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Using Linear Regression in the Context of Military Power Enhancement

Ivan Okromtchedlishvili[1]
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Abstract

The article explores the application of linear regression in the context of military power enhancement. Linear regression analysis is employed to identify the key factors that contribute to military strength, such as defense expenditure and military personnel levels. The study utilizes data from 31 NATO member and partner countries and employs open-source data for analysis. The research aims to determine the impact of various independent variables on the dependent variable, the Military Strength Ranking for 2022, and identify which variables can be adjusted to achieve greater military power. The study's hypotheses are tested to establish the significance of each variable. The results indicate that defense expenditure and military personnel are statistically significant factors influencing military power. A higher defense budget and greater military personnel correlate positively with a higher Military Strength Ranking. However, the study acknowledges the challenge of balancing defense spending with civilian priorities, known as the "guns versus butter" dilemma. The importance of efficiently allocating defense funds to maximize military capability is emphasized, as history has shown that mere financial resources do not guarantee security. The study recommends increasing the share of military personnel, reducing administrative costs and optimizing structural units, particularly in supply and administration areas and the civil office's structural units, to enhance military capability within existing defense budgets. Additionally, the role of reserve forces is highlighted as a valuable resource for augmenting combat capabilities. The article underscores the need to strike a proper balance between active and reserve components of military capability.

Keywords:
Linear regression, military power, defense expenditure, military personnel.

1 Ilia State University, Associate Lecturer, MA Course in Defense Management, PhD in Business Administration

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Introduction

Originally proposed by Sir Francis Galton in 1885, linear regression is a statistical method employed to establish and quantify the relationship between the variables under consideration.[2]

Linear regression analysis elucidates the connection between a set of independent variables and a dependent variable by formulating an equation in which the coefficients delineate the relationship between each independent variable and the dependent variable. This equation can also be employed for making predictions.

Mathematically, the simplest form of linear regression can be expressed as follows: $Y = a + b \times X + e$. In this equation:

- Y signifies the value of the dependent variable, which is the variable being predicted or explained.
- “a” or Alpha represents a constant that corresponds to the value of Y when X equals zero.
- “b” or Beta denotes the coefficient of X, which signifies the slope of the regression line, illustrating how much Y changes for each unit change in X.
- X represents the value of the independent variable, which is what predicts or explains the value of Y.
- “e” represents the error term, signifying the discrepancy in predicting the value of Y given the value of X (although it is typically not explicitly shown in most regression equations).[3]

The multivariable regression model can be expressed in the following manner: $Y = a + b1 \times X1 + b2 \times X2 + \ldots + bn \times Xn + e$.

Increasing military power is essential for national security, defense against potential threats, and maintaining geopolitical stability. A strong military act as a deterrent to aggression, provides the capability to respond to crises, and enhances a country’s influence in international affairs. Linear regression can aid in achieving this goal by analyzing historical data to identify key factors that contribute to military power, such as defense expenditure, personnel levels, etc. By understanding the relationships between these variables and military strength, decision-makers can allocate resources more effectively, develop evidence-based defense policies, and prioritize areas for improvement.

In this study, a linear regression analysis model was utilized to establish the correlation between a set of independent variables (x) - including Defense expenditure in US dollars at current prices and exchange rates for 2020, Defense expenditure as a percentage of real GDP for 2020, and Military personnel for 2020 - and the dependent variable (y) - Military Strength Ranking for 2022, as indicated in Table 1.

This model was instrumental in quantifying the influence of each of the mentioned input variables (x) on the military power index (y), thereby facilitating an analysis of which inputs could be adjusted to enhance military power. Based on the study’s outcomes, recommendations were formulated to improve a nation’s military capability.

