neoclassical framework.

2.2. Empirical literature

Recent literature on migration primarily examines its relationship with remittances in countries experiencing high human capital

outflows in search of better opportunities. In this context, we introduce new dynamics to the existing discourse on human capital development and migration patterns in Nigeria. Our study contributes to the ongoing debate by focusing on key areas such as gross fixed capital formation and human capital development, represented by government expenditure on education, health, and other social services, in relation to migration patterns, measured by net migration. To strengthen our analysis, we have explored the most recent studies in this field.

For instance, Nwachukwu [11] examined the driving forces for educational improvement in Nigeria using human capital development as the key variable. The study employed quantile regression analysis to determine the level of synergy between the level of education in Nigeria and human capital development. The analysis of the results suggested a strong synergy between the level of education and growth in human capital development for the study period. Furthermore, the study recommends a continuous effort by the government to ensure sustainable educational growth in Nigeria. This ensures improvements in critical aspects of quality education and human development.

Similarly, Ezeudu and Tukur [10] studied the interplay of key aspects of human capital development, covering migration level in the rural and urban areas, level of advanced education, unemployment, and poverty level in Nigeria. The paper employed qualitative and quantitative approaches and established that an advanced level of education is a key determinant of migration to developed countries with a high level of economic opportunities. In addition, significant migration from rural to urban areas is highly associated with the number of school enrollments, thus compelling people to increase participation in Western education. The paper also underscores the multidimensional negative effects of migration, unemployment, and poverty on job creation, as well as on the level of foreign direct and portfolio investments. This paper offers that to achieve sustainable economic growth and a higher standard of living, there is a strong need to invest consistently in the education and health sectors. These findings corroborate with the work of Olsson [13], who concluded that a lack of job availability and job security contributes to the continuous increase in the rate of migration in Nigeria.

Olanrele and Awode [23] investigated the effects of foreign aid on human capital development indicators from 1981 to 2017. Employing an autoregressive distributed lag (ARDL) model, the researchers examined the impact of sector-specific aids on life expectancy and primary school enrollment rates. The study controlled for government expenditures in the health and education sectors, both capital and recurrent. The results indicated that foreign aid targeted at the health sector positively influenced life expectancy, while educational aid significantly boosted primary school enrollment. These findings underscore the importance of targeted foreign aid in enhancing human capital development, which can influence migration patterns by addressing some root causes of emigration.

Popogbe and Adeosun [24] examined determinants of net migration from 1990 to 2019. Utilizing an ARDL, they assessed variables such as life expectancy, infant mortality rate, population growth rate, and unemployment rate. Their findings revealed that higher population growth rates and unemployment were associated with increased migration rates, while improved life expectancy and lower infant mortality rates corresponded with reduced migration. The authors advocate for enhanced human capital development through improved healthcare and population management to mitigate migration rates.

Samson et al. [25] established that a nation cannot attain sustainable economic growth without making significant investments in its human resources. Thus, countries must invest in education and advance technical skills to achieve higher productivity in the economy. Moreover, it is imperative to maintain welfare advancement and economic advancement and to enhance income distribution. This study suggests various indicators of poverty as a major obstacle to Nigeria's socioeconomic development. The paper finds a strong relationship between education, poverty reduction, and employment opportunities in Nigeria. Olopade [18] conducted a panel study for Nigeria and Saudi Arabia using structural Vector Autoregressive (VAR) analysis. The study showed a strong and significant impact of investment in education and the level of educational enrollment. In addition, the paper found that education reduces poverty levels in both Nigeria and Saudi Arabia.

Additionally, structural challenges such as insecurity, flooding, and low agricultural output hinder the government's capacity to invest adequately in educational development. Some studies have used the Python programming language in analyses such as common languages in Python by Peng et al. [26] and performance of Pythonic idioms by Leelaprute et al. [27].

