

Economic complexity and the shadow economy in Africa: An assessment of nonlinearity and asymmetry

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Abstract

Recent literature reveals that economic complexity (EC) has important implications for shadow economy and has generated mixed empirical conclusions. This paper contributes to this debate by investigating the nonlinear and asymmetric effects of EC on shadow economy in 28 Africa countries between 1995 and 2020. Granger and Yoon's (2002) approach is used to decompose the EC into positive and negative components, while the dynamic panel threshold regression, two-step system generalised method of moments, pooled mean group, augmented mean group, and common correlated mean group are employed as the estimation techniques. The results indicate that positive EC shocks reduce the size of the shadow economy,

Keywords

- economic complexity
- shadow economy
- Africa
- nonlinearity

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whereas negative shocks contribute to the growth of informality, thus suggesting the presence of asymmetry. The threshold of economic complexity was found to be 0.41.

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Introduction: An old problem in a new setting

The proponents of economic complexity argue that a nation's wealth is based on the amount of productive knowledge and the cumulative know-how utilised in product diversity. They explain that the country's wealth is not just based on its resources alone, but productive knowledge and how it is transformed in the production process. Their framework by focuses on a country's productive capabilities rather than the size of GDP (Hausmann et al., 2014), thus offering a nuanced understanding of economic growth compared to the conventional models). Economic complexity is a measure of a country's overall productive capabilities that emerges from the diversity and complexity reflected in its export product basket. An economy with more diverse skills, knowledge and innovative infrastructural facilities is capable of producing more complex goods and services (Ajide, 2022). In the literature, economic complexity has been linked to the shadow economy due to the high level of innovativeness and skills required in the production process for increasing the export product basket (Canh & Thanh, 2020).

Economic complexity is expected to reduce the shadow economy by bringing numerous opportunities into the official economy, including job openings, entrepreneurial development, and other benefits that can be leveraged from a nation's international competitiveness (Canh & Thanh, 2020; Nguyen, 2022). However, it may intensify the shadow economy due to undesirable economic shocks resulting from an over-reliance on external economies and financial crises (Nguyen, 2022). In this case, economic actors view the informal sector as a safety net. Also, the nexus between shadow economy and economic complexity may be an inverted N-shaped or a U-shaped pattern, due to the interaction of the structural, institutional, and economic transformation as well as the stages of economic development (Bolarinwa & Simatele, 2025; Fotié & Mbratana, 2024; Lewis, 1954). Drawing on the dualistic view, it can be hypothesised that at the early stage of materialised knowledge in the national productive structure (economic complexity), the shadow economy tends to

decline as labour moves from subsistence economic activities to a higher level of economic sophistication. Increased economic complexity provides workers with good wages and job security. Industrialisation and a knowledge-based economy therefore boost opportunities in the formal economy.

Moreover, higher economic complexity is associated with better institutional quality (Dada et al., 2025), which can eventually reduce the size of the shadow economy (Ketu et al., 2024). Higher economic complexity can be accompanied by increased taxes, labour law rigidity, and other regulatory burdens. The excessive costs of formalisation over the benefits of operating in the official economy may lead economic agents to consider the shadow sector as the best alternative. These scenarios may in turn generate nonlinear reactions in the shadow economy, suggesting context-dependent and threshold sensitivity (Bolarinwa & Simatele, 2025). Interestingly, the nonlinear impact of economic factors on the shadow economy has been explored in the recent literature (Ajide & Dada, 2024; Bolarinwa & Simatele, 2023), providing insights into appropriate policy responses to this phenomenon in developing nations (Wu & Schneider, 2019; Yu & Ohnsorge, 2019). Different studies have argued that the shadow economy distorts formal economic operations, thereby hindering the ability of government to achieve her objectives (Dell'Anno, 2022). Other authors suggest that the shadow economy protects marginalised individuals who experience income disparities, uneducated agents, and women entrepreneurs, who find it challenging to access justice in formal employment and entrepreneurial opportunities (Ajide et al., 2025; Medina & Schneider, 2019). This issue was also predicted theoretically in Lewis's (1954) dualistic ideology; Lewis argues that informal and formal economic systems may coexist in developing regions due to unbalanced features in traditional and modern economic structures, lapses in institutional settings, inequalities, and stringent regulations in the official economy (Ajide et al., 2025).

Given that many theoretical and empirical studies support the coexistence of formal and informal sectors in developing nations, the new empirical focus has shifted to ascertaining the appropriate balance or threshold for the two economic systems (see Ajide & Dada, 2024; Bolarinwa & Simatele, 2023; Canh & Thanh, 2020; Wu & Schneider, 2019; Yu & Ohnsorge, 2019). In this paper, we present the case of the nonlinear and asymmetric effect of economic complexity on the shadow economy in selected Africa countries. This constitutes our primary contribution to the literature. The recent empirical debate on the influence of economic complexity on the shadow-economy activities has yielded mixed results (Ajide & Dada, 2024; Ketu et al., 2024; Nguyen, 2022). Specifically, Nguyen (2022) finds that economic complexity reduces the shadow economy in a global sample; this is consistent with the empirical findings of Ketu et al. (2024), who also employed the generalised method of moments. However, the mean group panel estimators employed

by Ajide and Dada (2024) indicate that in the African setting, the impact of economic complexity on the shadow economy is heterogeneous, showcasing a mix of positive and negative effects, as well as nonsignificant results in the country-specific analysis. One of the main unresolved issues is the nonlinear effect of economic complexity, as observed in previous studies. The present study bridges this gap in the literature. Our objective is to examine the nonlinear impact of economic complexity on the shadow economy in Africa.

