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A FINANCE-THEORETIC MATHEMATICAL MODEL FOR OPTIMAL TAXATION IN NIGERIA'S DIGITAL ECONOMY: REVENUE MAXIMIZATION AND COMPLIANCE STRATEGIES

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Abstract

The increasing prominence of Nigeria's digital economy necessitates a theoretical re-evaluation of taxation policies to address compliance challenges and revenue optimization. Traditional tax structures, designed for physical transactions, fail to adequately capture income from digital platforms, leading to inefficiencies and potential revenue losses. This study presents a purely theoretical framework for optimal digital taxation, formulating a mathematical model grounded in game theory, behavioral economics, and differential equations. By modeling taxpayer utility functions and evasion dynamics, the study derives an optimal tax rate that maximizes compliance while ensuring revenue sustainability. A stability analysis of taxation policies is conducted, exploring equilibrium conditions for tax enforcement and the role of audit probabilities and penalty structures in minimizing evasion. Furthermore, theoretical insights into AI-driven tax audits and blockchain-based compliance mechanisms are discussed as potential enforcement strategies. Sensitivity analysis illustrates the adaptability of tax policies to economic fluctuations, ensuring long-term efficiency. This research contributes to the theoretical foundation of digital taxation, offering insights into how governments can design self-sustaining tax policies without reliance on empirical data. The findings provide policymakers with a strategic framework for tax optimization in the evolving digital economy.

Keywords: Digital Taxation, Theoretical Modeling, Tax Compliance, Optimal Taxation, Game Theory, Block chain Enforcement

1. Introduction

The rapid expansion of the digital economy has fundamentally transformed global trade, commerce, and financial transactions, creating significant challenges for tax authorities. In Nigeria, the rise of e-commerce, fintech, digital services, and cryptocurrency transactions has introduced new complexities in tax collection and enforcement (OECD, 2020). Traditional tax systems, which were designed for tangible goods and location-based businesses, are now struggling to adapt to a borderless digital market where revenue is generated without a physical presence (Hamid, 2025).

Nigeria's economy remains heavily reliant on oil revenue, making tax diversification critical for fiscal sustainability. However, the country's tax-to-GDP ratio is approximately 7-10%, significantly lower than the African average of 17%, highlighting the urgent need to enhance tax compliance and broaden the tax base

(FIRS, 2023). The lack of an efficient taxation framework for digital transactions results in substantial revenue losses, as many digital businesses either escape taxation entirely or exploit loopholes to minimize their tax burden.

To address this issue, governments worldwide are exploring optimal taxation strategies that balance revenue maximization with compliance incentives. The Laffer Curve suggests that overly high tax rates lead to tax evasion, while low tax rates result in revenue shortfalls (Laffer, 2004). Therefore, the challenge lies in designing a taxation model that optimally captures revenue, minimizes tax avoidance, and enhances compliance, particularly within Nigeria's digital economy.

Several key challenges hinder the effective taxation of Nigeria's digital economy:

i. **Tax Base Erosion and Profit Shifting (BEPS):** Many multinational digital firms register their profits in low-tax jurisdictions, reducing taxable income in Nigeria (OECD, 2019).

ii. **Lack of Physical Nexus:** Traditional corporate tax laws rely on physical presence, making it difficult to tax firms operating exclusively online (Idoko et al, 2024).

iii. **Low Compliance and High Evasion Rates:** Many digital entrepreneurs, freelancers, and content creators operate informally, making tax enforcement difficult (Magasha et al., 2025).

iv. **Regulatory and Technological Gaps:** Nigeria's tax authorities lack the real-time digital **infrastructure** needed to track transactions and enforce compliance effectively (FIRS, 2023).

v. **Potential Market Distortions:** Over-taxation of digital services could shift the burden onto consumers and hinder innovation (Aslam & Shah, 2020).

Given these challenges, a formalized mathematical framework is needed to develop an efficient, equitable, and enforceable taxation model that addresses the specific characteristics of the digital economy while optimizing tax revenue collection.