2.3. Literature gap

Table 1 reveals several areas where research has been conducted on the relationship between migration and various socioeconomic factors, such as remittances, human capital development, education, and poverty. However, significant gaps remain that warrant further investigation. Most recent studies such as those by Nwachukwu [11] and Samson et al. [25] have analyzed human capital development's impact on education and entrepreneurship. However, they have not extensively explored the specific dynamics between human capital development indicators (such as public spending on health and education) and migration patterns in the Nigerian economy. There is a need for research that directly correlates these factors to provide a more comprehensive understanding.

Also, while several studies have employed quantitative and qualitative methods, there is limited use of advanced data analysis techniques like lasso and ridge regression, which can handle

Table 1
Smart art chart format of the literature review

Year	Number of papers reviewed
1970	2
1988	1
1992	1
1996	1
1997	2
1999	1
2004	1
2005	1
2014	1
2015	1
2017	1
2020	3
2021	2
2022	6
2023	3
2024	3

multicollinearity and provide more robust results. The application of such techniques, as proposed in the current study, can offer deeper insights into the nexus between migration patterns and human capital development, especially in Nigeria. Meanwhile, studies such as Ezeudu and Tukur [10] highlighted the policy implications of migration; however, there is a lack of specific recommendations tailored to leveraging human capital development to manage migration patterns. Specifically, research should focus on actionable strategies that can be implemented by policymakers to maximize the economic benefits of human capital development while addressing migration challenges.

To address these gaps, we employ lasso and ridge regression, which are modern analytical techniques for more robust analysis, using recent data to reflect current trends. This enables our study to provide specific policy recommendations to leverage human capital development for managing migration. Thus, this study contributes to the ongoing debates on the unidirectional or bidirectional causality between human capital development and migration patterns, ultimately informing more effective and inclusive policy measures in Nigeria and similar contexts.

3. Materials and Methods

The dependence theory, modernization theory, and human capital theory are a few of the pertinent theoretical works that were examined. It is claimed that people make decisions about their training and education to boost productivity depending on the nation's projected return on investment. This idea holds that a workforce with higher levels of education and competence facilitates a company's adoption and implementation of new technologies, hence enhancing the returns on investment in education and training. The modernization theory focuses on how education changes a person's behavior, beliefs, and values. Exposure to modernizing institutions like industry, schools, and the media instills contemporary attitudes and ideals. Openness to new ideas, independence from established authority, a readiness to anticipate and budget for unforeseen circumstances, and an increasing sense of social and personal efficacy are all examples of this mindset. Dependency theory is rooted in Marxist conceptualizations of the global economic system, which influence development patterns at both the core (developed nations) and the periphery (developing nations). It emerged as a framework to explain how structural imbalances in the global economy shape economic outcomes, often keeping developing countries dependent on and subordinate to wealthier nations. The strength of a state's budget, the degree of regime centralization, and external political integration are examples of global political characteristics that may support economic growth in developing nations.

3.1. Model specification

This paper synthetically adapts the writings of Ncube [28], Lucas [14], and Mankiw et al. [29]. Specifically, we introduce immigration into the analysis. Thus,

$$lnrgdp_t = \propto_0 + \propto_1 lnH_t + u_t \quad (1)$$

Equation (1) can then be modified into Equation (2), where immigration would be the dependent variable, and lnH_t would be split into spending by the government on education and health (geh_t) and (gee_t); this will make the equation become:

$$im_t = \propto_0 + \propto_1 geh_t + \propto_2 gee_t + \propto_3 oscs_t + \propto_4 gcf_t + u_t \quad (2)$$

where im_t was used to proxy net migration in Nigeria, $\propto_0$ served as the constant of the model, while $\propto_1$ served as the slope of government expenditure on health, $\propto_2$ served as the slope of government expenditure on education, $\propto_3$ served as a coefficient for other social and community service, and $\propto_3$ served as the coefficient for gross capital formation.

