**Asian Themes in Social Sciences Research**
ISSN: 2578-5516
Vol. 8, No. 1, pp. 54-68
2024
DOI: 10.33094/atssr.v8i1.2080
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Accepted: 10 December 2024 | Published: 27 December 2024

# Technical efficiency evaluation of Sudan's economy

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## Abstract

This paper aims to estimate the technical efficiency of Sudan's economy from 1960 to 2020 and explore the impact of economic policies on technical efficiency. It used stochastic frontier analysis and beta regression to estimate technical efficiency, the dependent variable that economic policy influences. The study preferred the Cobb-Douglas production function over the transcendental logarithmic production function (Translog). The first two years showed an upward technical efficiency trend, followed by a downward trend for 40 years. Following the 2005 signing of the peace deal that marked the end of the civil war, the technical efficiency trend rose, accompanied by oil exports. The technical efficiency differed from its optimal value by 20%. Policies pertaining to the economy that had an impact on technical efficiency included the devaluation of the currency rate, the increase in ordinary expenditures, indirect taxes, and the ratio of the balance of payments to the gross domestic product. Moreover, the elimination of trade barriers is of the utmost importance, and policymakers should be serious about enhancing the competitiveness and productivity of the economy. This may be accomplished by implementing tax reform and shifting the priorities of government expenditure, which will eventually result in the release of additional funds for development.

**Keywords:** *Economic policies, Oil exports, Tax reform, Technical efficiency, Trade obstacles.*
**Licensed:** *This work is licensed under a Creative Commons Attribution 4.0 License.*
**Funding:** *This study received no specific funding*
**Institutional Review Board Statement:** *Not Applicable.*
**Transparency:** *The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.*
**Competing Interests:** *The authors declare that they have no competing interests.*

## 1. Introduction

### *1.1. Background*

Through a variety of policies, all nations pursue economic growth as their primary goal. Since Gross Domestic Product (GDP) shows the income produced by various economic agents, it is a commonly used metric for assessing a country's economic behaviour. Each economic sector uses factor payments and products to measure the cost of producing goods and services in the economy. The level of technical efficiency in utilizing these resources can influence the varying outcomes of resource allocation to achieve a specific aim. Technical efficiency refers to the utilization of productive resources to optimize output from a specific combination of inputs. Thus, inefficiency can be defined as the discrepancy between actual production values and the highest possible values for a given technology (Fuente-Mella, Vallina-Hernandez, & Fuentes-Solís, 2020; Kibara & Balazs, 2019). Therefore, numerous publications have addressed this topic by examining various products in terms of their production function, cost function, or profit function. Pires and Garcia (2012) demonstrated that it is possible to use an appropriate breakdown of total factor productivity (TFP) to analyze a diverse set of countries over a long period of time. This breakdown allows for the assessment of not only the contributions of technical progress and technical efficiency change to long-term growth but also the impact of scale and distributive efficiency change. Efficiency is the goal of numerous global social and economic initiatives and reforms. The possibility of efficiency gains is a driving force behind the deregulation of markets, the elimination of trade barriers, and the privatization of state-run businesses.

Sudan's gross domestic product fluctuated around an average growth rate of 0.345; the maximum growth rate is 12.92; and the minimum is -9.11. The country, which has large agricultural and mineral resources, is


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strategically located between the Middle East and West Africa. It has received international financial support and implemented economic reform programs. However, it faces weaknesses such as a weakened democratic transition, a dependence on agriculture, oil, gold, and international aid, persistent human and food insecurity, high unemployment rates, corruption, and a reliance on out-dated technology. The agricultural sector contributes about 32% to GDP, followed by industry (18%) and services (50%).

### *1.2. Problem Statement*

Effective governance, encompassing economic, social, and political dimensions, is vital for growth and development. It should be participatory, accountable, transparent, and guided by legal principles. Poor governance can impede income generation, effective public spending, and trust. The main question is: were the huge investments in development projects supported by effective governance? What is the level of efficiency? What are the main economic policies that affect technical efficiency?

### *1.3. Objectives of the Study*

The objectives of this work are to assess the technical efficiency of the Cobb-Douglas and transcendental logarithmic production function in Sudan using a stochastic frontier approach and to examine the factors contributing to efficiency.

### *1.4. Justification and Scope of the Study*

The government's primary goal is economic growth, which should be evident in societal welfare. The economy should operate at full capacity to achieve the target. Therefore, measuring the technical efficiency of Sudan's economy for the period 1960–2020 is a necessity, using gross domestic product as the primary measure of technical efficiency.

## 2. Current Policies

### *2.1. Sudan's Development Plans*

The 1940s saw the creation of Sudan's first economic plan, an investment program for 1946–1951, and another program for 1951–1956, which succeeded it. However, it is thought that the ten-year plan 61/1962-70/1971 was the first real attempt at planning because it transformed the economic programs from being haphazard to being based on precise quantitative and qualitative goals. The government in 1970–1975, as part of the socialist approach, drafted the first five-year plan. Its principles included centralizing planning and implementation, monopolizing public institutions for investment and commercial activity, and modifying the plan when system orientations changed. According to Aliraqi (2018) the nation accumulated enormous debt early in the 1980s because of several issues, including the unreliability of development projects and the lack of objectivity in their planning. During the 1980s, the government established three-year rolling programs. The Triple Economic Rescue Program of 1990–1993 reinforced the direction of economic openness that the National Salvation Revolution of 1989 initiated. The program's goals were to move the Sudanese economy away from stagnation and toward production, as well as to alter the institutional, financial, and economic structures required to ensure everyone's participation, achieve social balance, and correct distortions in the country's economic structure. The program included privatizing public-sector utilities, attempting to stabilize the exchange rate, cancelling import and export licenses, and lifting all price restrictions. All of these actions helped to break the government-dependent economic stagnation, and by the middle of 1992, the GDP growth rate had increased by roughly 7.4%, mostly due to the notable 25% increase in agricultural production. The collapse of inflation to record levels in 1996 was an obvious indication of his deficiencies in handling the wider economic crisis in Sudan (Aliraqi, 2018). After the Comprehensive National Strategy (1992–2002) failed to achieve its goals, the government introduced the Quarter-Century National Strategy. Both strategies are nearly identical in terms of dimensions, objectives, legal framework, planning reference, and pillars. Naturally, their theoretical frameworks may have drawn inspiration from the Malaysian experience. The former strategy focused on exporting oil. Additionally, the end of the Civil War resulted in increased efficiency.

### *2.2. Fiscal Policy*

Governments use fiscal policy as an important tool to allocate and redistribute resources, especially in developing countries, to offset the private sector's insatiable resource allocation and distribution. It indirectly raises or lowers taxes, causing the economy to spend more or less. Fiscal policy can have a beneficial and negative impact on the economy. Positive government actions, such as infrastructural services, education, health, and Research and Development (R&D), can boost employment and lower unemployment. Negative government actions, such as expenditures on wages and salaries, administration, the military, and security, can also have a negative economic impact. Sudan's government raises funds for public initiatives using both tax and non-tax income. Tax revenue encompasses both direct and indirect taxes, whereas non-tax revenue includes contributions from businesses, banks, pension plans, interest, fees, and public service costs. Oil revenues were a substantial source of federal revenue in the late 1990s and early 2000s (Ahmed, Rahamtalla, & Michael, 2004). The median shares of direct tax and indirect tax in total taxes are 17% and 83%, the maximum 0.45% and 99%, and the minimum 55% and 0.009%. The direct tax share is more dispersed than the indirect tax, where the coefficients of variation are 0.63 and 0.14, respectively. Three chapters cover current expenditures. Chapter 1 covers all government employees' earnings and pay, including the federal government's payments to the Social Security and Pension Funds. Chapter 2 deliberates the items and services



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obtained by government bodies. This type of spending includes social subsidies. The final chapter looks at the Federal Rule Chamber's compensation for state agricultural taxes, as well as current and development contributions to states. The share of ordinary expenditure in total expenditure exhibited a median of 0.87, a maximum of 0.985, a minimum of 0.38, and a coefficient of variation of 0.021. It is worth noting that education and health receive less than 3% of the budget, whereas the top government receives more than 12% in administrative expenditure.