Main Part

1. Literature Overview

According to Bluman, regression is a statistical approach widely employed by researchers in various fields to elucidate the relationship between variables.[4] There are two types of relationships recognized: the first is simple regression, involving two variables – an independent (explanatory) variable and a dependent (response) variable. The second type is multiple regression, which entails two or more independent variables used to predict a single dependent variable. The nature of this relationship between variables can be linear or nonlinear, as well as positive or negative.[5]

In their article, Kumari & Yadav explained the fundamental concepts and provided guidance on performing linear regression calculations in SPSS and Excel.[6]

Foong et al. introduced a novel technique that incorporates the use of test statistics, p-values, and the coefficient of determination in hypothesis testing.[7]

Schober & Vetter pointed out that linear regression is an exceptionally versatile method with broad applicability in medical research, capable of addressing various research questions and study objectives.[8]

2 Kh. Kumari, & S. Yadav, Linear regression analysis study. Journal of the Practice of Cardiovascular Sciences, 4(1), 2018. 33-66, p.1 https://tinyurl.com/dae3zv8f

3 California State University. (No date). PPA 696 RESEARCH METHODS SIMPLE REGRESSION. https://tinyurl.com/7cv86s77

4 A. G. Bluman, *Elementary statistics: a step-by-step approach 8th Ed.*, p. 534. McGraw-Hill, 2012. https://tinyurl.com/2b4453e7

5 Ibid.

6Kh. Kumari, , & S. Yadav, Linear regression analysis study. Journal of the Practice of Cardiovascular Sciences, 4(1), 2018, 33-66 https://tinyurl.com/dae3zv8f

7N.G. Foong, , Ch. Y., Ming, Ch. P. Eng, & N. K. Shien, An Insight of Linear Regression Analysis. Scientific Research Journal, 15(2), 2018, 1-16, p. 4 https://tinyurl.com/3eu9kejj

8 P. Schober, , & Thomas R. Vetter, Linear Regression in Medical Research. Anesthesia & Analgesia, 132(1), 2021, 108-109, p. 108

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Edelman et al. attempted to enhance the accuracy of predicting total procedure time (TPT) by employing linear regression models based on estimated surgeon-controlled time (eSCT) and other pertinent variables.[9]

Schneider et al. regarded linear regression analysis as a crucial statistical tool for analyzing medical data. They briefly expounded on the theory behind linear regression analysis and provided illustrations for interpreting statistical parameters.[10]

Uyanık & Güler aimed to illustrate the process of multiple linear regression analysis by investigating whether the five independent variables in the standard model (specifically, end-of-the-term scores obtained from courses in measurement and evaluation, educational psychology, curriculum development, guidance, and teaching methods) could significantly predict the KPSS score, which served as the dependent variable. This analysis was based on ANOVA statistics.[11]

Li et al. examined the factors influencing wartime equipment waste and introduced a predictive model for wartime equipment waste using multiple regression analysis. They employed the ordinary least-squares approach, complex correlation coefficient, and t-test in their analysis.[12]

Choi & Suh proposed a research framework to systematically forecast spare parts demand for military aircraft. They evaluated the predictive performance of various data mining techniques and identified which managerial feature set was most effective for accurately forecasting military aircraft spare parts demand.[13]

Khan & Al Zubaidy, in a study involving students from different programs at a Military College, explored the connection between students' performance and factors such as military or physical training, academic aptitude, and the time spent on training needs analysis modules.[14]

Boekestein utilized logistic regression analysis to predict future violent conflicts globally and identify variables that significantly contributed to violent conflict.[15]

Kalin applied linear regression to a range of countries under the United States European Command (EUCOM) and the United States to assess the efficiency of each country in achieving military power. The study also investigated the overall relationship between military power and the selected variables.[16]

The summarize, linear regression analysis is a versatile method that finds utility in a wide array of domains, including the defense sector. Researchers in different domains use linear regression to understand relationships between variables, whether simple or multiple, and predict outcomes. The mentioned studies demonstrate the use of linear regression in medical research, education, wartime equipment waste prediction, spare parts demand forecasting for military aircraft, performance analysis of military college students, and predicting future violent conflicts. It shows how linear regression remains a versatile and valuable statistical method in addressing diverse research questions and aims.

2. Research Methodology

All variables for this study were pulled from open sources.

