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TECHNOLOGICAL SOPHISTICATION AND FINANCIAL DEVELOPMENT IN AFRICA: THE MODERATING ROLE OF INSTITUTIONAL QUALITY

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Abstract. The present study attempts to examine the nexus between technological sophistication and financial development in Africa. More specifically, whether the former contributes to the latter, and whether this nexus depends on institutional quality. To this aim, we use annual panel data for 52 African countries covering the period 2002 to 2020. Fixed-effects models are applied, complemented with institutional threshold regression, heterogeneity analysis, and various robustness checks. The empirical findings reveal that technological sophistication, as proxied by high-technology exports, has a positive effect on financial development (FD). The rule of law also appears to exert a positive effect. This significantly reinforces the nexus between financial development and technological sophistication. Further, the threshold analysis reveals that it is only after a critical level is reached in institutional quality that technological sophistication becomes much more effective. In addition, the positive effects are mainly observed in countries with stronger institutional environments and are more pronounced for financial institutions rather than financial markets. This fact highlights how financial development in Africa is of a multidimensional nature. Therefore, it suggests that technology policy alone is not sufficient. Investment efforts in technological capability should be additionally sustained with regulatory quality in African countries. Also, stronger institutions, investor protection, and digital financial infrastructure must be taken into account so as to better convert technological capability into deeper, inclusive, sustainable financial systems.

Keywords: technological sophistication, financial development, institutional quality, rule of law, Africa.

JEL Classification: O33, G20, O16, O55.

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1. Introduction

Financial development is an essential and central requirement for economic transformation. An efficient financial system helps mobilize savings and allocate credit. It also supports investment, facilitates payments, and helps firms manage risks. With regard to African economies, these functions are especially important as the continent keeps facing persistent constraints in financial access, intermediation, market depth, and institutional credibility (Allen et al., 2011, 2014; Demetriades & Fielding, 2012; Aluko & Ibrahim, 2020).

At the same time, these economies are going through a rapid technological transformation. The expansion of digital services, mobile connectivity, information and communication technology (ICT), and technology-related trade has created new opportunities. Opportunities

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aiming at reducing transaction costs and widen access to finance. Prior studies have shown that digital finance and ICT adoption can support financial inclusion, economic activity, and financial sector transformation (Ozili, 2018; Myovella et al., 2020; Khera et al., 2021; Shen et al., 2021). More recent African evidence suggests that technology and digital trade, along with the use of the Internet, have an association with financial development-related outcomes in Sub-Saharan Africa (Azeez et al., 2025). In the same vein, Edo (2025) showed that, across emerging regions, digital transformation positively sustains financial development. More particularly, observations are made in Sub-Saharan Africa, with emphasis on the complementary roles of monetary policy, institutional quality, and fiscal policy. However, the expansion of technology does not automatically turn into financial development. This is noticed especially in countries where the institutional capacity remains weak.

Although technology helps expand financial possibilities, it is still necessary to determine whether these possibilities translate into financial systems. Financial systems that are deeper, more efficient, and more inclusive. It results that the impact of technology on finance may not be linear or automatic. Relevant theories (e.g., the Institutional theory and law-and-finance arguments) suggest that rule enforcement, investor protection, regulatory quality, and the control of corruption are essential components of financial development (North, 1991; La Porta et al., 1998; Acemoglu et al., 2005). In environments like Africa, that are characterized by weak institutions, technological capabilities, and shallow financial systems coexist. This is because weak enforcement, poor regulation, and corruption are capable of obstructing the conversion of technology-related opportunities into formal financial deepening. What is being implied is that the moderating effect of institutional quality may not be limited to the relationship between technology and finance. It may also define a minimum threshold above which technological sophistication becomes productive financially. This view is further supported by recent studies which show that institutional quality strengthens the contribution of financial inclusion, innovation, and digital transformation to economic and financial outcomes (Abdulai et al., 2026; Madani et al., 2026).

Several existing studies have examined related channels of influence. For example, we can mention Chinoda and Kapingura (2024). They studied institutions, governance, digital financial inclusion, and growth in Sub-Saharan Africa. Later, Saeed et al. (2025) examined access to and governance of information and communication technology in the finance-growth nexus. Coming to Azeez et al. (2025), they analyzed technology, digital trade, the use of the Internet, and financial sustainability in Sub-Saharan Africa. The moderating role of institutional quality in the economic complexity-financial development nexus in Africa was studied by Olaniyi and Odhiambo (2023). Still with institutional quality, more recently, studies demonstrated that it amplifies the stabilizing effect of financial inclusion (Chaurasiya & Singh, 2026). Also, Nsiah and Tweneboah (2025) show that after institutional quality exceeds a critical threshold, only then does financial inclusion become more effective in the reduction of poverty. Likewise, Madani et al. (2026) found that the effects of institutional quality and financial development on green technological innovation are not linear. Also, these effects depend on thresholds that are development-specific. These studies are important, as they reinforce the growing consensus that institutions have a conditional effect on the effectiveness of technology and finance. Yet, they leave a question unanswered. The question of

whether technological sophistication promotes financial development in Africa through an institutional-quality channel. Moreover, they leave open the question of whether the relationship between technology and finance is different across institutional regimes and the main dimensions of financial systems in Africa.