### *2.3. External Sector Policies*

#### *2.3.1. Exchange Rate Devaluation*

Since September 1978, the International Monetary Fund (IMF) has advised Sudan's succeeding administrations to depreciate the Sudanese pound over time to reduce the country's trade imbalance. Even though it did not satisfy the Marshall-Lerner criterion, which stipulates that a nation's total export and import demand elasticities must be greater than one, devaluation proceeded. It is a critical component of the strategy's effectiveness. They did not meet the Marshall-Lerner criterion, which requires that the total of a country's export and import demand elasticities be greater than one. The maximum growth of supply-side forces determines a country's balance-of-payments limit when its growth rate falls below the maximum growth of its economy. This growth rate must be compatible with a current account equilibrium or a sustainable expansion of foreign borrowing.

#### *2.3.2. Foreign Trade Policies*

The Ministry of Foreign Trade has implemented protectionist policies, such as import and export levies. Another option for limiting imports was to use quota systems, which impose import and export licenses as well as restrict foreign currency transactions using unilateral exchange rates. In February 1992, the finance minister liberalized the economy by removing mechanisms like quotas and licensing to ensure the availability of specific items. The country joined the Common Market and the Customs Union of Eastern and Southern Africa (COMESA). According to a former minister, corruption is common in the external sector, including tenders, firm registration, concessions, and exemptions. This results in capital transfers that return to the country as foreign investment, taking advantage of the privileges and exemptions offered to foreign investors, which then facilitate the acquisition of privatized public businesses.

## 3. Literature Review

Rosid, Xuefeng, Hossain, Hasan, and Sultanuzzaman (2021) used stochastic frontier analysis to investigate the relationship between total net worth and GDP in 106 countries from 2009 to 2018. Credit Suisse and the World Bank provided data on net wealth and global development indicators. They discovered that GDP has a negative impact on wealth maximization efficiency. The robust regression analysis demonstrated that imports, broad money, and the exchange rate have a detrimental effect on a country's wealth efficiency, while the country's historical efficiency has a beneficial impact on the succeeding year's efficiency.

Kibara and Balazs (2019) work examines the use of parametric SFA and non-parametric DEA in measuring production efficiency. Researchers prefer parametric SFA because it treats deviations in a random manner, taking measurement mistakes and noise into account. They prefer a one-stage latent class stochastic frontier model over standard SFA models, which assume that all production technologies are homogeneous. The study also demonstrates that easing up on the assumptions of random error independence and symmetry can fix the "wrong skewness" problem in stochastic frontiers. When addressing multicollinearity, a principal-components-based method does not need to omit irrelevant variables.

Fuente-Mella et al. (2020) study on 34 (Organisation for Economic Co-operation and Development) OECD countries from 2003 to 2012, discovered that nations with higher economic growth rates had higher efficiency rankings, with Luxembourg and the United States topping the list. The study discovered that we could evaluate a diverse range of countries over time using an adequate breakdown of total factor productivity (TFP). This split enables an evaluation of not just the contributions of technological advancement and technical efficiency change to long-term growth but also the impact of size and allocated efficiency change.

Auci, Laura, and Manuela (2019) assessed the productivity of 15 European countries by employing the Cobb-Douglas and Translog models. The researchers found that the size of the government has a beneficial impact on efficiency. They used public expenditure as a measure of government size and found that different types of government might have either a positive or negative effect. From a policy standpoint, it is not advisable to reduce public spending to raise GDP.

Pires and Garcia (2012) estimated the World Stochastic Frontier (1950–2000) using an imbalanced panel of output and production components from wealthy and poor nations. Data from Penn World Tables supports the normal truncated distribution assumption. The projected value of technological inefficiency over time is positive, indicating a decreasing pace of technological efficiency.

Yihua (2008) attributed China's irregular economic growth to growing industrial efficiency gaps, a result of government policies and provinces with larger governing bodies, less rigid criteria, more human capital, and international trade operations.

Ali and Hamid (1996) investigated technological advancement and efficiency, as well as their contribution to economic growth and other elements of production, by employing more efficient ways in Pakistan's manufacturing and agriculture sectors. They attempted to quantify technical change, technical efficiency, and productivity using both Hicks neutral technical change and variable, continuous, and discrete technical



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change. Furthermore, this article examines the impact of technological progress on input demand. They discovered technical change occurring at a continual and variable rate.

Margono and Sharma (2004) examined the evolution of technical efficiency and total factor productivity (TFP) in Indonesian provincial economies from 1993 to 2000. They discovered that technological efficiency is only around 50%, with factors such as schooling years and sectorial differences influencing growth. TFP increased between 1.65% and 5.43%, with a 3.59% growth rate.

Walid and Alali (2009) used the Stochastic Production Frontier (SPF) technique to assess a country's technological efficiency and economic performance. They discovered a considerable difference between technological efficiency perceptions and traditional productivity indicators. Institutional elements such as trade openness, state institutions, and political systems all have a substantial impact on global economic performance.

Zwane, Biyase, Maleka, and Maluleka (2020) looked at technological efficiency drivers in Southern African Development Community (SADC) nations from 1985 to 2014. They estimated output efficiency using stochastic frontier analysis and a variety of datasets. The results reveal that labour, capital, and human capital all have a favourable impact on economic growth. Government spending and trade openness have a negative impact on technological efficiency. The analysis suggests that investing in human capital, labour, and technical efficiency will boost economic growth.

Christopoulos and McAdam (2015) study scrutinized technical efficiency in the Middle East and North Africa, and finds that political and social factors, as well as economic indicators, have a major impact on development and frontier efficiency profiles. The study employs a huge data set and robustness checks to provide a thorough baseline for other studies.

Jajri and Ismail (2006) stated that since the 1980s, Malaysia's manufacturing industry has played an important role in economic growth by adding to output and jobs. The government's goal is to have an industrialized nation by 2020. However, productivity has not hit its peak, with growth slower than wages. This research examines technical efficiency, technological change, and total factor productivity (TFP) developments in Malaysia's manufacturing industry. The results suggest that TFP growth is expanding, with food, wood, chemical, and iron items exhibiting high technical efficiency.

Shahabinejad, Zare Mehrjerdi, and Yaghoubi (2013) used Stochastic Frontier Analysis to examine the rise of total factor productivity (TFP) in 44 Asian nations. They discovered that in 75% of these economies, technological development had a negative influence on productivity growth. Japan experienced the highest productivity growth (2.55%), followed by Saudi Arabia, Korea, and Hong Kong. TFP growth in newly independent countries was the slowest due to a lack of technological progress.

Moussir and Liouaeddine (2022) inspected the effect of technological efficiency on economic complexity in developing countries. Using two methods, they discovered that underdeveloped countries produced only 16% of their potential outputs, compared to 51% in high-income countries. The study also indicated that technical efficiency has no substantial impact on economic complexity across regions.

Barasa, Knoben, Vermeulen, Kimuyu, and Kinyanjui (2017) investigated the impact of innovative activities on efficiency in manufacturing enterprises in developing nations. They believe that internal R&D improves efficiency, whereas foreign technology acquisition has the opposite impact. However, combining internal R&D with foreign technology reduces efficiency. The study suggests that domestic R&D may have a dynamic effect on efficiency, whereas poor human capital rates may impede R&D activity and foreign technology adoption.

Alsaleh and Abdul-Rahim (2019) study looked at the impact of economic factors on technical efficiency (TE) rates in the EU-28 bioenergy sector from 1990 to 2013. It found that labour input and GDP have a substantial impact on TE. The findings inspire governors and parliamentarians to look into TE rates, provide insights for bio-energy industry senates, and make recommendations to financiers focused on direct-investment income.

Achirawee and Xu (2018) examined Thailand's GDP efficiency from 1993 to 2017, finding 2017 as the poorest year in terms of efficiency. Data envelopment analysis (DEA) was employed to enhance the evaluation. To increase inputs and GDP, the study recommends eliminating negative values associated with slack movement and supporting export-led growth, company incubators, and entrepreneurship. The report offers strategic advice to Thailand's government on how to increase its GDP.