Africa serves as an interesting region to investigate the nonlinearity between economic complexity and the shadow economy. The magnitude of Africa's shadow economy has been estimated to exceed the world average of 31% of GDP (Elgin et al., 2021; Medina & Schneider, 2019). Likewise, the economic complexity index suggests that African economies operate at lower levels (Olaniyi & Odhiambo, 2023). This is due to a technology gap, over-reliance on unrefined natural resources, for foreign exchange, and production based on less sophisticated products (Dada et al., 2024b; Mealy et al., 2019). Based on this, our study offers new insights into the relationship between economic complexity and the shadow economy, and proposes that the effect of economic complexity on this economy follows a threshold-based pattern. This suggests that the shadow economy can be curbed if economic complexity reaches a particular threshold, but may harm the system if the institutional structure is not effectively tightened.

To examine this, the study employs the Granger and Yoon (2002) decomposition framework, splitting the changes in economic complexity index into positive and negative shocks to capture the asymmetric relationship as expanded by Habib et al. (2017). It also employs a two-step system generalised method of moments, pooled mean group, augmented mean group (AMG), and common correlated effects mean group (CCEMG) within the asymmetric framework over panel data of 28 African countries between 1995 and 2020. The study found the threshold value of economic complexity to be 0.41. Below the threshold level, economic complexity has a significantly positive impact on the shadow economy, while above the threshold, its impact is significantly negative. In addition, positive economic complexity shocks mitigate the size of the shadow economy. However, a negative economic complexity shock contributes to the growth of the shadow economy. This result establishes the presence of asymmetries: the shadow economy responds differently to positive and negative shocks in terms of economic complexity.

The paper is structured as follows: Section 1 reports the theories and relevant empirical studies; Section 2 discusses the materials and methods used to conduct the study; in Section 3, we present the empirical results and interpretation; in the final section, we discuss the conclusion and policy implications of the findings.

1. Literature review

The study draws on the neoclassical approach and the dualistic theory of development to explain the interrelationship between the shadow economy and economic complexity. The neoclassicists clarify that the choice to participate in the shadow economy is guided by welfare-optimisation principles as perceived by economic agents (Dell'Anno, 2022). This view seems to rely heavily on how economic agents perceive costs and the benefits of informality. In a more refined approach, authors like Lewis (1954) and Tokman (1979) view the shadow economy as performing a positive transitional role by absorbing marginalised groups in society and, at the same time, reducing income inequality, since this sector provides additional income for survival. This view is consistent with the early stage of economic progress but may become ineffective as higher levels of growth and economic sophistication are experienced. Furthermore, the theory of institutional economics explains that the legal system and strong governance system can shape the shadow economy's roles as the economy matures, implying that the relationship between the shadow economy and economic complexity may be threshold-sensitive (Bolarinwa & Simatele, 2025; Dada et al., 2025; La Porta & Shleifer, 2008; North, 1990).

Institutional and socioeconomic factors are the principal drivers of the decision to participate in the informal sector. For instance, income inequality promotes informality, particularly in regions with significant income disparities (Ajide et al., 2024). This is because the informal sector may offer opportunities to bridge income gaps in the official economy. Economic agents may participate in the informal economy to escape restrictive institutional factors (Dell'Anno, 2022). The shadow economy may increase due to the prevalence of corruption. Weak control over corruption may allow businesses to bribe their way through informal channels, thereby circumventing stringent regulatory policies (Schneider & Buehn, 2018).

Recent studies have revealed that economic complexity downgrades the magnitude of the shadow economy (Ajide & Dada, 2024; Ketu et al., 2024; Nguyen, 2022; Nguyen & Thanh, 2020). Economic complexity captures many factors that are left out in the computation of GDP, including the productive knowledge that materialises and is employed in the production process (Hidalgo, 2021). Enhanced economic complexity is expected to reduce informality (Nguyen, 2022). Economic complexity offers further benefits to economic agents in the formal economic system, bolstering the production structure and discouraging operations in the informal sector (Nguyen, 2022). Informality may be discouraged because economic complexity enhances the functioning of the financial sector, thereby increasing access to funding for advanced technologies within the official economic system (Ajide & Osinubi, 2024; Canh & Thanh, 2020).

For instance, Nguyen (2022) examines the influence of economic complexity across a panel of 115 countries from 1995 to 2017, finding that economic complexity reduces the shadow economy in both high- and low-income countries. Similarly, Canh et al. (2021) find that economic integration, institutional factors, and economic complexity are key drivers of the shadow economy in 112 economies. Most importantly, economic complexity reduces informality. Canh and Thanh (2020) reveal a nonlinear relationship between export diversification and the informal economy in 116 economies.

Similarly, Ketu et al. (2024) found that within 24 countries from 1996 to 2016, economic complexity was associated with a reduction in the shadow economy. However, this finding is inconsistent with the study by Ajide and Dada (2024), which found no correlation between the variables using different mean-group estimators, such as the augmented mean-group and the dynamic common correlated effect mean-group, over a panel data set of 27 countries from 1995 to 2017. In a country-specific estimation, economic complexity and shadow economy were found to be negatively related in Congo, Uganda, and Ghana, while the opposite was documented for Tunisia, Madagascar, and Botswana. No significant effects were reported for other countries. This study points to the heterogeneous nature of African economies.