This gap is addressed in this study. For this purpose, we examine whether technological sophistication promotes financial development in Africa. We also examine whether institutional quality moderates the relationship. The present study investigates technological sophistication seen as a broader measure of productive capability. This is contrary to previous studies, which put focus primarily on financial inclusion, digital finance, economic growth, or economic complexity. It simultaneously examines its moderating, direct, and threshold effects on financial development. This study contributes to the literature in four main ways. Firstly, it shifts the focus from digital access taken alone to technological sophistication as a broader indicator of productive capabilities, while at the same time acknowledging that high-technology exports stand as an important dimension of productive technological capability, although they do not capture fintech adoption, domestic innovation, or firm-level technological upgrading entirely. Nevertheless, they remain an ideal proxy for participation in technology-intensive exports and production, which is especially relevant to African economies' structural transformation. Secondly, it tests the quality of institutions as a conditioning mechanism in the technology finance relationship, including whether there is an institutional threshold beyond which technological sophistication becomes more effective in the promotion of financial development. The third way in which the study contributes is that it assesses whether this relationship is different across financial institutions, markets, access, depth, and efficiency. Also, it further examines heterogeneity between strong and weak institutional contexts in Africa. The fourth and final way is through the integration of threshold estimation, moderation analysis, and multidimensional financial development indicators within a unified empirical framework. Through this integration, the study provides a more comprehensive assessment of how, when put together, institutions and technology shape financial development in African economies.

From here on, the remainder of this paper follows the structure below: the relevant literature review and hypotheses are covered in Section 2. In Section 3 the study data and methodology are presented. Section 4 reports the empirical results and discusses the findings and policy implications. The conclusions is in Section 5.

2. Literature review and hypothesis development

2.1. Technology, productive capability, and financial development

The root of the connection between technology and finance can be found in the broader literature on innovation, productive transformation, and financial intermediation. Schumpeter (1934) argued that finance promotes innovation by providing businesses and entrepreneurs with the resources they need for the implementation of new combinations. The supply-leading hypothesis, as per Patrick (1966), at the same time suggests that financial development can stimulate real-sector transformation. This is accomplished by directing capital toward expanding and innovative sectors.

This logic is further extended and complemented by recent work on productive capability. For example, Hidalgo and Hausmann (2009) and Lapatinas (2019) have argued that productive knowledge and technological capability play a central role in economic transformation. Economies that are endowed with more sophisticated technological structures are highly likely to require more advanced financial services. Credit, trade finance, payment infrastructure, investment channels, and risk management instruments are among those services. In this sense, technological sophistication is capable of increasing both the demand for finance and the complexity of financial services required by firms and households.

In the present study, we use high-technology exports to proxy for technological sophistication. This proxy is relevant because it captures one dimension of productive sophistication, namely, the extent to which an economy participates in technology-intensive production and export activities. However, technological sophistication covers many dimensions. The proxy for high-technology exports does not fully capture domestic innovation capacity, fintech adoption, digital entrepreneurship, or firm-level technological upgrading. This limitation is particularly important in the African context, where high-technology exports may reflect only in part foreign-owned production, enclave activities, or an export structure based on assembly. As such, we interpret the proxy as an indicator of productive technological sophistication instead of a complete measure of domestic technological capability. Nonetheless, high-technology exports remain an ideal proxy because they reflect the participation of a country in higher value-added production and technology-intensive trade. The two of them require increasingly sophisticated investment mechanisms and financial intermediation.

With time, the role played by technology in African development has increasingly been supported by empirical studies. An example is that of Mensah et al. (2023), who showed that technology stimulates long-run output growth in Africa and strengthens the growth-enhancing role of financial development. Later, Azeez et al. (2025) found that the use of the Internet, digital trade, and technology are associated with financial development outcomes in Sub-Saharan Africa. Similarly, Edo (2025) reports that digital transformation helps promote financial development across emerging regions significantly. In addition, this has particularly strong effects in the Sub-Saharan Africa region. In addition, he highlighted that macroeconomic policies in combination with institutional quality and trade reinforce these gains.

From these findings, we can observe that technological progress has the capability to stimulate financial development through multiple channels. Among these channels, we have lower transaction costs and improved information flows. Additionally, we can identify greater financial inclusion and enhanced financial intermediation. However, the issue with these studies is that they fail to directly examine whether technological sophistication promotes financial development in Africa. Moreover, most of the currently available studies mostly put focus on ICT adoption, digitalization, or financial inclusion. Whereas relatively little to no attention has been devoted to technological sophistication as a broader measure of productive capability along with its implications for multidimensional financial development.

This leads to the first hypothesis:

H1: *Technological sophistication positively affects financial development in Africa.*

2.2. Institutions, governance, and financial systems

Financial development not only depends on economic resources but also depends on the rules governing financial transactions. North (1991) demonstrates this by arguing that institutions help reduce uncertainty and shape incentives. As for La Porta et al. (1998), they show that legal systems, investor protection, and enforcement quality serve to influence financial development (FD). Further, Acemoglu et al. (2005) emphasize the importance of institutions for long-run development.