3.2. Methodology

This paper employs the Python programming language to implement ridge and lasso (Least Absolute Shrinkage and Selection Operator) regression, from data that range from 1981 to 2021. Lasso is often applied in machine learning to handle high-dimensional data since it makes automatic feature selection easier. To do this, a penalty term is appended to the residual sum of squares, and the regularization parameter (λ or lambda) is then multiplied. This regularization parameter controls the level of regularization. Greater lambda values result in a larger penalty, which shrinks more coefficients toward zero. This, in turn, lessens the significance of some features or removes them completely from the model, leading to automatic feature selection. The ridge regression makes up for machine learning models' excessive fitting of the training set. Regression analysis with ridge regression explicitly accounts for multicollinearity. This is helpful when creating multi-parameter machine learning models, especially when those parameters have large weights. Although the regularization of linear regression models is the main topic of this article, logistic regression can also make use of ridge regression. Tibshirani [30] put forward the lasso regression for data analytics; mathematically, the lasso regression can be expressed as:

$$\text{Lasso function} = \Sigma(y_i - y_i)^2 + \lambda\Sigma|\beta_j| \quad (3)$$

In Equation (3), y is the predicted variable, while β is the coefficient of the predictor variable. This can be transformed into our model by substituting Equations (1) and (2) with Equation (3). The model could then be estimated as:

$$\text{Lasso function} = \Sigma(im_i - im_i)^2 + \lambda\Sigma|\beta H_j| \quad (4)$$

In Equation (4), im_i could be used to proxy immigration, while βH_j is used to proxy Nigerian human capital development. Conversely, the ridge regression is estimated as a relationship between the dependent and independent variables. Ridge regression was propounded by Hoerl and Kennard [31]. The ridge regression was estimated as:

$$Y = XB + e \quad (5)$$

In this case, X stands for the independent variable, B is the regression coefficient, and Y is the dependent variable, and e represents the residual errors. The ridge regression of Equation (5) could then be modified into

$$im_t = BH_t + e \quad (6)$$

where im_i could be used to proxy net migration, while βH_j is used to proxy human capital development in Nigeria. Then e is the residual error; it is worth noting that ridge regression can be given a Bayesian interpretation.

Python was selected for estimation due to its efficiency in handling large datasets, seamless integration with machine learning techniques, and flexibility in model optimization. Unlike traditional econometric software such as Stata or EViews, Python allows for advanced hyperparameter tuning, automation, and improved visualization, enhancing both accuracy and interpretability. Its

powerful libraries, such as scikit-learn, facilitate ridge and lasso regression, making it a robust tool for analyzing migration and human capital trends.

3.2.1. Data processing and model selection

Before estimation, the dataset underwent preprocessing to ensure accuracy and reliability. Missing values were handled using mean imputation where appropriate, while outliers were examined and treated to minimize distortions in the analysis. Feature selection was conducted using lasso regression, which applies regularization to identify the most relevant predictors, reducing model complexity and improving interpretability.

Given the potential for multicollinearity among human capital indicators (e.g., government spending on education, health, and infrastructure), variance inflation factors were computed. The high correlations observed necessitated the use of ridge regression, which effectively mitigates multicollinearity by shrinking coefficient estimates without eliminating key variables. This approach ensures that all relevant economic indicators remain in the model, preserving the integrity of the analysis.

4. Results and Interpretation

In the context of evaluating the results of lasso and ridge regression models, the outcomes and their interpretations are quite nuanced and provide valuable insights into the relationship between the predictors and the response variable. We will choose which of the analyses gives a better statistical and economic finding for our study that focuses on human capital development and migration patterns in Nigeria.

4.1. Descriptive statistics

The properties of a dataset are summed up or described using descriptive statistics. They offer concise summaries of the measurements and the sample. The standard deviation, mean, minimum, maximum, and various quantiles of the analysis are among the results of the descriptive statistics.