A total of 31 NATO member countries, as well as aspirant and partner nations like Ukraine, Georgia, and Moldova, were chosen for the Excel-based regression analysis. The data was organized such that each variable occupied a separate column, as illustrated in Table 1.

Defense expenditure encompasses all expenditures, both current and capital, related to a state's armed forces. In theory, a higher level of defense expenditure suggests better military capability and, consequently, a higher position in the Military Strength Ranking. However, as Harrison pointed out, how money is allocated in defense matters just as much as the total amount available. History is replete with

https://tinyurl.com/4rbjhcxu

9 E. R. Edelman, S. M. J.van Kuijk, A. E. W.Hamaekers, M. J. M. de Korte, G. G.van Merode, & W. F. F. A. Buhre, Improving the Prediction of Total Surgical Procedure Time Using Linear Regression Modeling. Front. Med., 4, Article 2017,85, p. 1 https://www.frontiersin.org/articles/10.3389/fmed.2017.00085/full

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12 Li, Z., Chen, G., & Li, Q. Model to Predict Wartime Equipment Waste Based on Multiple Regression Analysis. 1802. Journal of Physics: Conference Series, 2020. https://tinyurl.com/mwft5ems

13 B.Choi, & J. H. Suh, Forecasting Spare Parts Demand of Military Aircraft: Comparisons of Data Mining Techniques and Managerial Features from the Case of South Korea. Sustainability, 12(15), 2020, p. 3. https://doi.org/10.3390/su12156045

14 W. Z. Khan, & Al S. Zubaidy, Prediction of Student Performance in Academic and Military Learning Environment: Use of Multiple Linear Regression Predictive Model and Hypothesis Testing. International Journal of Higher Education, 6(4), 2017, 152-160. https://eric.ed.gov/?id=EJ1151836

15 B. C. Boekestein, A Predictive Logistic Regression Model of World Conflict Using Open-Source Data. Theses and Dissertations. 2015. https://scholar.afit.edu/etd/101

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instances of wealthier nations being defeated by more modestly resourced adversaries.[17]

The commitment made by North Atlantic Treaty Organization (NATO) members in 2014 to increase their defense expenditure as a percentage of real GDP to 2% by 2024 continues to be a topic of discussion in NATO regarding military spending.[18] The United States notably outperforms other countries in this regard (3.72% in 2020). When evaluating appropriate levels of such spending, it is crucial to assess its effectiveness and alignment with other national priorities.

Military personnel are a crucial component of readiness, alongside equipment, supplies, training, and maintenance. A mission-ready force relies on having an adequate number of qualified military personnel, who play a pivotal role in military capability, especially combat-ready forces. It's essential to note that increasing military personnel must be accompanied by the development of other components across the entire DOTMLPF[19] spectrum to achieve comprehensive military readiness.

Regarding the dependent variable, Global Firepower (GFP) has been providing a unique analytical assessment of data related to 140 modern military powers since 2006.[20] GFP ratings are based on a country's potential war-making capability on land, sea, and air using conventional means. These ratings incorporate factors such as manpower, equipment, natural resources, finance, and geography, with more than 50 individual factors contributing to the final GFP rankings. These rankings offer valuable insights into a volatile global landscape where the potential for conflict looms. Essentially, the GFP rating serves as an indicator of a state's defense organization performance, with an improved ranking signifying enhanced efficiency and effectiveness of defense programs. For this study, a reverse military power index was used, implying that a higher military power index represents a stronger country, while a lower initial military index suggests a stronger position.

Table 1

Variables for the Regression Analysis

№	Variables	Dependent		Independent		
	Country	Military Strength Ranking for 2022	Military Strength Ranking for 2022 (reversed)	Defense expenditure in US dollars at current prices and exchange rates for 2020	Defense expenditure as a percentage of real GDP, for 2020	Military Personnel, for 2020
	United States	0.0453	35.8958	784952000000	3.72	1346000
	France	0.1283	5.7275	52727000000	2.03	208000
	United Kingdom	0.1382	5.2184	61925000000	2.29	156200
	Italy	0.1801	4.7871	26071000000	1.38	175500
	Turkey	0.1961	4.4351	13396000000	1.86	437200
	Germany	0.2322	4.3067	58902000000	1.55	186900
	Spain	0.2901	3.7337	12828000000	1.00	122500