In African economies, institutional weaknesses are still a major constraint affecting financial development. In fact, weak contract enforcement and corruption, to which is added regulatory inefficiency, can undermine confidence in formal finance. This will also distort credit allocation. Following this line of thought, Olaniyi and Odhiambo (2023) argue that weak institutional environments in Africa allow rent-seeking and opportunism. As a result, this can divert financial resources away from R&D, technology, and entrepreneurial innovation. Later, Adekoya et al. (2025) also develop the role of institutional quality. They show that in Africa this role is complex, especially when there is an interaction between finance and technological innovation. More recent evidence further reinforces the central role of institutions. For example, Boukhatem and Ben Moussa (2025) report their findings using evidence from the MENA region. In their analysis they show that institutional quality has a positive association with long-run economic performance. Yet they also show that, at the same time, weak institutional environments constrain the benefits of financial inclusion development. A year later, in a similar way, Chaurasiya and Singh (2026) demonstrated that institutional quality and financial inclusion jointly can lower financial risk in the BRICS economies. Further, the results show that their interaction produces a significantly stronger effect. Such an effect is not produced when either factor is considered individually. Drawing from these findings, it appears that institutional quality goes beyond directly supporting financial sector development. It also strengthens the effectiveness of complementary financial and technological mechanisms.

Institutions matter in this context because they have an influence on whether financial actors trust contracts. Also, they have an influence on whether investors are protected. Their effect goes further, as they influence the possibility for innovative firms to access credit. They further influence whether digital financial activities are credibly regulated. Strong institutions also improve regulatory certainty and market confidence. They also diminish information asymmetries. Similar types of institutions also facilitate a more efficient allocation of financial resources directed toward activities that are productive and technology-intensive.

This present literature review suggests that when institutions are stronger, the greater the improvement in financial development. This will be observed through the strengthening of regulation, trust, enforcement, as well as allocation of resources. Overall, it appears that both the theoretical and recent empirical literature consistently indicate that, in developing economies, institutional quality constitutes a fundamental prerequisite for sustainable financial development. This is even more obvious in developing economies characterized by significant governance constraints. As such, the second hypothesis of this study states:

H2: *Institutional quality positively affects financial development in Africa.*

2.3. Why institutions may condition the technology–finance relationship

The previous two reviews imply that technology and institutions matter for financial development, but both are unlikely to operate in an independent way of each other. In fact, technological sophistication can create demand for more advanced financial services. But while this is true, it is institutional quality that determines if financial systems can respond effectively. In countries or areas where legal enforcement is weak, technology firms may struggle to access credit. As well, where regulation is poor, digital finance may be able to expand, yet without bringing improvement to stability or efficiency. And where corruption is high, finance may be diverted from productive technological sectors. Therefore, institutions are capable of converting technological sophistication into financial development by reducing uncertainty and transaction costs. Through this, they will limit information asymmetry, which will ensure investor protection, and improve the credibility of financial contracts.

Also, it matters that this conditioning not be considered nonlinear. In institutional environments that are weak, technological sophistication may remain disconnected from formal financial development. This is because financial systems do not have the enforcement capacity and regulatory quality needed to support technology-intensive activities. By contrast, the moment institutional quality reaches a pretty sufficient level, technological sophistication is more likely to help stimulate credit allocation, digital finance, payment infrastructure, and demand for more advanced financial services. Thus, the role of institutions may include moderation, but also include a threshold effect. An example is that of Nsiah and Tweneboah (2025), who identify thresholds of institutional quality beyond which financial inclusion becomes significantly more effective in helping reduce poverty across African countries. This suggests that once minimum governance conditions are achieved, institutional improvements begin generating increasing returns. This threshold perspective provides additional theoretical support. It supports assessing whether technological sophistication exerts stronger effects on financial development after institutional quality surpasses a critical level.

The conditioning role being discussed is further supported by other related evidence related to the African context. Chinoda and Kapingura (2024), in their study, found that, in sub-Saharan Africa, governance and institutions strengthen the nexus between digital financial inclusion and economic growth. A year later, Saeed et al. (2025) showed that access to ICT amplifies the finance and growth relationship, while governance further strengthens it. Tidjani and Madouri (2024) found that financial inclusion and financial technology have a supporting role in sustainable development in Africa, but their interaction is weakly negative, indicating that technology-finance complementarities are not guaranteed. Olaniyi and Odhiambo (2023) also show that institutional thresholds are important in the finance–economic complexity nexus. Chaurasiya and Singh (2026) recently reported that institutional quality significantly strengthens the contribution of financial inclusion to financial stability, while Abdulai et al. (2026) found that institutional quality catalyzes the effect of innovation on entrepreneurship development in Africa. It is in the same vein that Nsiah and Tweneboah (2025) managed to identify institutional quality thresholds beyond which financial inclusion becomes substantially more effective. This thus provides more support for the examination of institutional threshold effects in the technology and finance nexus.

Overall, these studies appear to suggest that technology-related financial gains are dependent on institutional conditions. Therefore, in the present research, institutional quality is expected to strengthen the effect technological sophistication has on financial development. In addition, the analysis examines whether it is only after institutional quality crosses a critical threshold that this relationship gets stronger. Thus, the third hypothesis is formulated as follows:

H3: *Institutional quality positively moderates the effect of technological sophistication on financial development.*

2.4. Financial development as a multidimensional outcome

Financial development requires several components; it is not a single process. This process includes the development of financial institutions and markets, as well as improvements in financial access, depth, and efficiency. Since technological sophistication may affect these dimensions in different ways, this distinction becomes very important. As an example, technology may expand access through digital channels before it improves the capital market depth. Technology may also strengthen financial institutions faster than financial markets do. This is even more so in economies characterized by shallow securities markets.