The descriptive statistics above shows that gcf had the highest mean value, followed by mig. Table 2 further shows that geh had the least mean value. The standard deviation showed that mig had the highest value, and this means that mig time series is highly dispersed from its central tendency. This is followed by gcf, which has a value of 12320.02; the value with the least standard deviation is geh with a value of 123.87. With a value of 19791.00, mig has the greatest median value at the median, followed by gcf, while oscs has the lowest value at 11.61. With a value of 107212, the variable with the highest maximum value is mig; it is followed by gcf, which has a value of 58293.95.

4.2. Correlation analysis

A statistical technique for determining the direction and intensity of a relationship between two quantitative variables is correlation analysis. Finding the relationship between the changes of one variable and another is helpful.

Table 3
Correlation analysis of human capital development and migration patterns in Nigeria

	gee	geh	oscs	gcf	mig
gee	1.00	0.99	0.97	0.91	–0.28
geh	0.99	1.00	0.96	0.92	–0.29
oscs	0.97	0.96	1.00	0.89	–0.25
gcf	0.91	0.92	0.89	1.00	–0.28
mig	–0.28	–0.29	–0.25	–0.28	1.00

The result of the correlation shows that gee and geh have the highest correlation, followed by geh and oscs with a value of 0.97. The least correlation is oscs and mig with a value of −0.25. This showed they had a weak and negative relationship. The result of the correlation in Table 3 also showed that gee and mig, geh and mig, gcf and mig, and oscs and mig have a negative relationship. According to the relationship, we anticipate that Nigeria's migratory patterns and human capital will be negatively correlated.

4.3. Heat map

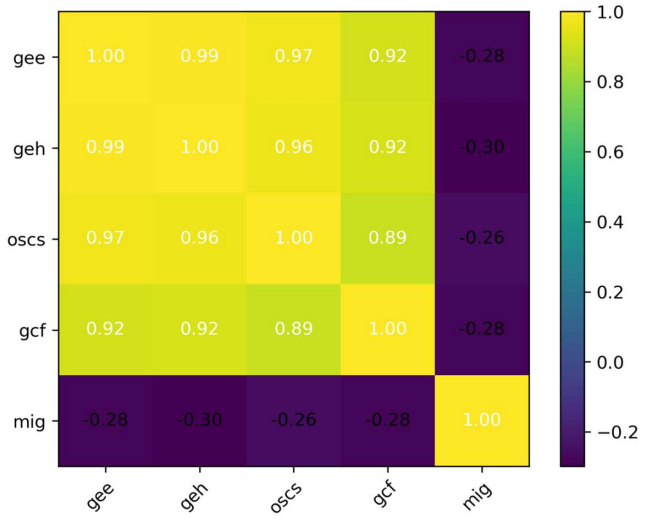
A heat map is a powerful data visualization tool that displays the magnitude of data values as colors within a matrix. This type of visualization is beneficial for identifying patterns, correlations, and trends within large datasets. The values are typically represented by a color gradient, where cooler colors like purple signify lower values and warmer colors like yellow indicate higher values.

From the heat map in Figure 1, it can be deduced that the relationship between migration (MIG) and human capital (HC) is inverse and weak, while various measures of human capital exhibit strong correlations with each other. This implies that changes in one human capital indicator will likely affect the others, indicating a high level of multicollinearity among these variables.