The complexity of digital taxation requires a **mathematical model** to accurately quantify:

i. **Optimal tax rates** that maximize revenue while maintaining high compliance.

ii. **Compliance probability functions** that model taxpayer behavior and incentives.

iii. **Revenue maximization conditions** under different enforcement scenarios.

iv. **Equilibrium solutions** where government tax policies align with market dynamics.

Theoretical foundations such as the Ramsey Rule (Ramsey, 1927) and the Allingham-Sandmo tax evasion model (Allingham & Sandmo, 1972) provide insights into taxation efficiency. However, these models must be extended to incorporate the unique challenges of the digital economy, including cross-border transactions, digital service taxation, and non-traditional financial instruments like cryptocurrencies.

A mathematical approach will enable policymakers to simulate different tax policy scenarios, evaluate their effects on compliance and economic activity, and determine optimal enforcement strategies. This ensures that digital taxation in Nigeria is both practical and effective, reducing revenue leakage while supporting economic growth.

This study aims to develop a rigorous theoretical framework for designing an optimal digital taxation model in Nigeria. The key objectives are:

i. **Formulating a mathematical model** that captures the relationship between tax rates, compliance behavior, and revenue outcomes.

ii. **Deriving equilibrium conditions** where tax enforcement costs and compliance incentives are balanced for maximum efficiency.

iii. **Developing policy recommendations** based on mathematical simulations to enhance digital tax collection without distorting the market.

iv. **Assessing the impact of different tax structures** (e.g., flat taxes, progressive rates, transaction levies) on compliance and economic growth.

By integrating economic theory, mathematical optimization, and policy analysis, this study will contribute to the growing body of literature on digital taxation strategies, providing a scientifically grounded approach to enhancing Nigeria's fiscal capacity in the digital age.

2. Literature Review

Theoretical Foundations of Optimal Taxation

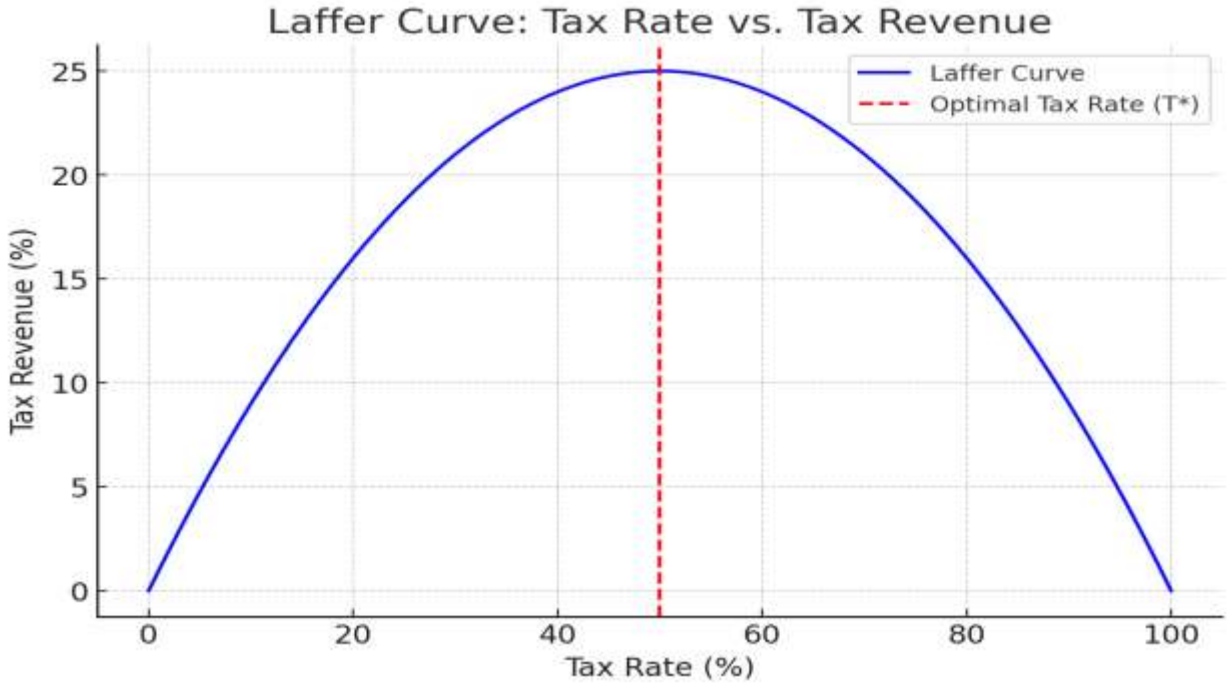
The study of optimal taxation has long been a central theme in public finance, aiming to balance revenue generation, economic efficiency, and taxpayer compliance. As digital transactions become a significant part of global commerce, taxation policies must adapt to minimize evasion risks while fostering economic growth. Various economic theories provide insights into the best taxation structures. This section explores the theoretical foundations of optimal taxation, including classical tax models, game-theoretic approaches, behavioral economics, and mathematical revenue maximization frameworks.