This distinction becomes particularly relevant for Africa, as is evident in many African economies. This is because financial systems are more institution-based and less market-based. Banks, microfinance institutions, and payment providers often play a more central role than stock markets. Stock markets are known to be frequently characterized by shallowness, illiquidity, weak integration, and limited listed firms and investor participation. It results that technological sophistication may first affect financial institutions before producing effects visible in capital markets. The way technological sophistication affects financial institutions would be through credit, payments, digital channels, and intermediation.

In recent years, many empirical studies further support this multidimensional perspective. In fact, a finding by Edo (2025) shows that the contribution of digital transformation to financial development is different across emerging regions; this is reinforced by institutional quality and macroeconomic conditions. In a similar way, it was shown by Adekoya et al. (2025) that technological innovation exerts heterogeneous effects across financial institutions and markets in Africa. What is suggested is that different dimensions of financial development have different responses to technological progress. These findings indicate that, across its underlying components, aggregate measures of financial development may conceal important differences.

Azeez et al. (2025), in their study, have demonstrated the existence of non-homogeneous effects of technology-related variables across financial development indicators in sub-Saharan Africa. Among these indicators, they identified access, depth, and efficiency. In the same vein, other recent studies increasingly tend to argue that the analysis of financial development (in its separate dimensions) provides a more comprehensive understanding. This understanding focuses on how institutions and technology, combined, influence financial systems, instead of solely relying on aggregate indices. This comes in support to the need to move beyond aggregate financial development and examine the disaggregated outcomes. This will allow the

identification of heterogeneous responses across financial markets, access, efficiency, depth, and financial institutions. This approach, beyond being multidimensional, also represents one of the major contributions of this study. In fact, it allows a more nuanced evaluation of the channels through which institutional quality and technological sophistication, when put together, help shape financial development in Africa. These considerations lead to the study's fourth and last hypothesis:

H4: *The technological sophistication effect is different across financial institutions and markets, access, depth, and efficiency.*

3. Data and methodology

3.1. Data and sample

In this study, we use annual panel data for African countries from 2002 to 2020. The dataset was constructed by merging three datasets. These datasets are the International Monetary Fund (IMF) Financial Development Index Database, the World Bank (WB) World Development Indicators (WDI), and the World Bank Worldwide Governance Indicators (WGI). The initial data collection covered 54 African countries spanning 2000 to 2024. However, the final sample is restricted by data availability and macroeconomic variables. As such, the final dataset covers 52 African countries from 2002 to 2020. The retained countries are listed in Table 1 below.

Table 1. List of countries included in the analysis

No.	Country	No.	Country	No.	Country
1	Algeria	19	Eswatini	37	Namibia
2	Angola	20	Ethiopia	38	Niger
3	Benin	21	Gabon	39	Nigeria
4	Botswana	22	Gambia	40	Rwanda
5	Burkina Faso	23	Ghana	41	São Tomé and Príncipe
6	Burundi	24	Guinea	42	Senegal
7	Cabo Verde	25	Guinea-Bissau	43	Seychelles
8	Cameroon	26	Kenya	44	Sierra Leone
9	Central African Republic	27	Lesotho	45	South Africa
10	Chad	28	Liberia	46	South Sudan
11	Comoros	29	Libya	47	Sudan
12	Congo, Republic of	30	Madagascar	48	Tanzania
13	Congo, Democratic Republic of	31	Malawi	49	Togo
14	Côte d'Ivoire	32	Mali	50	Tunisia
15	Djibouti	33	Mauritania	51	Uganda
16	Egypt	34	Mauritius	52	Zambia
17	Equatorial Guinea	35	Morocco		
18	Eritrea	36	Mozambique		

Note: Somalia and Zimbabwe were excluded from the final sample because of insufficient or inconsistent observations across the core variables after merging datasets.

The country-year panel is organized around the variables listed below in Table 2. Also, the sample period ends in 2020 since the financial development indicators are not consistently available beyond that year for the full African sample.

Table 2. Variable definitions and sources

Variables	Definition	Source
fd_index	Financial Development Index	IMF
fi_index	Financial Institutions Index	IMF
fi_access	Financial Institutions Access Index	IMF
fi_depth	Financial Institutions Depth Index	IMF
fi_eff	Financial Institutions Efficiency Index	IMF
fm_index	Financial Markets Index	IMF
fm_access	Financial Markets Access Index	IMF
fm_depth	Financial Markets Depth Index	IMF
fm_eff	Financial Markets Efficiency Index	IMF
credit	Domestic credit to private sector (% of GDP)	WDI
hightech	High-technology exports (% of manufactured exports)	WDI
ict_exports	ICT service exports (% of service exports)	WDI
rule_law	Rule of Law	WGI
gov_eff	Government Effectiveness	WGI
reg_qual	Regulatory Quality	WGI
corr_ctrl	Control of Corruption	WGI
gdppc	GDP per capita	WDI
inflation	Consumer price inflation (annual %)	WDI
trade	Trade (% of GDP)	WDI
internet	Individuals using the Internet (% of population)	WDI
mobile	Mobile cellular subscriptions per 100 people	WDI
tertiary	Gross tertiary school enrollment (%)	WDI

Note: IMF denotes the International Monetary Fund Financial Development Index database; WDI denotes the World Bank Development Indicators; WGI denotes the World Bank Worldwide Governance Indicators.