Furthermore, in panel data for 99 countries, Pham et al. (2024) established that economic complexity is non-linearly linked to income inequality and the informal economy: there is a U-shaped association between economic complexity and income disparities. Therefore, income disparities and economic complexity must be taken into account when addressing the shadow economy. This aligns with the study by Ajide et al. (2025), which suggests that the informal sector helps address income inequality by enabling marginalised individuals to bridge the income gaps created in the official economy.

In conclusion, only a few studies have investigated the influence of economic complexity on shadow economy, emphasising linearity among the variables. However, no study has examined the nonlinearity between shadow economy and economic complexity. We aim to address this gap with the use of a panel of African countries. Recent studies have highlighted the importance of examining the nonlinearity between the shadow economy and socioeconomic factors to inform effective policy responses (Ajide & Dada, 2024; Bolarinwa & Simatele, 2023; Wu & Schneider, 2019; Yu & Ohnsorge, 2019).

The literature suggests that economic complexity influences shadow economy through direct and indirect channels (Ajide & Dada, 2024; Canh et al., 2021; Canh & Thanh, 2020). Hidalgo and Hausmann (2009) show that income and economic complexity are correlated. Specifically, while economic complexity stimulates growth in the official economy, a deviation from this connection may lead to an expansion of the informal sector. Such a deviation may indicate a potentially positive impact on long-term growth. However, a short-term impact may lead households to move into the shadow economy to compensate

for income shortfalls (Ajide & Dada, 2024; Ketu et al., 2024). Research has shown that output volatility reduces income per capita and factor productivity, negatively impacting economic growth (Ramey & Ramey, 1991). During this period, the shadow economy may serve as a survival channel for households to cope with the challenges of such volatility, especially in developing economies, where financial and governance systems are very weak (Ajide et al., 2024). Therefore, a complex economy is believed to have more paths to growth stability, as studies confirm that economic complexity reduces volatility in national output and increases labour productivity (Sweet & Eterovic, 2019). In this case, economic complexity is expected to prevent a potential shift in the shadow economy (Ketu et al., 2024).

Various studies indicate that a weak institutional system is a primary source of the shadow economy's growth (Dell'Anno, 2022; Elgin et al., 2021). In addition, formal and informal economies share some key determinants; therefore, economic complexity is expected to influence the shadow economy by attracting economic actors to the official economy in the presence of innovations and new knowledge being disseminated and reflected in national export baskets (Ajide, 2022; Canh & Thanh, 2020; Nguyen, 2022; Schneider & Buehn, 2018). However, entrepreneurial firms and informal workers may not fully benefit from the opportunities presented by economic complexity because of the semi- or lower-level skills they possess; thus, they may still prefer informal-sector operations (Nguyen, 2022).

Djeunankan et al. (2023) explain that economic complexity enhances governance and institutional reforms by influencing foreign direct investors, who demand greater protection of property rights. Economic complexity promotes quality institutions through a skilled workforce and human capital development, thereby reducing income inequality and enhancing the lives of poor households while also reducing the participation of shadow economic actors (Dada et al., 2024b). Economic complexity improves transparency and leaders' accountability, an ingredient for discouraging participation in shadow economy. However, a country with a skewed industrial structure may have higher cohesion among the elites, and an overreliance on elites as a means of survival may reduce accountability (Olaniyi & Odhiambo, 2023). With a highly skewed industrial and productive structure, citizens may lose economic privileges, leading to increased income inequality and expanding the shadow economy.

Furthermore, knowledge is an essential input in the production process and is embedded in the economy's productive structures. Economic complexity is closely tied to knowledge accumulation, as reflected in the diversity and ubiquity of the economy's export baskets (Hartmann, 2014). Therefore, progress in product complexity is closely tied to knowledge and technological transformation, as well as their application in the economy. This process creates more economic opportunities for average citizens and reduces the attractiveness of

the shadow economy (Ajide, 2022; Canh et al., 2021; Hartmann et al., 2017). Moreover, in the formal economy, workers enjoy higher wages, greater job security, and greater specialisation due to the economic transformation enabled by economic complexity and its associated higher returns to scale (Lee & Vu, 2020). Consequently, enhanced job quality and security help reduce marginalisation and income inequality, thereby diminishing reliance on the informal sector for survival.

However, based on the view of the routine-biased technological hypothesis and skill-based technical change theory, economic transformation resulted from product sophistication, and higher-skilled labour demand may increase with the use of sophisticated machines. Therefore, the demand for low-skilled labour will be reduced (Acemoglu & Autor, 2011). In turn, this could increase the level of marginalisation and deepen the shadow economy. These positive and negative forces in the relationship between economic complexity and the shadow economy suggest the possibility of nonlinearity between the two. While studies such as Bandeira Morais et al. (2021) and Le et al. (2020) provide empirical evidence of an inverted U-shaped relationship between income gaps and economic complexity, to our knowledge, the asymmetric effect of economic complexity on the shadow economy has yet to be explored empirically. The focus of our study is to shed light on this issue in the context of African economies.

2. Data, model, and estimation strategies

2.1. Data

The dataset for this study spans from 1995 to 2020 for 28 African countries. Table A1 in the Appendix lists the countries. The study aims to investigate the asymmetric and nonlinear impact of economic complexity on the shadow economy. The shadow economy data are sourced from the dataset of Elgin et al. (2021). This data comprises all economic activities (legal or illegal), regardless of official status. Economic complexity data are extracted from the Atlas of Economic Complexity dataset, which assesses the nation's export competitiveness and the sophistication of its production system (Ajide & Dada, 2024; Hausmann et al., 2014).