Table 2
Descriptive statistics of human capital development and migration patterns in Nigeria

	gee	geh	oscs	gcf	mig
count	41.00	41.00	41.00	41.00	41.00
mean	148.20	89.74	96.80	7957.66	1964.09
std	193.82	123.87	141.63	12320.02	100170.24
min	0.16	0.04	0.03	87.14	–507539.00
25%	2.40	0.57	0.64	285.59	–41526.00
50%	57.95	24.52	11.61	2473.47	19791.00
75%	325.19	180.00	224.70	9897.20	60446.00
max	646.79	423.35	448.96	58293.95	107212.00

Figure 1
Pictorial representation of the heat map of migration patterns



To address this, ridge regression is preferred, as one of its key properties is shrinking coefficients toward zero without eliminating any predictors, ensuring all remain in the model. Ridge regression is particularly useful in the presence of multicollinearity or when retaining all predictors while minimizing their impact. Lasso regression also performs shrinkage but can exclude irrelevant predictors by setting some coefficients to zero. However, we will base our final model selection on the autoregressive coefficients and choose the most appropriate regression approach for interpretation.

4.4. Scatter plot matrix

A matrix for scatter plots is a data visualization tool that allows for the examination of relationships between multiple variables simultaneously. This type of plot consists of a grid of scatter plots, where each plot represents a pair of variables. By plotting each variable against every other variable in a dataset, a scatter plot matrix enables the user to quickly identify correlations, patterns, and potential outliers among the variables. In a scatter plot matrix, each cell in the grid shows a scatter plot of two variables. The diagonal cells typically display the distribution of each variable, often in the form of histograms or density plots. This comprehensive visualization approach is particularly useful for exploratory data analysis, as it provides a compact way to view interactions and relationships within a dataset.

From the above pictorial representation of Figure 2 of the scatter matrix, it can be seen that there are a few outliers between the dependent variable and each of the indicators of human capital, and there is a specific tendency in the interaction between migratory patterns and human capital, which means the result we will have from the analysis is not going to be dynamic.

4.5. Results of ridge and lasso regression

Ridge and lasso regression are two techniques used to address the problem of overfitting in linear regression models by adding regularization terms to the loss function. Although both methods aim to constrain the model complexity by penalizing the magnitude of the coefficients, they do so in different ways, leading to distinct effects on the model. Ridge regression is the process of adding a penalty term to the loss function based on the sum of the squared values of the coefficients; this process is called L2 regularization. This penalty discourages large coefficient values, effectively shrinking them toward zero but never actually reaching zero. As a result, ridge regression retains all predictors in the model but reduces their impact. This technique is particularly useful when dealing with multicollinearity, where predictors are highly correlated, as it helps stabilize the estimates of the coefficients without excluding any predictors. On the other hand, lasso regression, also known as L1 regularization, adds a penalty term that is determined by the absolute values of the coefficients. Unlike ridge regression, lasso can shrink some coefficients to exactly zero, thereby performing variable selection. This means that lasso not only reduces the impact of less important predictors but can also exclude them entirely from the model.

Table 4 shows the results of the lasso and ridge regression analyses. The lasso regression shows that government spending on education increases the impact on migration patterns, with a coefficient of 2.34%. This means that as the government increases its overall spending, there tends to be a rise in migration. This could be due to improvements in infrastructure, services, and economic opportunities that make certain areas more attractive, encouraging people to move there. On the other hand, government expenditure on health shows a significant negative impact on migration patterns, with a coefficient of −13.51%. This indicates that higher spending on healthcare leads to a considerable decrease in migration. Improved healthcare services and better access to medical facilities might enhance the quality of life, reducing the need for individuals to migrate in search of better health services.

Spending on other social and community services also has a positive impact on migration, with a coefficient of 4.74%. This suggests that increased investment in these areas makes regions more appealing due to better social amenities and community services, attracting people to move there. Lastly, gross capital formation, which represents investments in infrastructure and capital assets, has a smaller positive impact on migration patterns, with a coefficient of 0.02%. This means that as investments in infrastructure and equipment increase, there is a slight increase in migration. This could be