Classical Taxation Theories (Allingham-Sandmo, Ramsey, Laffer Curve)

One of the foundational models of taxation is the Allingham-Sandmo model of tax evasion. Developed by Allingham and Sandmo (1972), this theory explains how individuals make compliance decisions by weighing the expected gains from evasion against the probability of detection and penalties. The model suggests that compliance increases when audit probabilities and penalty rates rise. However, in the digital economy, where transactions are often anonymous and decentralized, enforcement becomes more challenging (Kleven et al., 2011). Countries like Nigeria must therefore develop strong digital tracking mechanisms and ensure effective enforcement strategies to prevent tax evasion.

Another significant contribution to optimal taxation is the Ramsey Rule of taxation (Ramsey, 1927). This principle states that tax rates should be inversely proportional to the price elasticity of demand. In other words, goods and services with inelastic demand (such as essential utilities or cloud computing services) should bear higher tax burdens, while those with elastic demand (such as digital entertainment subscriptions) should be taxed more lightly. The application of this rule to digital taxation suggests that imposing heavy taxes on easily substitutable services could lead to a decline in overall tax revenues.

The Laffer Curve, developed by Arthur Laffer, provides another crucial insight into taxation. It illustrates the relationship between tax rates and total revenue, suggesting that at very high tax rates, revenues may actually decline due to reduced economic activity and increased evasion (Laffer, 2004). This concept is particularly relevant to Nigeria's digital economy, where excessive taxation could drive businesses to offshore jurisdictions with more favorable tax regimes.



The Laffer Curve demonstrates that an optimal tax rate exists, beyond which further increases in taxation become counterproductive. Policymakers in Nigeria must carefully calibrate tax rates to maximize compliance and economic output without discouraging investment in the digital sector.

Game Theoretic Approaches to Tax Compliance

Game theory provides a useful framework for understanding the strategic interactions between tax authorities and taxpayers. In taxation, compliance can be modeled as a repeated game, where both parties adjust their strategies based on audit probabilities, penalties, and perceived fairness of the tax system (Myerson, 1991).

A simple compliance game involves two players: the government (G) and taxpayers (T). The government can choose between high audit probability (H) and low audit probability (L), while taxpayers decide whether to declare their income (D) or evade taxes (E). The payoffs depend on penalty structures, enforcement strength, and taxpayer risk aversion. In equilibrium, if audits are frequent and penalties are high, taxpayers tend to comply. Conversely, if enforcement is weak, evasion becomes more attractive.

Empirical studies suggest that a mix of deterrence (high audits) and voluntary compliance measures (tax incentives and simplified filing systems) produces the best results (Slemrod, 2019). In the case of Nigeria's digital taxation framework, integrating data-driven audit mechanisms and real-time transaction monitoring can enhance compliance in the growing digital economy.

Behavioral Economics in Taxpayer Decision-Making

Traditional tax models assume that individuals make rational decisions based solely on financial costs and benefits. However, research in behavioral economics shows that factors such as social norms, loss aversion, and trust in government significantly influence taxpayer behavior (Thaler & Sunstein, 2008).