3.2. Variables

For this study, we use financial development as the dependent variable. The main measure for it is the IMF Financial Development Index (*fd_index*). To examine whether the results differ across financial system structures, this study also uses the Financial Institutions Index (*FI_index*) as well as the Financial Markets Index (*FM_index*). Further robustness tests use disaggregated financial development indicators: financial institution depth (*fi_depth*), access (*fi_access*), and efficiency (*fi_eff*), as well as financial market depth (*fm_depth*), access (*fm_access*), and efficiency (*fm_eff*). Domestic credit to the private sector (credit) is used as an alternative financial development measure.

The main explanatory variable is technological sophistication, proxied by high-technology exports as a percentage of manufactured exports (*high-tech*). ICT service exports as

a percentage of service exports (*ict_exports*) are used as an alternative technology proxy. Although high-technology exports do not capture all dimensions of domestic technological capability, they provide a useful indicator of productive sophistication and participation in technology-intensive activities. Accordingly, the present study interprets them as a proxy for one important dimension of technological sophistication, rather than simply a comprehensive measure of technological capability. In the African context, comparable cross-country measures of innovation capacity, technology adoption, and firm-level technological upgrading are known to remain limited over long periods of time. As such, high-technology exports provide a consistent indicator of the participation of countries in technology-intensive production and their integration into higher value-added manufacturing activities. The importance of this interpretation lies in the fact that, in Africa, high-technology exports may partly reflect export enclaves or foreign-owned production rather than fully domestic innovation capacity. As a consequence, the indicator should be interpreted as capturing productive technological sophistication instead of domestic innovation alone.

Institutional quality is the moderating variable. The main institutional measure is the rule of law (*rule_law*). Three alternative institutional indicators are used for robustness: government effectiveness (*gov_eff*), regulatory quality (*reg_qual*), and corruption control (*corr_ctrl*). We also use Rule of Law as the threshold variable, as it captures the enforcement environment through which technological capability can be translated into financial contracts, investor protection, credit allocation, and formal financial deepening.

The control variables are GDP per capita (*gdppc*), inflation (*inflation*), trade openness (*trade*), and internet use (*internet*). Additional control variables, which include mobile subscriptions (*mobile*) and tertiary school enrolment (*tertiary*), are used in the extended robustness specifications.

3.3. Model specification

The baseline model of the present study helps estimate the direct effect of technological sophistication on financial development:

$$FD_{it} = \alpha + \beta Tech_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \quad (1)$$

where FD_{it} denotes financial development in country i at time t, $Tech_{it}$ represents technological sophistication, X_{it} is the vector of control variables, μ_i captures country fixed effects, λ_t captures year fixed effects, and ε_{it} is the error term.

The institutional specification adds institutional quality:

$$FD_{it} = \alpha + \beta Tech_{it} + \delta Inst_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}. \quad (2)$$

In order to assess whether institutional quality has a moderating effect on the technology–finance relationship, this study estimates:

$$FD_{it} = \alpha + \beta Tech_{it} + \delta Inst_{it} + \theta\left(Tech_{it} \times Inst_{it}\right) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}. \quad (3)$$

The coefficient of interest is θ. A positive and significant value of θ would suggest that institutional quality strengthens the effect of technological sophistication on financial development.

Because the model includes an interaction term, the marginal effect of technological sophistication is

$$\frac{\partial \mathrm{FD}_{it}}{\partial \mathrm{Tech}_{it}} = \beta + \theta \mathrm{Inst}_{it}. \tag{4}$$

Accordingly, this study reports the marginal effect of technological sophistication at low, mean, and high levels of institutional quality. To go beyond a purely linear moderation framework, the study additionally estimates an institutional-threshold specification. Following this approach, the effect of technological sophistication is allowed to be different below and above an estimated Rule of Law threshold. The threshold model can be expressed as in Equation (5) below:

$$\mathrm{FD}_{it} = \alpha + \beta_1 \mathrm{Tech}_{it} \mathrm{I}\left(\mathrm{Inst}_{it} \leq \gamma\right) + \beta_2 \mathrm{Tech}_{it} \mathrm{I}\left(\mathrm{Inst}_{it} > \gamma\right) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}, \tag{5}$$

where γ is the estimated institutional threshold, I(.) is an indicator function, β_1 captures the effect of technological sophistication below the threshold, and β_2 captures the effect above the threshold. This specification tests whether technological sophistication contributes to financial development only after institutional quality reaches a sufficient level.

3.4. Estimation strategy

The main estimation approach is fixed effects with country and year effects included. Country fixed effects control for time-invariant differences across countries, while year fixed effects control for common shocks that affect African economies over time. We cluster the standard errors at the country level. The reason for this approach is that it is appropriate for panel data because it serves to reduce bias from unobserved country-specific heterogeneity that is constant over time (Baltagi, 2008; Wooldridge, 2010).