17 T.Harrison, Rethinking Readiness. Strategic Studies Quarterly, 8(3), 2014, 38–68, p. 41 https://csbaonline.org/uploads/documents/Rethinking-Readiness.pdf

18 J.Techau, The politics of 2 percent, NATO and the security vacuum in Europe. Carnegie Endowment for International Peace, 2015. https://tinyurl.com/5c5z6w8h

19 DOTMLPF-P is a tool that allows senior leaders to analyze their organizational capabilities from the perspective of "Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy" when making future strategic decisions. https://acqnotes.com/acqnote/acquisitions/dotmlpf-analysis

20 Global Firepower, 2022, March 1Military Strength Ranking.
https://www.globalfirepower.com/countries-listing.php

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	Ukraine	0.3266	3.4016	5924000000	4.10	209000
	Canada	0.3601	3.3736	23595000000	1.44	71000
	Poland	0.4179	3.1759	13590000000	2.28	120000
	Greece	0.4506	2.8681	5019000000	2.65	107600
	Norway	0.5455	2.6527	7272000000	2.01	20800
	Netherlands	0.5937	2.5771	13125000000	1.47	40000
	Romania	0.5938	2.5072	5051000000	2.03	66400
	Czech Republic	0.6161	2.3944	3201000000	1.31	26800
	Portugal	0.7282	2.2436	3306000000	1.43	28700
	Hungary	0.8633	1.7083	2770000000	1.79	22700
	Denmark	0.8677	1.6836	4979000000	1.40	18100
	Slovak Republic	0.9617	1.5252	2050000000	1.96	12900
	Croatia	0.9962	1.4729	1031000000	1.80	15200
	Bulgaria	1.1071	1.3664	1075000000	1.55	25600
	Belgium	1.1451	1.3265	5427000000	1.05	25200
	Lithuania	1.7083	0.8633	1176000000	2.11	16300
	Slovenia	1.9486	0.8573	568000000	1.08	7000
	Georgia	2.0014	0.8169	292000000	1.80	20650
	Latvia	2.2758	0.6953	743000000	2.22	7000
	Moldova	2.5799	0.5859	44500000	0.40	5150
	Estonia	2.6527	0.5455	719000000	2.32	6600
	Albania	3.0023	0.4276	188000000	1.27	6700
	Montenegro	4.8015	0.1695	83000000	1.73	1900
	North Macedonia	5.7275	0.1283	154000000	1.25	6100

Developed by the author, based on[21]

The central research question of this study can be framed as follows: What influence did the independent variables (x) - Defense expenditure in US dollars at current prices and exchange rates for 2020; Defense expenditure as a percentage of real GDP for 2020; and Military personnel for 2020 have on the dependent variable (y) - the Military Strength Ranking for 2022? Additionally, which of the independent variables could be adjusted to enhance military power?

This research question leads to the following hypotheses:

H0: The independent variables - Defense expenditure, Defense expenditure as a percentage of real GDP, and Military personnel - do not exert an impact on the dependent variable - the Military Power Index.

H1: The independent variables - Defense expenditure, Defense expenditure as a percentage of real

21 *https://www.nato.int, https://sipri.org, https://data.worldbank.org. https://www.iiss.org, https://www.globalfirepower.com/*

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GDP, and Military personnel - do indeed have an impact on the dependent variable - the Military Power Index.

3. Results and Analysis

The R-squared value of approximately 0.99 (rounded to two decimal places) signifies that our model explains roughly 99% of the variability in the dependent variable. In general, a higher R-squared value indicates a stronger model fit.

The standard error of the regression reveals the typical level of error in the regression model's predictions. Based on the output, we can infer that, on average, the predicted values deviate from the observed values by approximately 0.75 units (as presented in Table 2).