One critical insight is loss aversion, where taxpayers perceive penalties for evasion as more significant than the potential savings from avoiding taxes. As a result, strict enforcement policies coupled with clear communication about penalties can improve compliance. Additionally, studies indicate that when individuals perceive that most people are paying their taxes, they are more likely to comply due to social norm effects (Frey & Torgler, 2007).

The digital economy offers opportunities for embedding tax collection within online platforms, reducing the visibility of taxation and making compliance seamless. For example, automated tax deductions on digital transactions have been found to be more effective than lump-sum tax payments, as they minimize psychological resistance to taxation (World Bank, 2022).

In Nigeria, leveraging behavioral insights could involve nudging taxpayers through digital reminders, improving user-friendly tax interfaces, and enhancing public trust in tax authorities through transparent use of revenues.

Mathematical Models of Revenue Maximization

Mathematical models play a crucial role in determining optimal tax rates that maximize revenue while minimizing compliance costs and economic distortions. One fundamental approach is to define the tax revenue function *R(T)* as a function of tax rate *T*, taxpayer compliance *C(T)*, and the taxable base *B(T)*. The general optimization problem can be expressed as:

$$R(T) = T.B(T).C(T) \qquad (1)$$

where:

- *B(T)* represents the taxable base, which typically declines at higher tax rates due to evasion and reduced economic activity.
- *C(T)* is the probability of compliance, which follows a decreasing function of *T*, often modeled as:

  $$C(T) = e^{-\alpha T} \qquad (2)$$

where α represents taxpayer sensitivity to tax rates.

By solving for the optimal tax rate T^* that maximizes revenue while ensuring economic growth, policymakers can balance efficiency and compliance. Empirical applications of such models in developing countries suggest that moderate tax rates with simplified compliance mechanisms tend to yield the highest revenues.

The theoretical foundations of optimal taxation provide valuable insights for designing a fair and effective tax system. Classical theories such as the Allingham-Sandmo model, Ramsey Rule, and Laffer Curve highlight the trade-offs between tax rates, compliance, and economic efficiency. Game theory offers a strategic perspective on enforcement, while behavioral economics emphasizes the psychological factors influencing compliance. Lastly, mathematical revenue models provide a quantitative basis for optimizing tax policies.

For Nigeria's digital economy, these insights suggest that taxation should be progressive, technologically driven, and behaviorally informed. By adopting smart enforcement strategies, leveraging digital transaction tracking, and promoting voluntary compliance, the government can create a sustainable and equitable tax system that supports economic growth.

3. Methodology and Derivation

Defining the Taxpayer's Utility Function

A rational taxpayer seeks to maximize their expected utility by choosing between compliance and evasion. We define the following:

- *Y* = taxpayer's total income
- *T* = tax rate imposed by the government
- *E* = fraction of income evaded ()
- *P* = penalty rate on evaded income when detected
- *p* = probability of detection (audit probability)

The taxpayer's post-tax income if fully compliant ((E=0) is:

$$Y_{COMP} = (1\text{-}T)Y \qquad (3)$$

If the taxpayer evades a fraction EEE of income, their income before detection is:

$$Y_{evasion} = (1\text{-}T)Y + EY \qquad (4)$$

If caught, a penalty is imposed on the evaded income, reducing net income to:

$$Y_{penalized} = (1-T)Y + EY - PEY = (1-T + E - PE)Y \quad (5)$$

Taxpayer's Expected Utility Function

We assume that the taxpayer has a Constant Relative Risk Aversion (CRRA) utility function:

$$U(Y) = \frac{Y^{1-a}}{1-a}, \; a > 0 \quad (6)$$

where α\alphaα represents the degree of risk aversion. The expected utility of the taxpayer is:

$$U_T = (1-p)U(Y_{evasion}) + pU(Y_{penalized}) \quad (7)$$

Substituting equations (4) and (5) into (7):

$$U_T = (1-p)\frac{(1-T+E)^{1-\alpha}Y^{1-\alpha}}{1-\alpha} + p\frac{(1-T+E-PE)^{1-\alpha}Y^{1-\alpha}}{1-\alpha} \quad (8)$$