Wijeweera, Villano, and Dollery (2024) study uses panel data from 1997 to 2004 and a stochastic frontier model to investigate the connection between GDP growth and foreign direct investment (FDI). The findings indicate that while skilled labour from FDI boosts economic growth, corruption has the opposite effect.

Laurits, Dale, and Lawrence (2001) demonstrated the duality between price and quantity and emphasized the significance of additive and homogeneous production possibilities in statistical testing of production theory.

Kumbhakar and Tsionas (2011) discussed recent advancements in efficiency measurement using stochastic frontier (SF) models in various fields. They discussed input-oriented technological efficiency, latent class models, and local maximum likelihood approaches. They highlight recent developments in estimating challenging models and include advancements in other fields.

Romer (1986) study presented specific model of long-term growth, which makes the assumption that knowledge is an input with rising marginal productivity. According to this model of commercial equilibrium, big nations grow more quickly, private agents can magnify minor disruptions, and growth rates can rise over time.



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Rusydiana, Rani, and Cahyono (2021) study examined the Stochastic Frontier Approach (SFA) research on Islamic economics and finance (IEF) using 109 articles. Results show a significant increase in publications from 2009-2019, with the most published in the International Journal of Islamic and Middle Eastern Finance and Management. The SFA application research is divided into four clusters, with cost efficiency being the most widely used.

The state-of-the-art in stochastic frontier analysis (SFA) in econometrics is highlighted in Nguyen (2020) work, which also emphasizes novel research approaches for more reliable and effective outcomes. Although there are still unresolved issues, SFM in microeconomics is helpful for examining regression models and production efficiency. This is the first econometric survey of SFA.

Mastromarco and Ghosh (2009) investigated the effects of R&D spending, imports of machinery and equipment, and foreign direct investment (FDI) on the total factor productivity of emerging nations using stochastic Frontier analysis. They discover that while R&D, capital goods, and FDI increase efficiency, their benefits rely on the amount of human capital that has been acquired. For R&D, formal schooling is increasingly crucial.

Schmidt (2002) comparing various estimation techniques, stated that when estimating production efficiency, stochastic frontier models take maximally or minimally into account. These models' random noise causes a one-sided departure from the frontier, a phenomenon commonly referred to as inefficiency. We also employ data envelopment analysis and other nonparametric methods that do not explicitly incorporate randomness. Both authors, Lovell and Kumbhakar, are prominent figures in the subject; Lovell co-authored important papers, while Kumbhakar was the most significant.

Cornwell and Peter (2008) A production function provides the maximum possible output with inputs, defining a boundary or "frontier" that deviations from can be interpreted as inefficiency. Stochastic frontier analysis (SFA) provides techniques to model the frontier concept within a regression framework, allowing for the estimation of inefficiency. This chapter focuses on estimating production frontiers and measures of technical inefficiency relative to them, using panel data and econometric and statistical detail.

Wang and Schmidt (2002) stated that for stochastic frontier models with one-sided inefficiency u that can be estimated in a single step, this work suggests a class of one-step models. It makes the case that two-step processes are biased and provides Monte Carlo data that demonstrates this. The study makes the case that one-step models are more suited to comprehending how company features affect efficiency levels.

Lovell (1995) examined the econometric methodology for efficiency analysis. He differentiated between the econometric methodology and the mathematical programming methodology. He examined several empirical studies that illustrate the utilization of the econometric approach, particularly in the domains of (1) agricultural productivity, (2) labor market efficiency and equity, (3) standard of living assessment, (4) quality service establishment, and (5) environmental externality evaluation.

This study is relevant to previous research because it employs stochastic frontier analysis to assess the efficacy of the gross domestic product. Beta regression distinguishes the influence of economic policies on the dependent variable, technical efficiency.

## 4. The Methodology

### *4.1. Model Specification*

The data envelope analysis (DEA) technique deterministically measures efficiency, assuming that deviations from ideal output levels are due to inefficiency. Stochastic Frontier Analysis (SFA) uses econometric methods to distinguish between technological inefficiency and random shocks, efficiently identifying both. SFA enables departures from the frontier, allowing for differentiation between random shocks and technical inefficiency. We will use the SFA as the analytical method to estimate Sudan's production function, which depends on two factors of production: labour force and capital. Given the challenges in obtaining comprehensive data on the entire series of capital stock, we opt to use gross fixed capital formation as a substitute. The resulting technical efficiency from Equation 3 will serve as the dependent variable in Equation 5, which I will estimate using beta regression. This is because the dependent variable's technical efficiency values fall between 0 and 1.

$$y_t = \alpha + f(X_{it}\beta) + (v_i - u_i) \quad (1)$$

Equation 1 represents a model where $y_t$ is the logarithm of production for a given period t, $f(X_{it}\beta)$ is the linear production function (CD, Translog), i represents the index for different units, $X_{it}$ is a vector of input variables, $\alpha$ is the frontier intercept, β is an unknown parameter, $u_i$ is a non-negative random variable representing technical inefficiency, assumed to follow a truncated normal distribution with mean μ and variance $\sigma^2$ u, and $v_i$ is a random error assumed to follow an independent and identically distributed normal distribution with mean 0 and variance.$\sigma_v^2$.

Technical efficiency, with the maximum attainable output for given inputs, is:

$$te_t = \frac{y_t}{y_t^*} = \frac{f(X_t;\beta)e^{-u_t}e^{v_t}}{f(X_t;\beta)e^{v_t}} = e^{-u_t} \in [0,1] \quad (2)$$

Equation 3 through 5 comprise the empirical models.

$$logy_t = \alpha + \beta_1 logl_t + \beta_2 logk_t + v_t - u_t;\ v_t \sim N(0, \sigma_v^2);\ u_t \sim F \quad (3)$$

Where y is the output (real GDP), L is the labour force, and k is a proxy for capital stock (Fuente-Mella et al., 2020). Additionally, we assume that variables and Independent and Identically Distributed (IID) are independent across observations. Other options include modified Ordinary Least Squares (OLS) or the generalized method of moments estimators, but Maximum Likelihood (ML) typically provides the best



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estimate for this model because it satisfies the distributional assumption F, which is necessary to identify the inefficiency term. To determine the technical efficiency level, we utilize the command frontier method.

$$frontier\ logy\ logk\ logl, vce(robust) \qquad (4)$$

The predict command $predict\ te,\ te$ will compute the technical efficiency series.

$$(te)_t = \alpha + \beta_1(xdv)_t + \beta_2(itgr)_t + \beta_3(bopr)_t + \beta_4(ordgr)_t \qquad (5)$$

Where $(te)_t$ is the technical efficiency, $(xdv)_t$ is the Sudanese pound devaluation series, $(bopgr)_t$is the ratio of the balance of payments to GDP, which is a proxy for foreign sector policy. The growth rates of indirect tax to revenue $(itgr)_t$ and ordinary expenditure. We selected these variables as the primary determinants of technical efficiency using economic theory and empirical investigation, as presented in the following paragraphs.

The transcendental logarithmic production function (Translog) is an approximation of the constant elasticity of substitution (CES) production function that takes the form of Equation 6 that argues log of output explained by $\log x_i$ and the product $\log x_i \log x_j$ :

$$logy = log\beta_0 + \sum_{i=1}^{n} \beta_i logx_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij}\ logx_i logx_j \qquad (6)$$

The efficiency parameter, the input's output elasticity, and the measure of complementarity between them are all present. The function consists of three components: linear, nonlinear, and interactive. This function is unique in that the level of input determines the marginal product, which represents the addition to the total product resulting from the inclusion of an additional factor.

### *4.2. Empirical Justification for Model Variable Selection*

Economic growth models that build on Kaldor's work argue that the external balance limits total growth. This is because a trade imbalance can only emerge when exports outpace imports, and no nation can sustain a continuous trade deficit. As a result, overall growth is dependent on restoring external balance equilibrium. Kaldor has also noted that, according to Holland, Vieira, and Canuto (2004) there is a positive link between the volume of international trade and economic growth as a stylized fact. However, the exact nature of this correlation remains uncertain.