For the sake of estimating the institutional threshold analysis, we allow the coefficient on high-technology exports to be different across low and high institutional regimes. We select the Rule of Law threshold endogenously by running a search over candidate values and choosing the one that minimizes the residual sum of squares. This approach gives a practical way to test whether institutional quality creates a non-linear condition for the technology–finance nexus.

In order to account for heterogeneity across the African economies, the study also groups countries into weak and strong institutional regimes by using the median value of the Rule of Law indicator. This helps the analysis examine whether the effect of technological sophistication differs between countries with weaker governance conditions and stronger governance conditions.

In the same vein, the analysis then tests for cross-sectional dependence using the Pesaran CD test (Pesaran, 2004). Where cross-sectional dependence is detected, the Driscoll–Kraay standard errors are used since they are robust to heteroskedasticity, serial correlation, and cross-sectional dependence (Driscoll & Kraay, 1998; Hoechle, 2007).

To reduce concerns about simultaneity, we use lagged explanatory variables for additional specifications:

$$\mathrm{FD}_{it} = \alpha + \beta \mathrm{Tech}_{it-1} + \delta \mathrm{Inst}_{it-1} + \theta\left(\mathrm{Tech}_{it-1} \times \mathrm{Inst}_{it-1}\right) + \gamma X_{it-1} + \mu_i + \lambda_t + \varepsilon_{it}. \tag{6}$$

Finally, the system generalized method of moments (system GMM) is used as a robustness check for endogeneity. The dynamic model is specified as follows:

$$FD_{it} = \rho FD_{it-1} + \beta Tech_{it} + \delta Inst_{it} + \theta\left(Tech_{it} \times Inst_{it}\right) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}. \quad (7)$$

The system GMM is used only as a robustness estimator, as our main identification relies on fixed-effects models. The purpose it serves is to verify that the main findings stay robust after accounting for potential endogeneity. Endogeneity can arise from omitted variables, reverse causality, and the dynamic persistence of financial development. For the GMM regression, we report the Arellano–Bond AR (1) and AR (2) tests, the Hansen test, and the number of instruments. In order to limit the proliferation of instruments, the instrument count is kept below the number of countries, as per Roodman (2009). The system GMM is appropriate for addressing persistence, simultaneity, and dynamic endogeneity in panel models (Arellano & Bover, 1995; Blundell & Bond, 1998).

3.5. Robustness tests

We follow five steps for robustness checks. We first replace the dependent variable with *fi_index*, *fm_index*, and *credit*. The second step is to use disaggregated IMF indicators for the analysis: *fi_depth*, *fi_access*, *fi_eff*, *fm_depth*, *fm_access*, and *fm_eff*. The third step is to examine nonlinear and regime-specific effects by estimating institutional-threshold regressions and dividing the sample into weak and strong institutional regimes. In the fourth step, the main proxy for technology, high-tech, is replaced by *ict_exports*. In the fifth step, we replace the main institutional variable, *rule_law*, with *gov_eff*, *reg_qual*, and *corr_ctrl*. Finally, the model is estimated again using Driscoll–Kraay standard errors, lagged explanatory variables, and system GMM.

3.6. Diagnostic tests and graphical analysis

The study reports diagnostic tests for multicollinearity, serial correlation, heteroskedasticity, and cross-sectional dependence. The variance inflation factor (VIF) was employed to assess multicollinearity. As for heteroskedasticity, it was examined using the modified Wald test. To assess serial correlation, the Wooldridge test was used, and cross-sectional dependence was accounted for using the Pesaran CD test.

The empirical analysis is further supported by four figures. These figures show trends in financial development indicators, trends in technological sophistication, and a scatter plot between financial development and technological sophistication. A marginal-effects plot complements the whole, showing how the effect of technological sophistication changes across levels of institutional quality.

4. Empirical analysis

4.1. Descriptive statistics and preliminary evidence

This section presents the core analysis of the present study. The descriptive statistics for the final sample are presented in Table 3. In the order of their presentation, the mean value of

the Financial Development Index is 0.145, while the Financial Institutions Index has a higher mean of 0.224, and the Financial Markets Index has a much lower mean of 0.060. What this observation suggests is that financial development is driven more by financial institutions than by financial markets in the African context. The low mean values of financial market depth, access, and efficiency further indicate that African financial markets remain relatively shallow. This pattern shows consistency with Allen et al. (2011, 2014), who emphasize persistency in financial development and inclusion gaps in African economies. Further, it provides preliminary support to separately assess financial institutions and markets throughout the empirical analysis. As a matter of fact, technological sophistication may not affect all dimensions of financial development in a uniform way.