Table 2

Summary Output

Regression Statistics	
Multiple R	0.993386034
R Square	0.986815813
Adjusted R Square	0.985350903
Standard Error	0.755086722
Observations	31

Within Excel's ANOVA table, the most crucial statistic is the Significance F, which corresponds to the p-value for the F-test assessing the overall significance of the model. This test evaluates whether the model, with all of its independent variables, offers a better explanation for the variability in the dependent variable compared to a model with no independent variables. If the test result is statistically significant, it indicates that the model is effective.

Our p-value for the overall F-test is 1.76781E-25 (as displayed in Table 3). This notation uses scientific notation, where the "E-25" implies shifting the decimal point 25 positions to the left. This value is smaller than any reasonable significance level. Consequently, we can deduce that our regression model, taken as a whole, is statistically significant.

Table 3

ANOVA Table

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1152.232609	384.0775364	673.6359255	1.76781E-25
Residual	27	15.39421086	0.570155958		
Total	30	1167.62682			

The table below (refer to Table 4) displays the parameter estimates for the independent variables in our model, including the intercept value (constant).

Our model comprises three independent variables: Defense expenditure measured in Current prices and exchange rates US dollars for 2020, Defense expenditure as a percentage of real GDP for 2020, and the Military personnel in 2020.

For the Defense expenditure variable, the coefficient is approximately 2.86656E-11. The positive sign indicates that as Defense expenditure increases, there is a tendency for the Military Strength Ranking to increase as well. This suggests a positive association between these two variables, meaning that for every one-unit increase in Defense expenditure, the Military Strength Ranking increases by an average of approximately 2.86656E-11.

Regarding Defense expenditure as a share of real GDP (%), the coefficient is 0.078969912. This signifies that for each one-unit increase in Defense expenditure as a share of real GDP (%), the Military Strength Ranking increases by an average of 0.078969912.

Lastly, the coefficient for Military personnel is 9.02932E-06. This implies that with every one-unit increase in the count of Military personnel, the Military Strength Ranking increases by an average of approximately 9.02932E-06.

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Table 4

Coefficients Table

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.140795626	0.396525398	2.876979962	0.007750685	0.327192713	1.954399	0.327193	1.954399
Defense Expenditure, Current prices and exchange rates US dollars, for 2020	2.86656E-11	2.9769E-12	9.629350406	3.17259E-10	2.25575E-11	3.48E-11	2.26E-11	3.48E-11
Defense Expenditure as a share of real GDP (%), for 2020	0.078969912	0.226270214	0.349007104	0.729791137	-0.385298217	0.543238	-0.3853	0.543238
Military Personnel, for 2020	9.02932E-06	1.76409E-06	5.118391948	2.21592E-05	5.4097E-06	1.26E-05	5.41E-06	1.26E-05

The p-values associated with the coefficients serve as indicators of the statistical significance of the dependent variable. When the p-value falls below the specified significance level, it allows us to reject the null hypothesis, which asserts that the coefficient is equal to zero, implying no relationship.

In the case of Defense Expenditure, the p-value is 3.17259E-10, which is less than 0.05. Consequently, this variable is deemed statistically significant.

Similarly, for Military Personnel in 2020, the p-value is 2.21592E-05, also less than 0.05, indicating its statistical significance.

Excel presents the p-values for both of these independent variables in exponential notation due to their exceptionally small values. This suggests that the coefficients are statistically significant at a very high level of confidence and implies a linear relationship.

Conversely, the Defense Expenditure as a percentage of real GDP (%) variable lacks statistical significance, as its p-value surpasses the typical significance threshold of 0.05. This implies that this particular variable might not have a meaningful impact on the dependent variable in this analysis. Following standard practice, it can be considered to exclude Defense Expenditure as a percentage of real GDP (%) from the final model, as retaining statistically insignificant variables may compromise the accuracy of the model.

4. Discussion and Conclusions

The aim of the Linear Regression Analysis was to investigate the association between three independent variables for the year 2020: Defense Expenditure measured in Current prices and exchange rates US dollars, Defense Expenditure as a percentage of real GDP, and Military Personnel, and the dependent vari-

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able, Military Strength Ranking for the year 2022. The goal was to determine which of the independent variables exerted the most substantial influence on the military power index and whether this influence was positive or negative.