Indirect taxes have the potential to have a detrimental effect on economic growth by increasing prices, reducing output and circulation, and influencing capital and investment allocation. In addition, these taxes can result in inequitable consumption patterns, as affluent individuals allocate a smaller proportion of their income towards consumer items, while impoverished individuals tend to spend a larger portion of their income on such things. We can reduce or exempt taxes to mitigate their impact on individuals with low incomes. In addition, they can reduce the competitiveness of domestic goods on global markets, which may lead to the implementation of export subsidies. Hence, authorities must ascertain the optimal tax rate to prevent detrimental effects on the economy and investments.

The empirical findings are diverse; some scholars found public spending to play an important role in economic growth, but at the same time, large government size can contribute to lower growth rates. Others hold the belief that reducing spending leads to a reduction in taxes, thereby mitigating distortions and potentially boosting economic efficiency (Auci et al., 2019).

Verifying the continued applicability of stochastic frontier analysis requires extensive diagnostic testing using two statistics. We can split the overall variance of the error term into two halves. Both the inefficiency component $\sigma_u^2$, and the random component $\sigma_v^2$ contribute to the variance $\sigma^2 = \sigma_u^2 + \sigma_v^2$. The Gamma statistic $\gamma = \frac{\sigma_u^2}{\sigma^2}$ represents the fraction of output attributed to technical inefficiency and ranges from zero to one. The calculation entails dividing the technical inefficiency component's variance by the overall error term's variance. If it is close to one, it simply signifies that the technical inefficiencies account for a large amount of variation, and the SF model is the best fit. Finally, if it is near zero, it simply indicates that technological inefficiencies account for very little variation. Therefore, estimating the stochastic frontier will be unfeasible due to the significant influence of chance.

Kumbhakar, Wang, and Homcastle (2015) advise against using this measure to evaluate the SF model's relevance. We may use a likelihood-ratio test statistic to estimate two models: the restricted Cobb-Douglass model (estimated by glm) and the unrestricted stochastic frontier$-2 * (L(H_r) - L(H_{ur}))$. When calculating this statistic, we compare it to the vital values stated in Kodde and Palm (1986). The critical values for one degree of freedom are 5.412 at 1% and 6.635 at 5%. The null hypothesis ($H_0$) states that there are no technical inefficiencies.

## 5. Results and Discussion

### *5.1. Data Requirement*

I gathered data from four sources: the Central Bureau of Statistics, the Central Bank of Sudan, the Ministry of Finance, and the World Bank, covering the period 1960 to 2020. The sample includes seven variables: real GDP (Y), the labour force (L), and gross fixed capital formation as a proxy for capital stock (K). In addition, a dummy variable represents the series of exchange rate depreciation (xdv), the growth rate of indirect tax (itgr), the growth rate of ordinary (current) expenditure (ordgr), and the ratio of the balance of payments to GDP (bopr). Moreover, the SFA produces technical efficiency (tef).



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### *5.2. Descriptive Statistics*

According to the data presented in the table the variable that exhibits the greatest degree of dispersion is the logarithm of gross fixed capital formation. Next in line are the ratios of the balance of payments to GDP and the budget deficit to GDP. The ratio of the balance of payments to the gross domestic product had the greatest range, followed by the ratio of routine expenditures to the percentage of GDP had the smallest range.

Table 1 presents descriptive statistics.

**Table 1.** Descriptive statistics.

| Variable | Observations | Mean | Std. dev. | Min. | Max. |
|---|---|---|---|---|---|
| logy | 61 | 9.29 | 0.696 | 8.41 | 10.640 |
| logk | 61 | 12.81 | 5.521 | 6.06 | 22.103 |
| logl | 61 | 6.95 | 0.381 | 6.28 | 7.584 |
| ordgr | 61 | 0.61 | 2.398 | -0.88 | 18.728 |
| te | 61 | 0.81 | 0.077 | 0.08 | 0.359 |
| itgr | 61 | 0.501 | 1.553 | -0.879 | 11.434 |
| bopr | 61 | -4.19 | 4.343 | -21.61 | 2.855 |

While the logarithms of output and labour force are the most widely distributed, the mean logarithm of capital is the highest. Ordinary government spending has a somewhat faster average growth rate than indirect taxes, but it is more widely distributed. The balance of payments is growing at a negative mean rate and is spread out more than regular spending. The average technical efficiency is 0.81.

The first difference is that the augmented Dickey-Fuller and Phillips-Perron unit root tests show that all variables are stationary except for the capital stock proxy and the ratio of the balance of payments to GDP.

The balance of payments is static, while the capital stock proxy is stationary via the NG-Perron unit root test. Johansen's cointegration tests reveal the existence of two integration equations involving the variables in Equation 3. This suggests a long-term relationship between output, labour force, and capital stock. At a critical value of 5%, the trace statistic of 0.99 is statistically significant. Equation 5 looks at the relationship between technological efficiency, the series of exchange rate devaluations, the growth rates of indirect taxes and ordinary expenditures, and the balance of payments to GDP. At 5%, the trace statistic (46.98) is statistically significant. The augmented Dickey-Fuller test statistic for cointegration with a structural break for equations two and four (-7.02, -6.91) is bigger than the asymptotic critical value (-5.86, -6.84) at 5% in the Gregory-Hansen cointegration test with breaks (Gregory & Hansen, 1996). This means that the null hypothesis of no cointegration is not true. The breakpoint is the forty-third, and the date of the increase in oil production and exports is 2002 (Annex). The variables in Equation 3 are not collinear because the variance inflation (VIF) factor test reveals that both gross fixed capital formation and labour force have a value of 1.49, which is less than the number 5. This indicates that the variables in Equation 2 are not collinear. Here are the variance inflation factors for the variables in Equation 5. The growth rates of indirect tax and ordinary spending are both 1.20, the ratio of the balance of payments to GDP is 1.17, and the exchange devaluation series is 1.13. This means that there is no evidence of multicollinearity between the variables. The VIF, on average, is 1.17.

Table 2 presents empirical results of Equation 2 and 5.

**Table 2.** Empirical results of Equation 2 and 5.

| Cobb Douglas production function | | | | |
|---|---|---|---|---|
| **Logy** | **Coefficient** | **Z** | **Coefficient** | **Z** |
| Frontier | | | | |
| logk | 0.124*** | 7.6e+07 | -0.753*** | -3.62 |
| logl | 0.121*** | 5.7e+07 | 3.337*** | 9.49 |
| Logksq | - | - | 0.001 | 0.08 |
| loglsq | - | - | -0.623*** | -5.18 |
| Logl*logk | - | - | 0.239*** | 2.94 |
| Constant | 7.117*** | 5.5e+07* | - | - |
| /lnsig2v | - | -454.080 | -38.333*** | - |
| /lnsig2u | - | -16.300 | -2.501*** | - |
| sigma_v | - | - | 4.74e-09 | - |
| sigma_u | - | - | 0.2863 | - |
| sigma$^2$ | - | - | 0.082 | - |
| lamda | - | - | 6.04e+07 | - |

**Note:** The symbol (*) indicates a rejection of the null hypothesis at 10%, (**) indicates a rejection at 5%, and (***) indicates a rejection at 1%.
LR test of sigma_u=0 chibar$^2$(01) = 0.90, Prob >= chibar2 = 0.171; (-) means not applicable.
The scientific number is represented by the letter e to indicate 10 raised to the power: 5.5e+07 = $5.5 \times 10^7$.



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Because they are positive and substantially different from zero, the estimated capital and labour coefficients are consistent with economic theory. The gamma statistic, which shows a near-one ratio of inefficiency variance to total variance, suggests that stochastic frontier analysis is relevant. At 1% and one degree of freedom, the likelihood ratio is more than 5.412; hence, we reject the null hypothesis of no technical inefficiencies, as stated in Kodde and Palm (1986).

After that, we used Equation 4 to make predictions about the technical efficiencies, and Figure 1 shows the outcome. The LR test rejects the null hypothesis that the inefficiency's standard deviation (sigma_u) equals zero at 1%, confirming the applicability of frontier analysis, since the probability associated with the Chi-square test is 0.000 while accepting that of Translog. The graph of Equation 5 variables illustrates that the growth rate of indirect tax and ordinary tax hit its peak in 2003, coinciding with the lowest level of technical efficiency. Despite fluctuations in the balance of payments ratio to GDP, it is stationary, with a constant and linear trend.