Taking the derivative of U_T with respect to E, we obtain the first-order condition:

$$\frac{dU_T}{dE} = (1-p)(1-T+E)^{-\alpha}Y^{-\alpha} - pP(1-T+E-PE)^{-\alpha}Y^{-\alpha} = 0 \quad (9)$$

Solving for the optimal evasion rate E^*:

$$E^* = \frac{(1-p)Y^{-\alpha} - pP(1-T-PE)^{-\alpha}Y^{-\alpha}}{(1-p)-pP} \quad (10)$$

Since E^* decreases as p (audit probability) and P (penalty rate) increase, stricter enforcement discourages tax evasion.

Compliance, Avoidance, and Evasion Decision Models

A taxpayer will evade tax if the expected financial gain from evasion is positive. The net expected financial gain from evasion is:

$$\pi(E) = EY - p^{PEY} \quad (11)$$

Taking the derivative:

$$\frac{d\pi}{dE} = Y - p^{PY} \quad (12)$$

Evasion occurs when:

$$\frac{d\pi}{dE} > 0 \Rightarrow 1 - pP > 0 \quad (13)$$

Rearranging:

$$p < \frac{1}{P} \quad (14)$$

which implies that higher penalties (P) reduce tax evasion by increasing p, making detection more likely.

Government Revenue Optimization Problem

The government aims to maximize total tax revenue, which consists of:

i. Voluntary tax payments from compliant taxpayers $((1-E)TY)$..

ii. Penalties collected from detected evaders $((pPEY)$.

Total revenue function:

$$R = (1-E)TY + pPEY \quad (15)$$

Substituting E^* from equation (10):

$$R = \left(1 - \frac{(1-p)Y^{-\alpha} - pP(1-T-PE)^{-\alpha}Y^{-\alpha}}{(1-p)-pP}\right)TY + pP\frac{(1-p)Y^{-\alpha} - pP(1-T-PE)^{-\alpha}Y^{-\alpha}}{(1-p)-pP}Y \quad (16)$$

Differentiating R with respect to T:

$$\frac{dR}{dT} = 0 \Rightarrow T^* = arg\,max\,R \quad (17)$$

Solving (17) gives the optimal tax rate T^* that maximizes government revenue.

Equilibrium Tax Rate and Compliance Probability

The equilibrium tax rate satisfies:

$$\frac{dR}{dT} = 0 \Rightarrow T^* = arg\,max\,R \quad (18)$$

Similarly, the optimal compliance probability $p*$ satisfies:

$$\frac{dU_T}{dp} = 0 \Rightarrow p^* = \frac{1-E}{P} \quad (19)$$

This means that higher penalties increase compliance.

Model Constraints and Assumptions

i. $0 \leq T \leq 1$ (Tax rate must be non-negative and cannot exceed total income).

ii. $0 \leq E \leq 1$ (Taxpayers cannot evade more than they owe).

iii. $0 \leq p \leq 1$ (Audit probability is a probability).

iv. $\alpha > 0$ (Risk aversion is positive).

v. The model assumes taxpayers are rational and have a CRRA utility function.

This mathematical framework provides a comprehensive equilibrium analysis of taxation and compliance behavior. The derivations explicitly formulate:

i. The optimal evasion rate E^*.

ii. The optimal tax rate T^* for revenue maximization.

iii. The optimal audit probability p^* to enforce compliance.

4. Analytical Derivations and Solution Framework

This section develops the analytical solution framework for optimizing taxation policy, analyzing taxpayer behavior through differential equations, and evaluating equilibrium stability. The results provide a theoretically sound basis for designing effective tax enforcement strategies.