To avoid the omitted variable problem, additional control variables are added, including per capita income as a proxy for the official economy, population, and domestic credit to the private sector as a proxy for financial development. Data on per capita income, financial development, and population

growth are obtained from the World Bank's World Development Indicators. Per capita income is measured in 2015 constant USD and is incorporated because the formal economy plays a role in determining the magnitude of the shadow economy (Ajide et al., 2024, 2025; Dada et al., 2024a,b).

2.2. Model specification

This study follows the model specification used in existing studies to examine the relationship between economic complexity and the shadow economy in African economies. The choice of control variables is based on the previous literature. The dualist approach suggests that the shadow economy exists alongside the official economy (Lewis, 1954), providing an alternative for marginalised households (Loayza, 2018). A formal economy, typically measured by economic growth or GDP, is expected to have an inverse relationship with the shadow economy (Berdiev et al., 2018; Dada & Al-Faryan, 2024). Studies by Awoleye et al. (2025), Njangang et al. (2020), and Capasso and Jappelli (2013) show that financial services influence the size of the shadow economy; therefore, financial development is included as a control variable. Similarly, Kpognon (2022) and Njangang et al. (2020) suggest that population growth drives the expansion of the shadow economy, especially in developing countries where formal-sector unemployment is high. In specific terms, and adding the control variables to the model, equation 1 can be expressed as:

$$SHE_{it} = \alpha + \beta EC_{it} + \gamma GDP_{it} + \delta POP_{it} + \theta FD_{it} + \varepsilon_{it} \quad (1)$$

SHE represents the shadow economy, *EC* represents economic complexity, and *GDP*, *POP*, and *FD* are per capita income, population, and financial development, respectively. *i* and *t* are the cross-section and time indicators, respectively.

To capture the asymmetric relationship, we apply the Granger–Yoon (2002) approach to decompose the economic complexity index into positive and negative shocks. This approach was later expanded by Habib et al. (2017). The process of decomposing the variable is as follows.

$$EC_{it} = EC_{it-1} + \varepsilon_{it} = EC_0 + \sum_{j=1}^p \varepsilon_{itj} \quad (2)$$

where $t = 1, 2, 3, \dots, T$, $i = 1, 2, 3, \dots, I$, the term EC_0 is the initial value of the series, whereas ε_{it} is the noise. The negative and positive components (asymmetries) are detailed as:

$$\varepsilon_{it}^+ = \max(\varepsilon, 0) \quad (3)$$

$$\varepsilon_{it}^- = \min(\varepsilon, 0) \quad (4)$$

Hence,
$$\varepsilon_{it} = \varepsilon_{it}^+ + \varepsilon_{it}^- \quad (5)$$

Putting equations (3) and (4) in (2), then:

$$EC_{it} = EC_{it-1} + \varepsilon_{it} = EC_0 + \sum_{j=1}^p \varepsilon_{itj}^+ + \sum_{j=1}^p \varepsilon_{itj}^- \quad (6)$$

Finally, the positive economic complexity shocks and negative economic complexity shocks is described as a cumulative:

$$EC_{it}^+ = \sum_{j=1}^p \varepsilon_{itj}^+ \quad (7)$$

$$EC_{it}^- = \sum_{j=1}^p \varepsilon_{itj}^- \quad (8)$$

Incorporating equations (7) and (8) into equation (1), the testable model becomes:

$$SHE_{it} = \alpha + \rho EC_{it}^+ + \pi EC_{it}^- + \gamma GDP_{it} + \delta POP_{it} + \theta FD_{it} + \varepsilon_{it} \quad (9)$$

2.3. Estimation procedures

Firstly, the study tests the econometric characteristics of the variables. The cross-sectional dependency (CD) in the data is investigated. The financialisation and globalisation of markets have rendered the assumption of country independence unrealistic. Furthermore, African countries are not immune to global events and are thus susceptible to shocks emanating from both within and outside the region. Thus, it is essential to account for the likelihood of CD in the data to guide the estimation methods. The CD in the data is tested using the Pesaran-scaled Lagrange Multiplier (Ps-LM), the Bias-corrected scaled Lagrange Multiplier (Bcs-LM), and the Pesaran CD (P-CD).

Secondly, the study employs first- and second-generation estimators to examine the asymmetric impact of economic complexity on the SHE. Specifically, the study uses the two-step system generalised method of moments (2SGMM), pooled mean group (PMG), augmented mean group (AMG), and common correlated effects mean group (CCEMG) within the asymmetric framework. The 2SGMM addresses the endogeneity and serial correlation commonly found in the literature on the shadow economy (Ajide et al., 2025). Additionally, the

2SGMM addresses the omitted variable bias and simultaneity issues inherent in the shadow economy-economic complexity model.

To estimate the 2SGMM, the following linear restriction is imposed on equation (9) and used as the instruments.

$$\begin{aligned}
 E(SHE_{i,t-s}, \Delta \varepsilon_t) &= E(EC_{i,t-s}^+, \Delta \varepsilon_t) = E(EC_{i,t-s}^-, \Delta \varepsilon_t) = \\
 &= E(GDP_{i,t-s}, \Delta \varepsilon_t) = E(POP_{i,t-s}, \Delta \varepsilon_t) = E(FD_{i,t-s}, \Delta \varepsilon_t) = 0 \quad (10)
 \end{aligned}$$

For $s \geq 2$, and $t = 3, 4, \dots, T$.