Table 3 displays the results of equation 5.

**Table 3.** Results of Equation 5.

| te | Coefficient | Robust std. err. | z | P>\|z\| |
|---|---|---|---|---|
| xdv | -0.651 | 0.227 | -2.87 | 0.004 |
| itgr | -0.199 | 0.080 | -2.50 | 0.012 |
| ordgr | -0.044 | 0.015 | -2.96 | 0.003 |
| bopr | -0.065 | 0.025 | -2.55 | 0.011 |
| Constant | 1.598 | 0.167 | 0.167 | 0.000 |
| Scale | | | | |
| xdv | 1.518 | 0.373 | 4.07 | 0.000 |
| Constant | 1.192 | 0.242 | 4.93 | 0.000 |

The frequency of exchange rate devaluation (xdv) is a scalar for two reasons. Firstly, we feel that it affects the variability of the calculated average, and secondly, it enhances the relevance of the covariates. The results of the margins test indicate that a one-period increase in the devaluation series leads to a 3% decrease in technical efficiency. A 1% increase in indirect taxes results in a 2% decrease in technological efficiency. An increase of 1% in the ordinary expenditure growth rate results in a corresponding decrease of 1% in technical efficiency. Nevertheless, a 1% increase in the balance of payments ratio results in a 3% improvement in technical efficiency.

Indirect taxes (itgr), ordinary expenditures (ordr), exchange rate devaluation, and technical efficiency (te) have an inverse relationship according to the conditional mean of technical efficiency (te) tested by the margins command. Conversely, the balance of payments positively correlates with technical efficiency.

### *5.4. Discussion*

Although the Cobb-Douglas production function violates the constancy of return to scale, the study favoured it over the transcendental logarithmic production function for three reasons. The null hypothesis is initially accepted by the study, which asserts that the sigma of u (technical efficacy) is zero. Subsequently, the logarithm of the capital sign is incorrect. Thirdly, the squared logarithm of capital is not statistically significant. As a consequence, the scale return decreased as a result of the estimation. The results found the Sudanese economy to be inefficient, implying that there is potential for growth of around 20% on average. Except for the first two years (1960 and 1961) in the sample period, technical efficiencies remained above 0.96 for eight years. This period coincided with the 10-year development plan's implementation. Several large projects were established. Only this period has seen a surplus budget and a balance of payments. The government fixed the exchange rate at 2.83 US dollars for one Sudanese pound. One of the negative aspects of this period was the increasing budget deficit in the second half of the decade, which escalated to 7% of GDP. This included the cost of debt-to-GDP increases, principal repayment, and debt service.

The following ten years saw an oscillation of technical efficiencies around the downward trend. During this period, poor implementation of the five-year plan resulted in its extension for an additional two years. The main economic policies were the confiscations and nationalization of foreign-owned businesses and schemes, which resulted in a contraction in the performance of the real GDP, an increase in imports with fewer exports, and a deteriorating balance of payments, which reached 9% of GDP at the end of the five-year plan. Despite this, the government set the exchange rate at 2.83. After two years, the government abandoned the six-year strategy because it failed to implement it. The debt ratio continued to rise, exceeding GDP, with implications for principal repayment and debt servicing that compounded the budget deficit.

In September 1978, the IMF suggested devaluing the currency rate to cover balance-of-payments deficits. Since then, there have been a series of devaluations, along with alternating technical efficiency around the decreasing trend, until the first shipment of oil in late 1999. Civil wars and environmental disasters influenced Sudan's economic performance. The end of the civil war in 2005 signalled the start of an increasing trend in technological efficiency. The fiscal policy over the sample period relied heavily on indirect tax and service fees, which constituted about two-thirds of government revenue. This problem did not encourage production.

Indirect taxes have a negative impact on the economy due to inadequate tax administration. Regardless of their income, all residents are subject to an indirect tax that includes excise duties, customs duties, and value-added. Indirect taxes increase production costs, reduce demand and supply, and create disparities between



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sectors and people. However, some groups are exempt from this tax based on their ethnicity or political affiliation. Customs duties impose taxes on vehicles and equipment at rates exceeding 350%. In addition, export taxes have diminished export competitiveness due to prolonged procedures, time-consuming processes, and multiple rates. Hence, authorities must ascertain the optimal tax rate to prevent any adverse effects on the economy and investment.

Conversely, the allocation of over two-thirds of public expenditure to military forces and security, at the expense of development expenditure, accounts for the adverse effects of the beta regression results. The 1990s implementation of the federal system led to a significant increase in government size. This system has created new states, ministries, and municipalities, resulting in a decrease in development spending and an increase in administration spending. When the government resorts to deficit finance and money printing, spending indirectly affects the economy by increasing inflation. Inadequate governance and corruption can weaken the state's capacity to collect revenue, reduce equity and efficiency of public expenditure, discourage private investment, and create inflation (Olusegun, Qiaoe Chen, & Marta, 2020).

## 6. Conclusions and Recommendations

### *6.1. Conclusions*

The study investigated the technical efficiency of Sudan's economy for the period 1960–2020. The variance inflation factor demonstrated that the model variables are not collinear. The Gregory-Hansen test for cointegration with structural breaks in 2002 confirmed the long-term relationship between the model variables. The study employed stochastic frontier analysis to examine the efficiency of Sudan's economy by estimating two production functions, the Cobb-Douglas and the Transcendental production functions. The Cobb-Douglas production function performed better than the Translog, which was unable to reject the null hypothesis that the technical efficiency term is not different from zero. The squared capital is not significant in terms of squared capital and the negative capital sign. The results of an investigation using beta regression to detect factors that affect efficiency indicate that both fiscal policy and exchange rate policy have an adverse impact on technical efficiency. Nevertheless, the presence of several tax rates and the implementation of multiple currency practices provide obstacles to business operations. Since 1990, the widespread prevalence of corruption, lack of accountability, transparency, and rule of law have had a significant impact on technical efficiency, as fiscal and foreign trade policies favoured the ruling party and its members, while the number of deprived people has steadily increased as a result of the adoption of economic policies, particularly after the announcement of the liberalization package. The fiscal structure exhibits deficiencies in both transparency and data quality. Contractual monitoring and digitization impede project monitoring. These governance weaknesses increased corruption and eroded public confidence in the administration.

### *6.2. Policy Recommendations*

#### *6.2.1. Revision of Liberalization Policies*

The economic liberalization policy reduced the states' grip on economic activity by easing or removing laws and administrative restrictions to enable the private sector. Examples of these policies include tax reform, market liberalization, market freedom, trade liberalization, foreign investment, privatization, and the massive devaluation of the exchange rate. These policies have led to a surge in inflation, a decline in food stability, poverty, and production, persistent deficits in the trade balance, and a negative balance of payments. Thus, there is a need for sustainable growth through increased production and productivity through the rehabilitation of schemes and, the replacement of outdated technology with a modern one, in addition to reverting to liberalization policies.

#### *6.2.2. Exchange Rate*

The stability of the exchange rate is one of the government's main goals, but the submission to the IMF and the World Bank's recommendations resulted in continuous depreciation. Empirical studies revealed that the money supply and the current account balance influence the exchange rate. Exporting finished or semi-finished goods boosts their value, reducing the trade deficit balance on the one hand and supporting economic growth by creating new jobs on the other. We recommend reducing private luxury imports, as well as government purchases, and establishing an import substitution policy. We also recommend curbing deficit financing, government imports, and boosting locally produced vehicles and furniture. Similarly, reforming diplomatic missions can help reduce current account balance deficits. In the oil sector, transparency is crucial, as the cloudy nature of oil proceeds necessitates the transparency of the export of crude oil, its products, and minerals, particularly gold, which can significantly contribute to the building of foreign exchange reserves. The government should also revise its policy on gold production and establish a fair purchase rate that aligns with global prices.