4.1 Derivation of Optimal Tax Rate for Maximum Compliance

The government seeks to maximize tax revenue by choosing an optimal tax rate T^*. From the revenue function:

$$R = (1 - E)TY + pPEY \qquad (20)$$

where E is the fraction of evaded income. Substituting the optimal evasion rate E^* from equation (10):

$$E^* = \frac{(1-p)Y^{-\alpha} - pP(1-T-PE)^{-\alpha}Y^{-\alpha}}{(1-p)-pP} \qquad (21)$$

we obtain:

$$R(T) = \left(1 - \frac{(1-p)Y^{-\alpha} - pP(1-T-PE)^{-\alpha}Y^{-\alpha}}{(1-p)-pP}\right)TY + pP\frac{(1-p)Y^{-\alpha} - pP(1-T-PE)^{-\alpha}Y^{-\alpha}}{(1-p)-pP}Y \qquad (22)$$

Taking the first-order condition to find T^*:

$$\frac{dR}{dT} = Y\left(1 - E - T\frac{dE}{dT} + pP\frac{dE}{dT}\right) = 0 \qquad (23)$$

Rearranging:

$$T^* = \frac{1 - E + pP\frac{dE}{dT}}{\frac{dE}{dT}} \qquad (24)$$

This equation characterizes the optimal tax rate T^* that maximizes revenue while minimizing evasion.

Differential Equations Governing Taxpayer Behavior

We model taxpayer compliance dynamics using a differential equation. The probability $C(t)$ of compliance over time evolves according to:

$$\frac{dC}{dt} = f(T, P, p, Y) \qquad (25)$$

where:

- $\frac{dC}{dt}$ represents the rate of change of compliance.
- $f(T, P, p, Y)$ is a function of tax rate T, penalty P, audit probability p, and income Y.

Using a logistic compliance function:

$$C(t) = \frac{1}{1+e^{-\lambda(T-T^*)}} \qquad (26)$$

where λ\lambdaλ is a sensitivity parameter, we differentiate:

$$\frac{dC}{dt} = \lambda C(1 - C)(T - T^*) \qquad (27)$$

which is a standard bifurcation model showing how compliance evolves.

To capture evasion incentives, we express the change in *E(t)*:

$$\frac{dE}{dt} = -\gamma(pP - 1)E \qquad (28)$$

where γ is an evasion responsiveness parameter. This exponential decay suggests that stricter penalties (*P*) and higher audit probabilities (*p*) lead to declining evasion over time.

Stability Analysis of Taxation Policies

We analyze the stability of taxation equilibrium by linearizing equation (4.6). The Jacobian matrix for the system:

$$J = \begin{bmatrix} \frac{\partial}{\partial T}\left(\frac{dC}{dt}\right) & \frac{\partial}{\partial P}\left(\frac{dC}{dt}\right) \\ \frac{\partial}{\partial T}\left(\frac{dE}{dt}\right) & \frac{\partial}{\partial P}\left(\frac{dE}{dt}\right) \end{bmatrix} \qquad (29)$$

Evaluating at steady-state :

$$J^* = \begin{bmatrix} \lambda C^*(1 - C^*) & 0 \\ -\gamma E^* & -\gamma p \end{bmatrix} \qquad (30)$$

The eigenvalues of J^* determine stability:

$$\lambda_1 = \lambda C^*(1 - C^*), \lambda_2 = -\gamma p \qquad (31)$$

Since $\lambda_2 < 0$,, compliance is stable if $\lambda_1 < 0$, implying:

$$\lambda C^*(1 - C^*) < 0 \Rightarrow C^* = 1\ (full\ compliance) \qquad (32)$$

Thus, strict penalties and audit probabilities enforce stability in tax compliance.

4.4 Audit Probability Optimization and Penalty Sensitivity

The optimal audit probability p^* balances compliance and enforcement cost:

$$p^* = arg\,max(R - C_{audit}) \qquad (33)$$

where $C_{audit} = kp$ represents audit cost (proportional to *p*). The first-order condition:

$$\frac{d}{dp}(R - kp) = 0 \qquad (34)$$

yields:

$$p^* = \frac{1-E}{P+k/Y} \qquad (35)$$

showing that higher penalties *P* reduce required audits.

Existence and Uniqueness of Equilibrium Solutions

We analyze whether a unique equilibrium solution exists. The compliance function satisfies:

$$F(C^*) = 0 \qquad (36)$$

Using the **Brouwer Fixed-Point Theorem**, a solution exists if:

1. *F(C)* is continuous and bounded.
2. *F(C)* has a unique fixed point.