Figure 2
Pictorial representation of scatter plot matrix of migration patterns

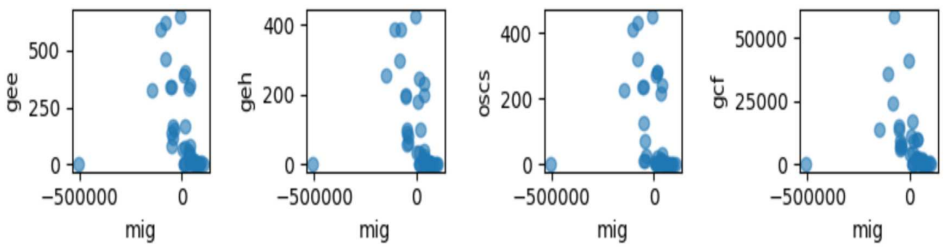


Table 4
Lasso and ridge regression results

Lasso coefficients		Ridge	Coefficients
Gee	234.40		
Geh	–1351.91		
Oscs	474.21	41.14	
Gcf	19241.14		
C	26042.19		–0.08
R-squared	–1.06		0.99

Table 5
OLS using Python

	Coefficient	Standard error	*t*-value	*p*-value
const	20836.77	20491.26	1.01	0.31
Gee	350.24	702.31	0.49	0.62
geh	–981.65	1017.54	–0.96	0.34
oscs	220.72	467.15	0.47	0.63
gcf	–0.50	3.29	–0.15	0.87
R-squared	1.09529E+16			
Adjusted R-squared	0.01			

because new economic opportunities and job creation in these areas draw people to move toward regions with higher investments.

The ridge regression shows that the coefficient of human capital after accounting for multicollinearity among the variables is 0.41%. In practical terms, this means that as human capital in Nigeria improves, there is a corresponding increase in migration patterns. Human capital encompasses factors such as education, skills, and health of the population.

Therefore, an increase in human capital could lead to more people moving, possibly because better education and skills open up new opportunities that encourage individuals to seek better employment or living conditions, either within the country or abroad. Lasso regression showed an R-squared value of −1.06, and the ridge regression showed to have an R-squared of 0.99. This means that lasso regression is not statistically correct; therefore, we adopt the ridge regression, which is statistically correct.

Ridge regression was chosen over lasso due to its superior handling of multicollinearity, which is prevalent among human capital development indicators such as government expenditure on education, health, and infrastructure. Unlike lasso, which can shrink some coefficients to zero and exclude certain predictors, ridge retains all variables, ensuring that key factors influencing migration are not omitted. This makes ridge more applicable in real-world economic analysis, where relationships between variables are often complex and interdependent. Additionally, the high R-squared value (0.99) in the ridge model confirms its better explanatory power compared to lasso, making it a more reliable choice for policy-driven analysis.

4.6. Robustness check using ordinary least squares (OLS) in Python

The OLS regression results show that government expenditure on education (gee), health (geh), social services (oscs), and gross fixed capital formation (gcf) have mixed and mostly insignificant effects on migration patterns, as indicated by their high *p*-values (greater than 0.05). The *t*-values are low, suggesting weak statistical significance.

In contrast, ridge regression accounts for multicollinearity among the predictors by shrinking coefficients rather than eliminating variables, as seen in Table 5. While OLS shows weak relationships between human capital indicators and migration, ridge regression provides a more stable estimation, with an R-squared of 0.99, indicating a much better fit. Ridge also ensures that all key economic factors remain in the model, making it more reliable for policy recommendations than OLS.

5. Discussions and Conclusion

The study highlights the risk of brain drain, but stronger policies such as competitive wages and entrepreneurship incentives are needed to retain skilled professionals. Human capital development can attract Foreign Direct Investment (FDI) while also increasing remittance inflows, offering both challenges and opportunities. Additionally, it is crucial to distinguish between internal and international migration, as rural-to-urban movement responds to domestic opportunities, while international migration is driven by global job prospects. Balanced policies can help manage both trends effectively.

The analysis reveals a significant positive relationship between human capital development and migration patterns in Nigeria, as evidenced by the ridge regression coefficient of 41.14. This relationship suggests that improvements in human capital development – through increased government expenditure on education, health, and other social services – tend to increase migration. This finding aligns with the neoclassical theoretical framework presented in the study, which posits that individuals make rational decisions to migrate based on economic incentives and opportunities.