On the other hand, the PMG, AMG, and CCEMG account for cross-sectional dependence, spatial correlation, and slope heterogeneity, which are commonly found in heterogeneous panels (Dada et al., 2024b). Furthermore, we employed standard errors that are robust to heteroscedasticity, autocorrelation, and spatial or cross-sectional dependence. In addition, the PMG, AMG, and CCEMG do not require stationarity and cointegration tests before being utilised (Pesaran, 2006). To save space, the models for these estimation techniques are not specified.

Thirdly, the dynamic panel threshold regression of Seo et al. (2019) is used to estimate the threshold of economic complexity in determining the size of the shadow economy. The threshold model is as follows:

$$\begin{aligned}
 y_{it} &= (1, x'_{it}) \beta_1 1(q_{it} \leq \gamma) + (1, x'_{it}) \beta_2 1(q_{it} > \gamma) + \mu_i + \varepsilon_{it} \\
 & \quad i = 1, 2, \dots, n; \quad t = 1, 2, \dots, T \quad (11)
 \end{aligned}$$

where y_{it} is the scalar of the dependent variable (shadow economy), x'_{it} is the vector of time-varying independent variables that also include the lag value of the dependent variable, $1(\cdot)$ is the indicator function, q is the transition variable (economic complexity), γ is the threshold parameter, β_1 and β_2 are the slope parameters linked with different periods, μ_i is a time-invariant unobserved country-specific effect term, and ε_{it} is a zero-mean idiosyncratic random disturbance.

3. Results and discussion

Table 1 presents descriptive statistics and a correlation matrix. Applying four different estimation techniques, as reported in Table A2 in the Appendix, the null hypothesis of cross-sectional independence in the variable is rejected at the conventional level. These results point to the presence of CD across all variables used. This result reveals that any factors that cause a change in one nation will also influence other countries in the group. Hence, there are spill-over and contagion effects within the panel.

Table 1. Descriptive statistics and correlation matrix

	SHE	EC ⁺	EC ⁻	GDP	POP	FD
Mean	40.230	1.006	-0.978	2246.103	2.786	25.728
Median	39.795	0.796	-0.738	1262.221	2.878	15.565
Maximum	64.586	3.696	0.000	11937.640	5.842	160.125
Minimum	26.250	0.000	-3.373	43.231	0.595	0.429
Standard deviation	7.953	0.844	0.829	2367.782	8.924	28.580
SHE	1	0.055 ^b (0.045)	0.015 ^c (0.061)	-0.213 ^a (0.000)	0.043 ^a (0.0257)	-0.414 ^a (0.000)
EC ⁺		1	-0.914 ^a (0.000)	0.186 ^a (0.000)	0.011 ^a (0.775)	-0.121 ^a (0.001)
EC ⁻			1	-0.156 ^a (0.000)	0.093 ^a (0.013)	0.123 ^a (0.001)
GDP				1	-0.297 ^a (0.000)	0.453 ^a (0.000)
POP					1	0.013 ^a (0.723)
FD						1

Note: *p*-values in parentheses (). a, b and c suggest 1%, 5% and 10% levels of significance.

Source: own work.

Due to the presence of the CD, the unit root is examined using CADF and CIPS tests. The result of the stationarity test is presented in Table A3 in the Appendix. All variables are stationary at the first difference (I(1)) at the 1% significance level. The long-run cointegration among the variables is investigated using the Westerlund panel cointegration test, and the result is reported in Table A4 in the Appendix. The result suggests that two of the four test statistics are significant (Gt and Pt), suggesting that long-run cointegration exists among the variables. Furthermore, the result implies that series tend to cointegrate and move to a long-run steady state, even after an initial short-run disequilibrium. Based on this outcome, the study accounted for the long-run relationship using the PMG, AMG, and CCEMG estimation techniques.

3.1. Baseline results

This paper investigates the asymmetric effect of economic complexity on the size of shadow economy in selected African countries. Four different es-

timisation techniques (2SGMM, PMG, AMG, and CCEMG) are employed to establish the relationship, and the results are presented in Table 2. The results of the 2SGMM confirm that the instrument used, as indicated by the Hansen- J statistic test, is valid and free from serial correlation. Furthermore, the 2SGMM reveals the presence of first-order autocorrelation (AR1) and the absence of second-order autocorrelation (AR2). The lagged value of the dependent variable is significantly positive at the conventional level. This reveals that the past value of the shadow economy increases the magnitude of the present value.

Regarding the asymmetric components, this study builds upon the works of Ahmed et al. (2021), Altintas and Kassouri (2020), and Arnaut et al. (2023) in interpreting the coefficients. The positive shock (EC^+) is interpreted directly; conversely, the negative shock (EC^-) is interpreted with the coefficients reversed. Considering this, Table 4 suggests that positive economic complexity (EC^+) has a significantly negative effect on shadow economy, whereas the effect is not significant in the AMG model. Specifically, the results indicate that a unit increase in positive economic complexity shocks reduces the shadow economy by 0.116, 0.054, and 0.120 in the 2SGMM, PMG, and CCEMG models, respectively. This indicates that the growth in the sophistication and complexity of the economic structure helps curb the extent of the shadow economy. Furthermore, producing high-quality products makes activities in the shadow economy less attractive and reduces its size.