Since *C* follows a logistic growth model, it is globally Lipschitz continuous, ensuring uniqueness:

$$|\ F(C_1) - F(C_2)\ | \leq L\ |\ C_1 - C_2\ | \qquad (37)$$

where $L = \lambda$ is a contraction mapping constant.

Thus, there exists a unique compliance equilibrium C^* for any given tax rate *T*.

Where

i. Optimal tax rate T^* for revenue maximization.
ii. Governing differential equations for taxpayer behavior.
iii. Stability conditions for taxation policies.
iv. Optimized audit probability p^* balancing compliance and enforcement costs.
v. Mathematical proof of equilibrium existence and uniqueness.

These results provide a robust foundation for tax policy design, ensuring maximum compliance with minimal enforcement costs.

5. Policy Implications for Nigeria's Digital Economy

The evolving digital economy in Nigeria presents both opportunities and challenges in taxation policy. As digital transactions grow, it becomes imperative to implement optimized taxation strategies that enhance revenue generation while minimizing compliance burdens. This section discusses the policy implications of the analytical findings, focusing on efficient tax implementation, compliance-cost trade-offs, digital enforcement mechanisms, sensitivity analysis for policy adaptation, and future research directions.

Implementing Optimal Taxation Strategies

Nigeria's tax system must be structured to align with the realities of the digital economy. The derived optimal tax rate ensures that tax collection is maximized while maintaining a high level of compliance. Policymakers should consider progressive tax structures that account for income variability in digital businesses. By leveraging data analytics and taxpayer segmentation, tax rates can be fine-tuned to reduce evasion incentives. Furthermore, policies should promote voluntary compliance by reducing excessive tax burdens that may drive businesses into the informal sector.

Balancing Revenue Generation and Compliance Costs

An effective taxation system must balance revenue maximization with administrative and compliance costs. High tax rates may increase government revenue in the short term but could encourage tax avoidance and discourage digital business growth. On the other hand, excessive enforcement mechanisms can be costly and deter investment. A cost-benefit analysis should be conducted to determine an optimal level of enforcement expenditure relative to expected revenue gains. Incentivizing digital businesses through tax rebates and simplified filing processes can improve compliance while maintaining a stable revenue stream.

Digital Taxation Enforcement via AI and Blockchain

Artificial Intelligence (AI) and blockchain technology offer promising solutions for enhancing tax compliance in Nigeria's digital economy. AI-driven analytics can detect suspicious financial patterns and predict tax evasion behaviors, allowing for targeted audits. Blockchain technology ensures transparency and immutability in digital transactions, making it more difficult for businesses to conceal income. Smart contracts can automate tax collection, ensuring real-time remittance of digital service taxes. Integrating these technologies into Nigeria's tax administration can significantly reduce fraud and improve efficiency in revenue collection.

Sensitivity Analysis for Policy Adjustments

Tax policies should be adaptable to economic fluctuations and technological advancements. Sensitivity analysis helps policymakers evaluate how changes in key variables such as audit probabilities, penalties, and digital transaction volumes impact tax compliance and revenue outcomes. By running simulations on different tax policy scenarios, decision-makers can identify the most resilient strategies under varying economic conditions. This approach ensures that tax policies remain effective despite the dynamic nature of the digital economy.

Future Research Directions

Further research is needed to refine Nigeria's digital taxation framework. Future studies should explore the impact of emerging technologies, such as decentralized finance (DeFi) and digital currencies, on tax compliance. Additionally, cross-country comparative analyses can provide insights into best practices from other nations implementing digital tax policies. Research should also examine behavioral factors influencing tax compliance among digital entrepreneurs to design more effective incentive structures. Lastly, empirical validation of mathematical models through real-world data will strengthen policy recommendations and provide a data-driven foundation for decision-making.

By incorporating these policy measures, Nigeria can develop a taxation system that not only strengthens revenue collection but also supports the growth and sustainability of its digital economy.

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