With regard to the technology variables, we observe that they also show substantial variations. For example, High-technology exports average 2.532 percent of manufactured exports, next to ICT service exports, which average 6.741 percent of service exports. These observations indicate that African economies are more engaged in ICT-related services compared

Table 3. Descriptive statistics

Variables	N	Mean	Std. Dev.	min	max
fd_index	988	0.145	0.110	0	0.643
fi_index	988	0.224	0.133	0	0.731
fm_index	988	0.060	0.106	0	0.583
fi_depth	988	0.112	0.160	0	0.878
fi_access	988	0.112	0.146	0	0.899
fi_eff	988	0.495	0.146	0	0.793
fm_depth	988	0.067	0.119	0	0.789
fm_access	988	0.067	0.160	0	0.915
fm_eff	988	0.041	0.136	0	1
credit	988	18.450	22.756	0	142.422
hightech	988	2.532	6.882	0	95.618
ict_exports	988	6.741	9.730	0	61.451
rule_law	988	44.913	11.338	0	74.672
gov_eff	988	37.347	12.381	0	72.739
reg_qual	988	43.934	10.166	0	72.799
corr_ctrl	988	35.242	12.678	0	72.948
gdppc	988	2363.192	2958.587	250.879	19481.646
inflation	988	7.534	16.916	–16.860	380
trade	988	60.085	44.322	0	347.720
internet	988	13.352	16.930	0	84.120
mobile	988	53.609	42.854	0	167.748
tertiary	988	6.714	10.189	0	58.544

Note: The table reports the descriptive statistics for the final country-year sample. Financial development indicators are obtained from the IMF Financial Development Index database. Institutional indicators are from the Worldwide Governance Indicators, and macroeconomic and technology variables are from the World Development Indicators.

to high-technology manufacturing exports. However, the high standard deviations for both variables indicate very strong cross-country differences in technological sophistication. This heterogeneity reinforces the need to examine not only the average effect of technological sophistication but also to check whether its financial-development effect is different when various settings of institutional conditions are considered.

Moving on to the institutional quality indicators, the observations show that they also vary across samples. While the rule of law has a mean value of 44.913, Government Effectiveness, Regulatory Quality, and Control of Corruption have mean values of 37.347, 43.934, and 35.242, respectively. This reveals the unevenness of the quality of institutions across African countries; such an observation aligns with North (1991), La Porta et al. (1998), and Acemoglu et al. (2005). In fact, these authors demonstrated that institutions shape economic and financial outcomes by exerting influence on enforcement, trust, and incentives. In addition, the observed substantial cross-country variation in institutional quality has implications. They suggest that the financial benefits of technological sophistication may not be uniform across the economies in Africa. Therefore, for the moderation and threshold analyses that follow, we are provided with an empirical basis.

For the purpose of checking for correlations among the variables, we run a pairwise correlation analysis (Table 4). From the results, we see a positive and significant correlation between financial development and the Rule of Law. A similar observation holds for

Table 4. Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) *fd_index*	1.000										
(2) *hightech*	0.015	1.000									
	(0.634)										
(3) *ict_exports*	–0.158***	0.079**	1.000								
	(0.000)	(0.013)									
(4) *rule_law*	0.622***	0.040	–0.024	1.000							
	(0.000)	(0.204)	(0.454)								
(5) *gov_eff*	0.695***	0.079**	–0.083***	0.797***	1.000						
	(0.000)	(0.013)	(0.009)	(0.000)							
(6) *reg_qual*	0.665***	0.063**	–0.029	0.808***	0.708***	1.000					
	(0.000)	(0.047)	(0.357)	(0.000)	(0.000)						
(7) *corr_ctrl*	0.591***	0.078**	–0.073**	0.788***	0.847***	0.808***	1.000				
	(0.000)	(0.014)	(0.021)	(0.000)	(0.000)	(0.000)					
(8) *lngdppc*	0.596***	–0.074**	–0.194***	0.364***	0.455***	0.338***	0.329***	1.000			
	(0.000)	(0.023)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
(9) *inflation*	–0.057	–0.025	–0.073**	–0.118***	–0.147***	–0.136***	–0.158***	–0.069**	1.000		
	(0.075)	(0.440)	(0.022)	(0.000)	(0.000)	(0.000)	(0.000)	(0.032)			
(10) *trade*	0.295***	–0.076**	–0.052	0.301***	0.367***	0.306***	0.302***	0.509***	–0.141***	1.000	
	(0.000)	(0.016)	(0.104)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
(11) *internet*	0.536***	0.111***	–0.029	0.369***	0.485***	0.357***	0.371***	0.560***	–0.095***	0.343***	1.000
	(0.000)	(0.001)	(0.360)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.000)	

Note: The *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$. The institutional quality indicators are not included in the main regression models but are used separately in the robustness checks.

Government Effectiveness, Regulatory Quality, Control of Corruption, GDP per capita, trade openness, and Internet use. From these observations, we learn that stronger institutions, higher income levels, openness, and digital access have an obvious connection with better financial development. Looking at the correlation between high-technology exports and financial development, it reveals a positive yet weak coefficient. The implication of this result is that the unconditional association has limitations. This observation suggests that the financial development and technological sophistication nexus is highly likely to depend on other country characteristics; in particular, institutional quality. The need for a multivariate regression analysis is therefore reinforced. The goal of the multivariate analysis is to help control for country fixed effects, year effects, and macroeconomic conditions.

The VIF results are reported in Table 5, with a mean VIF of 1.35 and all individual VIF values below the conventional threshold of 10. These values show that multicollinearity is not a serious concern in the baseline specifications.