#### *6.2.3. Tax Reform*

Various modifications to taxation systems, such as modifications to rates, exemptions, deductions, allowances, and other features, are encompassed by the term "tax reform." Tax reform is a critical policy instrument that governments can employ to promote economic growth, reduce tax burdens, and stimulate investment. Providing incentives for individuals to invest in productive activities can encourage investment and entrepreneurship by reducing marginal tax rates. Similarly, the elimination of specific deductions or



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credits can result in a more efficient allocation of resources and reduce distortions in the economy. An economic equilibrium between direct and indirect taxes is essential for sustainable development and equity.

#### *6.2.4. Government Expenditure Reform*

Sudan could potentially reduce disparities and efficiently deliver essential services to vulnerable communities, as well as address the underlying causes of conflict through the redistribution of public expenditure. The government should reduce the share of current expenditure and prioritize development expenditure instead. States continue to differ significantly in terms of poverty levels and development disparities; therefore, balanced growth should be the main goal of the federal government. The government should take into account the significant variations in each state's ability to generate money as well as the distribution of fiscal spending among states that reflect these regional imbalances.

#### *6.2.5. Balance of Payments*

The persistent deficits in the balance of payments primarily stem from the export of raw products like oil seeds, minerals, crude oil, and live animals. If there is a genuine desire to enhance local production, the government should opt to offset the import of consumer goods. Enhance the value of exports and limit luxury imports to increase their worth. The services account should be revised. The government also needs to address the proper pricing of export goods, prevent export smuggling, and harmonize the various levels of the Central Bank of Sudan's regulation of the foreign exchange market. The multiplicity of regulation circulars could lead to unfavourable outcomes, such as an increase in parallel market transactions and a surge in demand for foreign exchange resources. The approval of the advance payment in the regulation circular will prompt exporters to purchase foreign exchange on the black market for their goods, thereby exacerbating smuggling issues and depleting the country's foreign exchange reserves. The exportation of female livestock should be prohibited and criminalized because it affects directly the number of births.

#### *6.2.6. Corruption and Law Enforcement*

Authority is an effective tool for corruption, creating an environment that fosters and protects fraudulence. It encourages and supports corruption's spread and expansion. Corruption develops into a robust network that regulates legislation, prosecution, and accountability. When political, moral, and national systems fail, corrupt institutions attract vulnerable and dishonest individuals, resulting in poverty and illiteracy. Various methods of making money may lead to corruption. As previously stated, Sudan's lack of openness and accountability promotes extensive corruption. The Corruption Perceptions Index (CPI) found that in most periods, perceived levels of public sector corruption scored 173 out of 180, particularly in the second half of the sample period. The Auditor General's report reveals that there is no accountability for fraudsters' annual cash misuse. Enforcement of the law is a priority.

**Abbreviations**

| Symbol | Description |
|---|---|
| CD | Cobb Douglas Production Function. |
| Translog | Transcendental Logarithmic Production Function. |
| logy | Logarithm of Real GDP. |
| Logl | The logarithm of the labour force. |
| logk | The logarithm of gross fixed capital formation (Capital). |
| Te | Technical Efficiency. |
| Xdv | Series of Exchange Rate Devaluation. |
| Itgr | Indirect Tax Growth Rate. |
| ordgr | Ordinary (Current) Expenditure Growth Rate. |
| bopr | Balance of Payments ratio to GDP. |
| Lsq | Squared logarithm of Labor Force. |
| Ksq | Squared logarithm of Capital. |
| Lk | Interaction between logarithms of labour and capital. |
| TFP | Total Factor Productivity. |
| VIF | Variance Inflation Factor. |
| LR | Likelihood Ratio. |

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Annex 1 shows the results of the Gregory-Hansen cointegration test of equation variables. The null hypothesis of the Gregory-Hansen test states that there is no cointegration, in contrast to the alternative of cointegration with a single shift at an unknown point in time. According to the provided values of the three test statistics, we reject the null hypothesis of no cointegration, and accept that there is cointegration with a single shift at unknown point in time.

**Annex 1.** Gregory-Hansen test for cointegration with regime shifts.

Model: Change in regime and trend    Number of obs. = 61
Lags = 0 chosen by downward t-statistics    Maximum Lags = 2

| Equation 2 | Test statistic | Breakpoint | Date | Asymptotic critical values | | |
|---|---|---|---|---|---|---|
| | | | | 1% | 5% | 10% |
| ADF* | -7.02 | 43 | 2002 | -6.45 | -5.96 | -5.72 |
| Zt | -7.03 | 43 | 2002 | -6.45 | -5.96 | -5.72 |
| Za | -49.65 | 43 | 2002 | -68.43 | -100.47 | -63.10 |

**Note:** *ADF stands for augment dickey fuller.

In contrast to the alternative, which proposes cointegration with a single shift at some undetermined moment in time, the null hypothesis of the Gregory-Hansen test indicates that no cointegration exists. Below this paragraph, in Annex 2, we can see the outcomes of the Gregory-Hansen test for equation variable cointegration. We reject the null hypothesis that there is cointegration with a single shift at an unknown point in time, based on the values of the three test statistics that were presented.

**Annex 2.** Gregory-Hansen test for cointegration with regime shifts.

Model: Change in Regime and Trend    Number of obs. = 61
Lags = 1 chosen by downward t-statistics    Maximum Lags = 2

| Equation 4 | Test statistic | Breakpoint | Date | Asymptotic critical values | | |
|---|---|---|---|---|---|---|
| | | | | 1% | 5% | 10% |
| ADF | -6.91 | 43 | 2002 | -7.31 | -6.84 | -6.58 |
| Zt | -6.43 | 45 | 2004 | -7.31 | -6.84 | -6.58 |
| Za | -42.76 | 44 | 2004 | -100.69 | -100.47 | -82.30 |

Figure 1 illustrates the shares of direct and indirect tax to the total tax, as well as the share of ordinary government expenditure to the total expenditure. The indirect tax share significantly surpasses the direct tax share and exhibits a strong upward trend in relation to government ordinary expenditure. However, the direct tax shares show a downward trend.