The high R-squared value of 0.99 from the ridge regression indicates that the model effectively explains the variation in R-squared patterns based on human capital indicators. This robust statistical relationship underscores the strong connection between human capital development and migration decisions in Nigeria. The preference for ridge regression over lasso regression (which showed an R-squared value of −1.06) demonstrates the importance

of accounting for multicollinearity among human capital variables when analyzing their impact on migration.

The findings suggest a complex dynamic where investments in human capital, while beneficial for individual development, may inadvertently contribute to increased emigration. This phenomenon, often referred to as "brain drain," presents a significant policy challenge for Nigeria. As the government invests in education, healthcare, and skill development, the enhanced human capital becomes more mobile and marketable internationally, potentially leading to increased emigration if domestic opportunities do not keep pace with skill development.

The study demonstrates that human capital development significantly influences migration patterns in Nigeria, with improvements in human capital correlating with increased migration. This relationship highlights both opportunities and challenges for Nigerian policymakers. While human capital development is crucial for economic growth and development, the positive correlation with migration suggests the need for complementary policies to retain skilled individuals within the country.

This study, while providing valuable insights into the relationship between human capital development and migration patterns in Nigeria, has several potential limitations. One key concern is omitted variable bias, as factors such as political stability, security challenges, and global economic conditions, which may also influence migration, were not explicitly accounted for in the model. Additionally, data constraints pose a limitation, as the study relies on secondary data from 1981 to 2021, which may not fully capture recent policy shifts or informal migration trends. Another potential issue is confounding variables, where external factors, such as exchange rate fluctuations or foreign labor demand, could indirectly influence migration patterns alongside human capital indicators. Lastly, the use of ridge and lasso regression, while effective in handling multicollinearity, may still have limitations in fully capturing the dynamic nature of migration decisions.

6. Policy Recommendation

The results of the ridge regression analysis demonstrate a positive relationship between Nigeria's net migration trends and the development of human capital. Several policy recommendations can be made to optimize human capital investments and manage net migration effectively.

First, it highlights the need for the Nigerian government to continue and expand its investment in human capital development. Enhanced education, healthcare, and skill-building programs are evidently making the country more appealing to immigrants. This influx of immigrants can be leveraged to further boost the economy, provided that adequate opportunities and support systems are in place for these newcomers.

The government should, therefore, ensure that there are sufficient job opportunities and infrastructure to accommodate the increasing population. This includes not only investing in physical infrastructure like housing and transportation but also ensuring that the labor market can absorb and utilize the skills and talents of incoming migrants effectively.

Additionally, policies that foster integration and social cohesion are crucial. As more people migrate to Nigeria, it becomes important to create an inclusive society where newcomers can integrate smoothly and contribute positively to the community. This can be achieved through programs that promote cultural exchange, language acquisition, and community engagement.

Furthermore, the positive relationship between human capital and net migration underscores the importance of maintaining and improving the quality of education and healthcare services. High standards in these sectors are not only beneficial for the local population but also enhance the country's attractiveness to skilled migrants. Ensuring that these services remain accessible and of high quality will help sustain this positive trend.

The policy implications of the ridge regression analysis highlight the need for Nigeria to continue investing in human capital development while also preparing to accommodate and integrate a growing number of immigrants. By doing so, Nigeria can harness the benefits of this migration trend to foster economic growth and social development.

Disclaimer

This is the idea of the authors and not the institution which they represent.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Richard Umeokwobi: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization, Supervision. **Auwal Isah:** Conceptualization, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing. **Elijah Oludele Akanni:** Conceptualization, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration. **John Obeta:** Conceptualization, Investigation, Resources, Data curation, Writing – review & editing, Project administration.

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