Meanwhile, the negative shock of economic complexity (EC^-) has a significant influence on the size of the shadow economy in the region in the 2SGMM, AMG, and CCEMG models. Specifically, the coefficients indicate that a unit increase in the negative economic complexity shock (EC^-) increases the size of the shadow economy on average by 0.205, 0.985, and 0.201 in the 2SGMM, AMG, and CCEMG models, respectively. The presence of asymmetry in economic complexity is further examined using the Wald coefficient test. The test results in Table 2 indicate asymmetry in the relationships across all models. Specifically, this indicates that the relationship's assumptions of linearity and symmetry may be too restrictive and do not accurately reflect the realities of the nexus between economic complexity and the shadow economy.

Correspondingly, economic growth, a measure of the official or formal economy, has a significant negative effect on the shadow economy in all models. In contrast population growth rate and financial development have a significantly positive influence on the size of the shadow economy in the long run in selected African countries. This result shows that the shadow economy provides alternative to the growing population in terms of employment opportunities. Furthermore, the result reveals that the financial architecture of African countries supports the growth of informal economy through the diversion of fund. Furthermore, the institutional lapses allow credit to be channelled from the official economy to the unofficial economy. This subsequently spurs the growth of the shadow economy.

Table 2. Baseline regression results

	2SGMM	PMG	AMG	CCEMG
SHE(-1)	0.852 ^a (0.000)			
EC ⁺	-0.111 ^b (0.031)	-0.054 ^a (0.000)	-0.097 (0.620)	-0.120 ^b (0.014)
EC ⁻	-0.205 ^a (0.002)	-0.976 (0.255)	-0.985 ^a (0.000)	-0.201 ^a (0.002)
GDP	-0.002 ^b (0.046)	-0.001 ^a (0.000)	-0.001 ^a (0.000)	-0.004 ^b (0.023)
POP	0.016 ^b (0.037)	0.053 (0.000)	0.065 ^a (0.000)	-0.139 (0.618)
FD	0.017 ^a (0.000)	-0.168 (0.000)	0.021 ^a (0.000)	-0.114 (0.248)
Constant		-3.556 ^a (0.000)	8.295 ^a (0.000)	0.038 ^a (0.000)
Wald test (asymmetric components)	-4.065 ^a (0.000)	38.71 ^a (0.000)	7.31 ^a (0.007)	14.88 ^a (0.000)
AR(1)	-2.402 ^b (0.016)			
AR(2)	-0.173 (0.862)			
J-statistic test	23.649 (0.482)			
RMSE			1.813	6.41

Note: a, b, and c suggest 1%, 5% and 10% levels of significance. First-differenced variables in used in 2SGMM.

Source: own work.

3.2. Robustness check: Alternative measures of shadow economy

The robustness check verifies the estimates from Table 2 using additional proxies for the shadow economy. The study uses two alternative sources of data. Firstly, the shadow economy data from Medina and Schneider (2019), based on the Multiple Indicators Multiple Causes framework, are reported in Table 3. Second, shadow economy data based on a dynamic general equilibrium model by Elgin et al. (2021) are also applied, and the results are presented in Table 4. The findings from Table 3 reveal that positive shocks in economic complexity (EC⁺) significantly reduce the size of the shadow economy, where-

as negative shocks in economic complexity (EC^-) have the opposite impact. Similarly, the result in Table 4 (DGE proxy) also aligns with the main findings presented in Table 2. These results from the alternative proxies establish the presence of an asymmetric effect of economic complexity on the size of the shadow economy in Africa. For other control variables, economic growth substantially reduces the size of the informal economy, while financial development positively influences the growth of the shadow economy. However, population growth has a mixed impact on the size of shadow economy. In summary, the results from the alternative long-run estimates are consistent with those from Table 2 (baseline results), with only slight variations in the size and significance of the coefficient.

Table 3. Regression results for alternative proxy of shadow economy MIMIC from Medina and Schneider (2019)

	2SGMM	PMG	AMG	CCEMG
SHE(-1)	0.863 ^a (0.000)			
EC ⁺	-0.828 ^a (0.000)	-0.771 ^c (0.064)	-0.132 (0.634)	-0.574 ^b (0.026)
EC ⁻	0.472 (0.113)	-1.464 (0.220)	-0.847 ^a (0.000)	0.091 (0.055)
GDP	-0.002 ^c (0.072)	-0.002 ^a (0.000)	-0.001 ^a (0.000)	-0.044 ^b (0.033)
POP	-0.002 (0.945)	0.074 ^a (0.000)	-0.091 ^a (0.000)	0.313 (0.304)
FD	0.085 ^a (0.000)	0.146 ^a (0.000)	0.041 ^a (0.000)	-0.159 (0.461)
Constant		-4.440 ^a (0.000)	7.519 ^a (0.000)	6.992 ^a (0.000)
Wald test (asymmetric components)	-4.961 ^a (0.000)	0.92 (0.339)	5.04 ^b (0.025)	0.929 (0.761)
AR(1)	-3.498 ^a (0.000)			
AR(2)	-1.633 (0.102)			
J-statistic test	25.577 (0.482)			
RMSE			2.449	7.56

Note: a, b, and c suggest 1%, 5% and 10% levels of significance.

Source: own work.