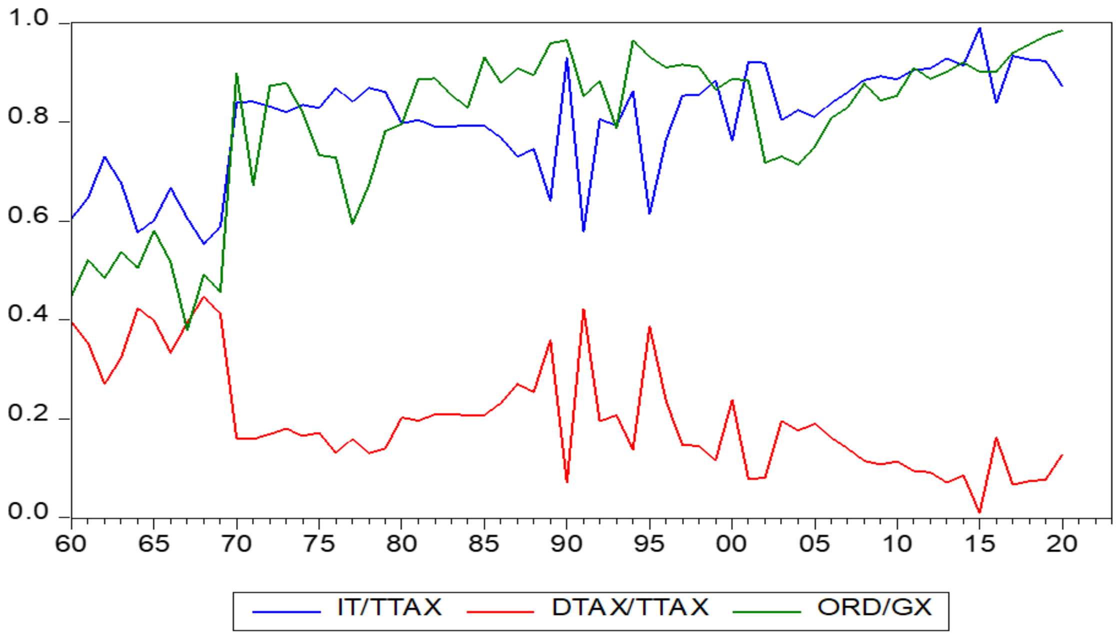


**Figure 1.** Share of direct and indirect tax in total tax.



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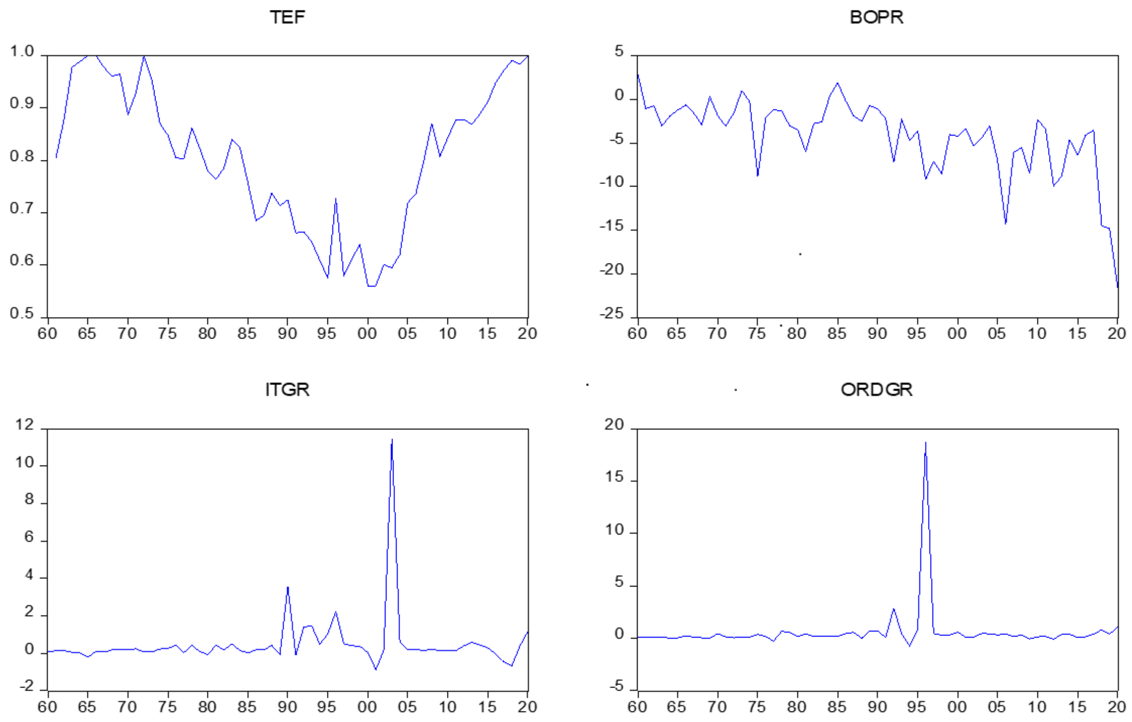


Figure 2. Variables of Equation 5.

Figure 2 depicts the remaining model variables, indicating a declining trend in the share of the balance of payments to GDP, while the growth rate of indirect tax and ordinary expenditure exhibits an anomaly in 2002, coinciding with the signing of the peace treaty that concluded the civil war. Technical efficiency demonstrates a downward trend from 1965 to 2004, followed by an upward trend in subsequent years.

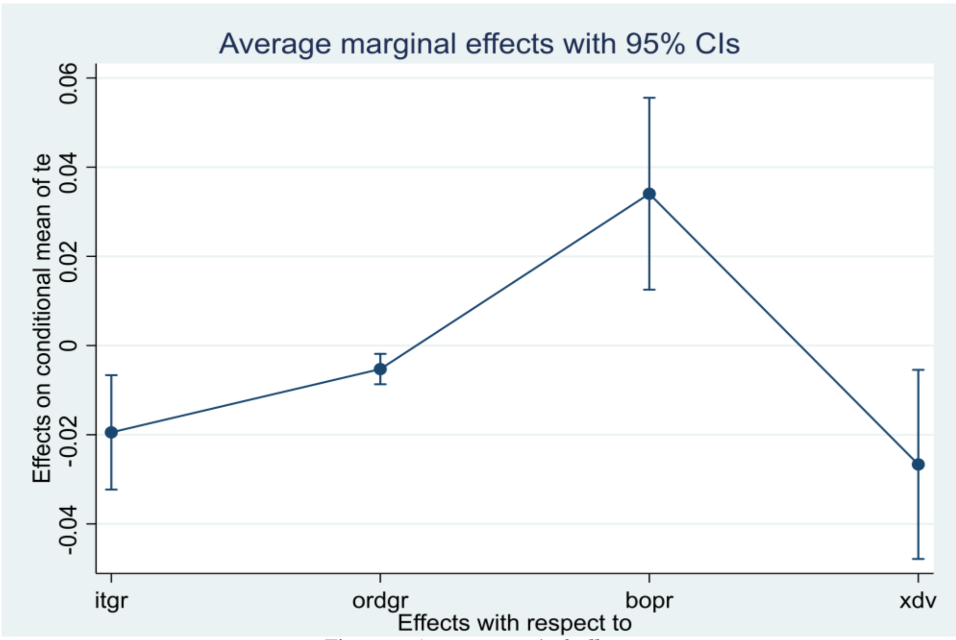


Figure 3. Average marginal effects.

Figure 3 presents that the exchange rate devaluation has the lowest average marginal effect at 95% confidence limits, followed by the growth rate of ordinary expenditure, while the ratio of the balance of payments to GDP has the most average marginal effect.

Annex 3 provides the time series of the ratios of direct and indirect tax to total tax, as well as the ratio of ordinary expenditure to total expenditure for the period 1960–2020.



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**Annex 3.** Explanation of the direct, indirect and current shares.

| Year | IT/TTAX | DTAX | ORD/GX | te |
|---|---|---|---|---|
| 1960 | 0.605 | 22.000 | 0.449 | 0.805 |
| 1961 | 0.647 | 21.000 | 0.522 | 0.877 |
| 1962 | 0.730 | 16.200 | 0.485 | 0.978 |
| 1963 | 0.676 | 22.000 | 0.537 | 0.989 |
| 1964 | 0.577 | 34.000 | 0.505 | 1.000 |
| 1965 | 0.601 | 24.000 | 0.581 | 1.000 |
| 1966 | 0.667 | 20.000 | 0.516 | 0.978 |
| 1967 | 0.606 | 27.600 | 0.379 | 0.961 |
| 1968 | 0.553 | 40.200 | 0.492 | 0.965 |
| 1969 | 0.588 | 41.200 | 0.456 | 0.887 |
| 1970 | 0.840 | 13.200 | 0.898 | 0.928 |
| 1971 | 0.841 | 16.200 | 0.672 | 1.000 |
| 1972 | 0.831 | 18.500 | 0.873 | 0.953 |
| 1973 | 0.820 | 21.400 | 0.878 | 0.871 |
| 1974 | 0.835 | 23.600 | 0.819 | 0.848 |
| 1975 | 0.828 | 30.900 | 0.733 | 0.805 |
| 1976 | 0.869 | 32.200 | 0.728 | 0.803 |
| 1977 | 0.841 | 41.700 | 0.594 | 0.862 |
| 1978 | 0.869 | 47.100 | 0.673 | 0.822 |
| 1979 | 0.860 | 55.000 | 0.781 | 0.779 |
| 1980 | 0.797 | 79.900 | 0.796 | 0.764 |
| 1981 | 0.804 | 109.000 | 0.887 | 0.785 |
| 1982 | 0.791 | 139.000 | 0.888 | 0.840 |
| 1983 | 0.791 | 207.000 | 0.855 | 0.825 |
| 1984 | 0.793 | 236.000 | 0.829 | 0.758 |
| 1985 | 0.792 | 241.000 | 0.931 | 0.685 |
| 1986 | 0.768 | 324.000 | 0.879 | 0.695 |
| 1987 | 0.730 | 470.000 | 0.908 | 0.738 |
| 1988 | 0.746 | 613.000 | 0.895 | 0.713 |
| 1989 | 0.641 | 950.000 | 0.959 | 0.725 |
| 1990 | 0.930 | 585.414 | 0.966 | 0.662 |
| 1991 | 0.578 | 5108.713 | 0.852 | 0.663 |
| 1992 | 0.805 | 4099.791 | 0.883 | 0.644 |
| 1993 | 0.793 | 10815.460 | 0.787 | 0.609 |
| 1994 | 0.862 | 9816.357 | 0.965 | 0.576 |
| 1995 | 0.614 | 78795.580 | 0.932 | 0.727 |
| 1996 | 0.765 | 124167.100 | 0.910 | 0.580 |
| 1997 | 0.853 | 104737.100 | 0.916 | 0.612 |
| 1998 | 0.854 | 144799.800 | 0.911 | 0.639 |
| 1999 | 0.884 | 154812.800 | 0.865 | 0.561 |
| 2000 | 0.762 | 381000.000 | 0.887 | 0.561 |
| 2001 | 0.922 | 147200.000 | 0.884 | 0.601 |
| 2002 | 0.919 | 172500.000 | 0.718 | 0.595 |
| 2003 | 0.804 | 523000.000 | 0.731 | 0.620 |
| 2004 | 0.824 | 740000.000 | 0.714 | 0.719 |
| 2005 | 0.810 | 951000.000 | 0.750 | 0.737 |
| 2006 | 0.838 | 951000.000 | 0.808 | 0.800 |
| 2007 | 0.860 | 916500.000 | 0.829 | 0.871 |
| 2008 | 0.885 | 884300.000 | 0.878 | 0.808 |
| 2009 | 0.893 | 930200.000 | 0.843 | 0.844 |
| 2010 | 0.886 | 1136000.000 | 0.853 | 0.877 |
| 2011 | 0.905 | 1061200.000 | 0.910 | 0.878 |
| 2012 | 0.908 | 1432600.000 | 0.887 | 0.869 |
| 2013 | 0.929 | 1713700.000 | 0.902 | 0.888 |
| 2014 | 0.914 | 3016800.000 | 0.920 | 0.912 |
| 2015 | 0.991 | 398000.000 | 0.902 | 0.949 |
| 2016 | 0.838 | 7678000.000 | 0.902 | 0.971 |
| 2017 | 0.933 | 4270000.000 | 0.939 | 0.991 |
| 2018 | 0.926 | 6791000.000 | 0.957 | 0.983 |
| 2019 | 0.923 | 9377000.000 | 0.974 | 1.000 |
| 2020 | 0.873 | 20354000.000 | 0.985 | 0.894 |