The analysis unveiled that the variables of Defense Expenditure and Military Personnel exhibited statistically significant p-values (less than 0.05), signifying their importance in the model. Conversely, the Defense Expenditure as a percentage of real GDP variable did not meet this level of significance and can therefore be omitted from the final model.

The study demonstrated that a higher Defense expenditure and greater number of Military personnel were positively associated with a higher military power index, which in principle aligns with expectations. Consequently, countries focusing on these factors would likely improve their position in the ranking of military power. However, since the coefficients are very small, this means that with each increase in defense expenditure or the number military personnel per unit, there is a very tiny change in the military strength ranking. For example, in the case of Georgia, doubling defense spending increases its position in Global Firepower by only 0.01 points. It is noteworthy that the same result can be achieved by creating one infantry battalion, which consists of four to six companies and can include about 1,000 soldiers.[22]

A crucial concern arises regarding the feasibility of most countries, including Georgia, being able to increase their military budgets and personnel to a degree that significantly impacts their positive ranking. Such a substantial increase might be achievable only for a garrison state, which prioritizes military strength above civilian living standards and is immune to public resentment. Nonetheless, such a strategy would lead to a gradual reduction in military capability due to the neglect of civilian investment, eroding the economic base from which military power is drawn.

Given limited resources, nations face the challenge of striking a balance between defense investment and civilian goods, commonly known as the “guns versus butter”[23] dilemma. This choice is influenced, in part, by considering the military expenditures and positions of potential opponents. During wartime, defense usually takes precedence over social programs, but in peacetime, decisions to increase defense spending are often complex. It is also essential to recognize that a substantial defense budget does not guarantee security; the key lies in the efficient and effective allocation of defense funds. In defense, the manner in which money is spent is as critical as the total amount available, and history has numerous examples of countries with fewer resources overcoming wealthier opponents.

Based on the above findings, the recommended approach is to consider increasing the share of military personnel and the combat component of the Ministry of Defense within the existing defense budget. This can be achieved by reducing administrative costs and optimizing structural units, particularly in supply and administration areas, as well as the civil office of the Ministry and its subordinate civil organizations (e.g., legal entities of public law). In this scenario, it is crucial to regard military personnel as a fundamental component of military capability, encompassing combat-ready forces. An increase in the count of military personnel implies the concurrent enhancement of other essential capability elements (spanning the entire DOTMLPF spectrum) that are indispensable for establishing a comprehensive military capability.

It is also highly advisable to give due consideration to increasing the share of the reserve component of the military capability of the defense forces, as it could significantly augment the overall number of combat forces within the allocated defense budgets. It should be kept in mind that maintaining the military capability of a state fully available at all times is impractical. Striking a proper balance between the active and reserve components of military capability is the most desirable yet challenging path. This necessitates a careful analysis to answer important questions, such as whether the focus should be on active units or reserves during peacetime. Given the existing limitations in resources, it might be more appropriate to substitute active forces with reserve forces as a potential solution. However, this matter requires thorough study and analysis.

Conclusion

the study analyzed defense expenditure and military personnel as important factors influencing military power, while other variables may also contribute to a nation’s military strength. Factors such as technological advancements, geopolitical alliances, and strategic military doctrines were not considered in this study, but may be further explored in future research.

22 https://www.defense.gov/Multimedia/Experience/Military-Units/army/#army

23 In the field of macroeconomics, the "guns versus butter" model serves as an illustration of a basic production possibility frontier. It illustrates how a country allocates its limited resources between investing in defense-related items and civilian goods. In this scenario, a nation faces a decision when it comes to utilizing its finite resources. It can opt to allocate resources to either "guns" (investing in defense or military) or "butter" (investing in the production of civilian goods), or find a balance between the two. This model can be viewed as a representation of the choices countries make between military and civilian expenditures, even in more intricate economic systems.

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Disclaimer

The views represented in this paper are those of the author and don't reflect the official policy or position of the Ministry of Defense of Georgia.

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