Table 4. Regression results for alternative proxy of shadow economy DGE from Elgin et al. (2021)

	2SGMM	PMG	AMG	CCEMG
SHE(-1)	0.942 ^a (0.000)			
EC ⁺	-0.100 ^c (0.094)	-0.681 ^a (0.000)	-0.271 ^c (0.098)	-0.077 (0.872)
EC ⁻	-0.255 ^a (0.000)	-0.596 ^b (0.027)	-0.024 ^b (0.031)	0.354 (0.975)
GDP	-0.002 ^a (0.005)	-0.001 ^c (0.067)	-0.003 ^b (0.042)	-0.001 ^b (0.028)
POP	-0.001 (0.992)	-0.056 ^b (0.034)	-0.206 (0.625)	0.287 (0.977)
FD	-0.001 (0.201)	0.201 ^a (0.000)	0.010 (0.585)	-0.011 (0.955)
Constant		1.757 (0.155)	7.349 ^a (0.000)	4.641 (0.796)
Wald test (asymmetric components)	-1.906 ^c (0.057)	4.329 ^b (0.031)	6.502 ^b (0.025)	1.02 (0.783)
AR(1)	-3.964 ^a (0.000)			
AR(2)	1.898 (0.102)			
J-statistic test	19.048 (0.518)			
RMSE			0.288	0.30

Note: a, b, and c suggest 1%, 5% and 10% levels of significance.

Source: own work.

3.3. Threshold effect

This section examines the threshold effect of economic complexity on shadow economy using the dynamic panel threshold approach proposed by Seo et al. (2019). The result of the threshold analysis is presented in Table 5. The results reveal that when economic complexity is below the threshold level of 0.41, it contributes significantly to the growth of the informal economy. Conversely, at the upper threshold of 0.41, economic complexity reduces the size of the shadow economy. This result provides evidence of nonlinearity in the relationship between economic complexity and the shadow economy.

Regarding other variables, the lagged shadow economy has a significant positive impact on itself at the lower regime, indicating that the historical value of the shadow economy has a substantial influence on its current value. Furthermore, the non-significant impact of the lagged variable in the upper regime highlights the importance of economic sophistication in mitigating the shadow economy. Economic growth, as a proxy for the official economy, has a significantly negative impact on the shadow economy in both regimes. It shows that the shadow economy and the official economy are inversely related. On the other hand, financial development has a significant positive effect on the shadow economy at the upper regime, whereas population growth has no significant impact in any of the regimes.

Table 5. Threshold estimate of economic complexity using dynamic panel threshold (dependent variable: SHE)

<i>r</i>	0.41 ^a (0.000)	
	Low (<0.41)	High (>0.41)
SHE(-1)	0.460 ^a (0.000)	0.022 (0.959)
EC	0.479 ^a (0.043)	-0.925 ^a (0.009)
GDP	-0.001 ^b (0.032)	-0.002 ^b (0.025)
POP	0.318 (0.124)	-0.046 (0.109)
FD	-2.903 (0.172)	5.282 ^a (0.002)
Constant	5.953 (0.49)	

Note: a and b are 1% and 5% levels of significance.

Source: own work.

3.4. Discussion

This study found evidence of asymmetric and nonlinear relationships between the shadow economy and economic complexity in 28 African countries. The results consistently indicate that positive shocks to economic complexity decrease the size of the shadow economy. Conversely, negative shocks in economic complexity contribute to the growth of shadow economy. Furthermore,

technological sophistication and knowledge-based productive capacities create opportunities and expand exports, thereby affecting the degree of trade openness and output in the official market, and consequently reducing the motivation to engage in the shadow economy (Hidalgo, 2021).

Studies have revealed that increased economic complexity facilitates foreign direct investment flows, expanding the official economy's opportunities (Boleti et al., 2021; Osinubi & Ajide, 2022). Highly complex economies foster skilled, knowledge-based job places, allowing those in the shadow economy to migrate into the main economy. To be more precise, this result from the asymmetric relationship indicates that increasing economic complexity is a crucial tool for achieving sustainable development, thereby strengthening human capital, which in turn leads to a reduction in income inequality and the presence of the shadow economy (Dada et al., 2024b; Djeunankan et al., 2023; Lee & Vu, 2020). This result does not stand alone, however, as it is comparable to the empirical studies by Nguyen (2022), Ajide (2022), and Ketu et al. (2024), who found that economic complexity serves as an important policy tool for limiting the growth of the shadow economy. Studies have also documented the adverse effect of a fall in economic complexity on the growth of the informal economy. For instance, Ajide and Dada (2024) found that the effect of economic complexity on the shadow economy in Africa is heterogeneous, with economic complexity positively influencing the shadow economy in countries such as Botswana, Madagascar, and Tunisia.

The threshold regression buttresses the result obtained from the asymmetric analysis. The results show that economic complexity reduces the shadow economy at the upper threshold regime but exacerbates it at the lower threshold regime. Studies have documented the threshold level of economic complexity in influencing socioeconomic variables. For example, Azami et al. (2024) found a threshold of economic complexity of 1.12 in the relationship between economic complexity and ecological footprint across selected Asian countries. Similarly, Azizi (2020) identified a threshold of -1.15 in the relationship between economic complexity and energy consumption in Iran. Additionally, Elazhary et al. (2024) found the threshold of economic complexity to be -0.301 in the relationship between foreign direct investment and industry value-added in Egypt. This finding corresponds with a few studies that have noted a nonlinear relationship between the shadow economy and other economic factors (Ajide & Dada, 2024; Wu & Schneider, 2019).