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Annex 4 displays the model variable's time series from 1960 to 2020. The variables are in logarithmic form.

**Annex 4.** Model variables

| Year | ordgr | bopr | logy | logl | logk |
|---|---|---|---|---|---|
| 1960 | 0.072 | 2.846 | 8.409 | 6.281 | 6.061 |
| 1961 | 0.086 | -1.068 | 8.506 | 6.304 | 6.128 |
| 1962 | 0.071 | -0.717 | 8.629 | 6.327 | 6.219 |
| 1963 | 0.134 | -3.039 | 8.645 | 6.349 | 6.234 |
| 1964 | 0.010 | -1.932 | 8.660 | 6.371 | 6.249 |
| 1965 | 0.019 | -1.232 | 8.663 | 6.393 | 6.253 |
| 1966 | 0.234 | -0.662 | 8.646 | 6.414 | 6.270 |
| 1967 | 0.108 | -1.567 | 8.632 | 6.435 | 6.285 |
| 1968 | 0.050 | -2.914 | 8.650 | 6.455 | 6.369 |
| 1969 | 0.034 | 0.290 | 8.569 | 6.484 | 6.372 |
| 1970 | 0.447 | -1.876 | 8.620 | 6.504 | 6.401 |
| 1971 | 0.130 | -3.059 | 8.704 | 6.523 | 6.458 |
| 1972 | 0.050 | -1.569 | 8.680 | 6.550 | 6.623 |
| 1973 | 0.121 | 1.004 | 8.613 | 6.569 | 6.799 |
| 1974 | 0.102 | -0.265 | 8.623 | 6.541 | 7.128 |
| 1975 | 0.393 | -8.830 | 8.599 | 6.585 | 7.320 |
| 1976 | 0.148 | -2.067 | 8.627 | 6.629 | 7.522 |
| 1977 | -0.253 | -1.180 | 8.730 | 6.655 | 7.758 |
| 1978 | 0.681 | -1.338 | 8.712 | 6.694 | 7.966 |
| 1979 | 0.539 | -3.045 | 8.678 | 6.732 | 8.088 |
| 1980 | 0.169 | -3.530 | 8.687 | 6.771 | 8.287 |
| 1981 | 0.407 | -5.998 | 8.745 | 6.810 | 8.507 |
| 1982 | 0.178 | -2.794 | 8.859 | 6.833 | 8.859 |
| 1983 | 0.234 | -2.597 | 8.880 | 6.844 | 0.234 |
| 1984 | 0.162 | 0.349 | 8.828 | 6.910 | 0.162 |
| 1985 | 0.175 | 1.905 | 8.764 | 6.946 | 0.175 |
| 1986 | 0.458 | -0.209 | 8.816 | 6.983 | 0.458 |
| 1987 | 0.557 | -1.897 | 8.949 | 7.001 | 0.557 |
| 1988 | -0.003 | -2.491 | 8.946 | 7.006 | -0.003 |
| 1989 | 0.700 | -0.696 | 9.031 | 7.012 | 0.700 |
| 1990 | 0.733 | -1.107 | 8.975 | 7.011 | 0.733 |
| 1991 | 0.061 | -2.162 | 9.044 | 7.009 | 0.061 |
| 1992 | 2.859 | -7.198 | 9.111 | 7.018 | 2.859 |
| 1993 | 0.454 | -2.277 | 9.156 | 7.037 | 0.454 |
| 1994 | -0.715 | -4.703 | 9.166 | 6.904 | -0.715 |
| 1995 | 0.877 | -3.615 | 9.534 | 6.947 | 0.877 |
| 1996 | 18.728 | -9.167 | 9.400 | 6.991 | 18.728 |
| 1997 | 0.467 | -7.089 | 9.519 | 7.034 | 0.467 |
| 1998 | 0.299 | -8.502 | 9.606 | 7.076 | 0.299 |
| 1999 | 0.288 | -4.036 | 9.485 | 7.113 | 0.288 |
| 2000 | 0.591 | -4.224 | 9.509 | 7.147 | 0.591 |
| 2001 | 0.097 | -3.321 | 9.608 | 7.170 | 0.097 |
| 2002 | 0.100 | -5.368 | 9.632 | 7.191 | 0.100 |
| 2003 | 0.468 | -4.395 | 9.691 | 7.212 | 0.468 |
| 2004 | 0.434 | -3.071 | 9.868 | 7.234 | 0.434 |
| 2005 | 0.315 | -7.028 | 9.918 | 7.258 | 0.315 |
| 2006 | 0.410 | -14.351 | 10.017 | 7.282 | 0.410 |
| 2007 | 0.183 | -6.052 | 10.119 | 7.306 | 0.183 |
| 2008 | 0.306 | -5.543 | 10.061 | 7.329 | 0.306 |
| 2009 | -0.075 | -8.448 | 10.121 | 7.351 | -0.075 |
| 2010 | 0.149 | -2.327 | 10.184 | 7.371 | 0.149 |
| 2011 | 0.183 | -3.384 | 10.205 | 7.390 | 0.183 |
| 2012 | -0.081 | -9.904 | 10.228 | 7.409 | -0.081 |
| 2013 | 0.377 | -8.818 | 10.294 | 7.428 | 0.377 |
| 2014 | 0.392 | -4.615 | 10.362 | 7.448 | 0.392 |
| 2015 | 0.089 | -6.426 | 10.430 | 7.468 | 0.089 |
| 2016 | 0.234 | -2.597 | 8.880 | 6.844 | 0.234 |
| 2017 | 0.162 | 0.349 | 8.828 | 6.910 | 0.162 |
| 2018 | 0.175 | 1.905 | 8.764 | 6.946 | 0.175 |
| 2019 | 0.458 | -0.209 | 8.816 | 6.983 | 0.458 |
| 2020 | 0.557 | -1.897 | 8.949 | 7.001 | 0.557 |



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