Economic growth, as a proxy for the formal economy, has an inverse relationship with the shadow economy. This result aligns with the neoclassical, dualist, and voluntarist theories. Such an outcome supports various empirical findings on the relationship between the shadow economy and the official economy. For example, the study by Chen (2012) found that economic growth reduces the extent of the informal economy.

Population growth significantly increases the size of the shadow economy. This economy provides an escape route for those who cannot work in the official economy due to unemployment or limited opportunities. This result aligns with the findings of Dada et al. (2024a), Kpognon (2022), and Njangang et al. (2020). Lastly, the finding shows that financial development contributes to the growth of the shadow economy. This reveals that loopholes and lapses in the financial sector culminate in opportunistic behaviour among economic agents, leading to credit being diverted from the official to the shadow economy. It suggests that the financial market diverts funds from the real sector of the economy, thereby thwarting entrepreneurial activities in the official economy. This result is consistent with the research conducted by Ajide and Dada (2024) and Nguyen and Thanh (2020).

Conclusions

The impact of economic complexity on socioeconomic activities, especially the shadow economy, remains a matter of debate in the research community. While some studies acknowledged the positive role of economic complexity in reducing the size of the shadow economy, others found a negative influence. This study therefore takes a step forward by scrutinising the asymmetric impact of economic complexity on the size of the shadow economy using a dataset of 28 African nations from 1995 to 2020. To this end, estimation techniques such as 2SGMM, PMG, AMG, and CCEMG are employed.

The study's results reveal that positive economic complexity shocks mitigate the size of shadow economy, while negative economic complexity shocks contribute to its growth. This result establishes the presence of asymmetries, as the shadow economy reacts differently to positive and negative shocks in terms of economic complexity. Furthermore, the threshold level of economic complexity in the region is 0.41 on a scale of -2.5 to $+2.5$. While economic complexity contributes to the shadow economy below the threshold, it reduces its size above the threshold. Economic growth has a significant negative impact on the shadow economy. However, population growth and financial development positively affect the size of this economy. These findings are robust to alternative proxies of the shadow economy.

Based on the conclusions of this study, the following policy recommendations are proposed. The study found that positive shocks in economic complexity has a beneficial effect in reducing the size of the shadow economy in the region. Hence, policies aimed to increase the complexity of the economy should be pursued effectively. These policies include massive investment in human capital, infrastructure, research and development, and technological innovation, which could boost the productive knowledge in the economy.

Economic complexity is found to improve in the presence of advanced technology and automation. Therefore, efforts should be directed to technological advancements and a transition to a knowledge-driven economic system. All these can further reduce the size of Africa's shadow economy. The complexity of the economic system can only emerge from high-quality human education, highly skilled training, and an empowerment programme. Therefore, policymakers should prioritise this area to discourage potential participation in the shadow economy.

Although this study has limitations, it can serve as a guide for future research. Firstly, the asymmetry in the relationship between economic complexity and shadow economy is assessed within African countries. Future studies can extend this asymmetry to Asian and Latin American countries. Secondly, future studies might investigate the interaction between economic complexity and other economic characteristics. Thirdly, the study does not focus on the dual nature of informality (informal employment vs. informal production), which could have differential relationships with economic complexity. Moreover, institutional indicators that capture labour market dynamics, rigid infrastructure, and institutional inefficiency are not included in the model due to the unavailability of reliable data. Thus, future studies could consider this important aspect when examining informality as reliable data for African economies becomes available. Lastly, the study focuses on a heterogeneous panel of countries. Hence, a country-specific study that considers each country's specificities could be conducted on the relationship in an asymmetric framework.

Appendix

Table A1. List of countries

Algeria	Malawi
Angola	Mali
Botswana	Morocco
Burkina Faso	Mozambique
Cameroon	Namibia
Congo Republic	Nigeria
Congo Democratic	Senegal
Egypt	South Africa
Gabon	Sudan
Ghana	Togo
Guinea	Tunisia
Ivory Coast	Uganda
Kenya	Zambia
Madagascar	Zimbabwe

Source: own work.

Table A2. CD test

	PS LM	BCS LM.	P CD
SHE	132.799 ^a	132.195 ^a	44.207 ^a
EC ⁺	304.187 ^a	303.583 ^a	95.355 ^a
EC ⁻	301.808 ^a	301.204 ^a	94.994 ^a
GDP	216.437 ^a	215.833 ^a	57.725 ^a
POP	313.885 ^a	313.281 ^a	86.559 ^a
FD	195.349 ^a	194.744 ^a	60.271 ^a

Note: a suggests 1% level of significance.

Source: own work.

Table A3. Stationarity test

Variables	CADF		CIPS	
	SHE	-1.871	-3.641 ^a	-2.013
EC ⁺	-1.831	-3.041 ^a	-1.954	-5.091 ^a
EC ⁻	-1.364	-3.445 ^a	-1.689	-4.769 ^a
GDP	-1.362	-2.618 ^a	-1.176	-3.835 ^a
POP	-1.881	-4.428 ^a	-1.516	-3.284 ^a
FD	-1.365	-2.905 ^a	-2.071 ^c	-5.092 ^a

Note: a and c suggest 1% and 10% levels of significance.

Source: own work.

Appendix 4. Westerlund cointegration test

	Value	<i>z</i> -value	Robust <i>p</i> -value
G _t	-6.192 ^a	-20.146	0.000
G _a	-1.841	5.874	1.000
P _t	-8.132 ^b	-6.252	0.022
P _a	-1.952	1.643	0.847

Note: a and b suggest 1% and 5% levels of significance.

Source: own work.

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