Table 5. Multicollinearity test: VIF

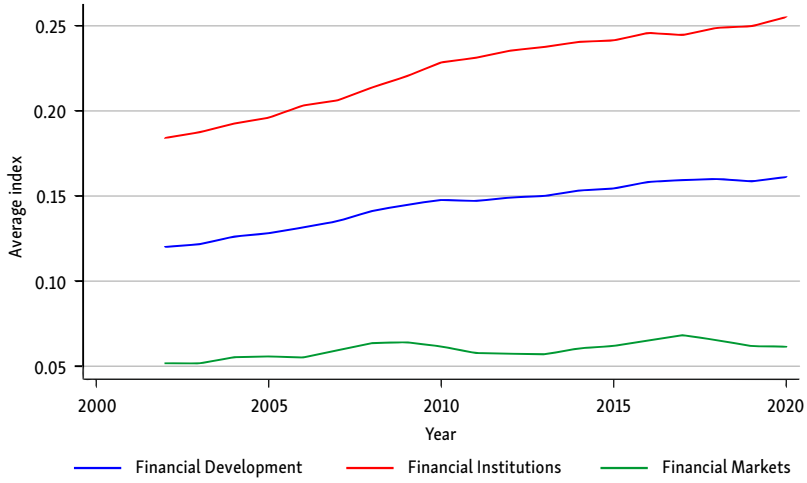
Variables	VIF	1/VIF
hightech	1.0500	0.9569
rule_law	1.2200	0.8217
lngdppc	1.8400	0.5440
inflation	1.0400	0.9588
trade	1.4000	0.7149
internet	1.5800	0.6323
Mean VIF	1.3500	

Note: The interaction term is excluded from the VIF calculation as the interaction variables are mechanically correlated with their component variables. A mean VIF below 10 suggests that multicollinearity is not a serious concern.

Looking at Figures 1, 2, and 3 below, we obtain additional evidence. As shown in Figure 1, financial institutions consistently outperform financial markets. This confirms that African financial systems have a strong institutionally-based tendency compared to market-based ones. A look at Figure 2 reveals that ICT service exports are generally higher than high-technology exports, although both indicators have fluctuated over time. Last, Figure 3 shows a weak relationship between high-technology exports and financial development (FD). Yet, this relationship is positive and unconditional. The wide dispersion of the observations suggests considerable heterogeneity across countries even though the fitted line is positive. This indicates that, taken alone, technological sophistication does not entirely explain the differences in financial development.

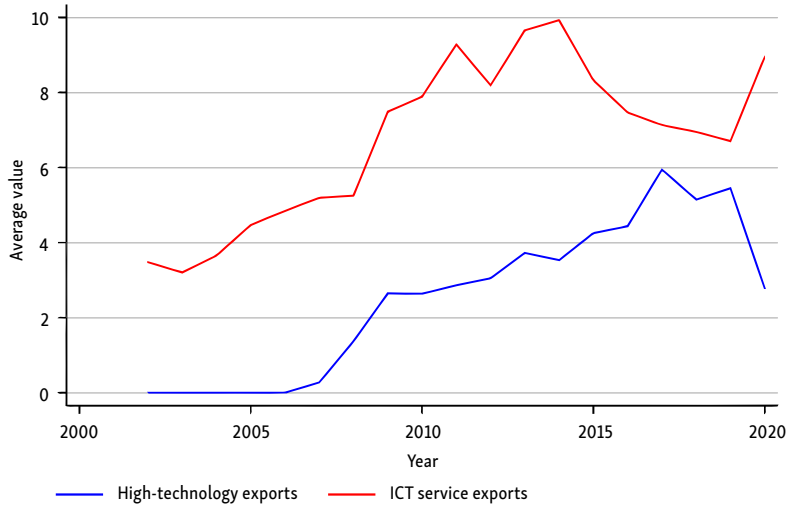
Overall, the results of the descriptive analysis do stress the importance of assessing whether technological sophistication promotes financial development conditionally. And in particular, whether this condition is through institutional quality.

From the above analysis, the need to examine whether technological sophistication contributes to financial development is supported, and whether this relationship depends on institutional quality is to be verified.



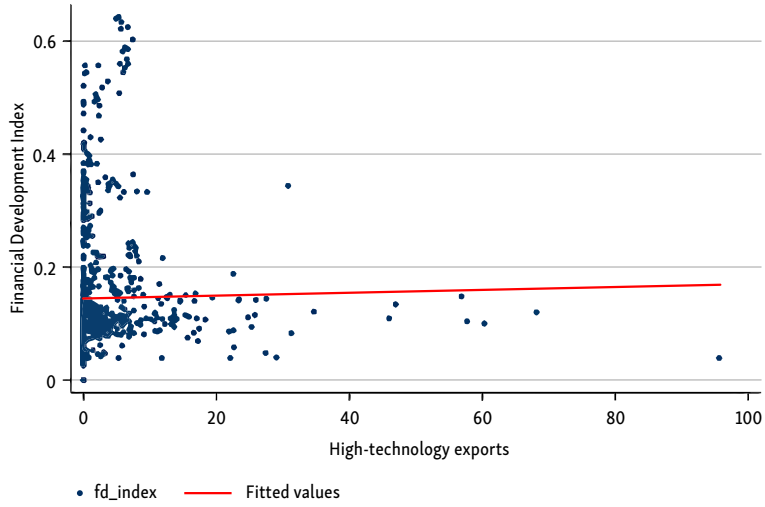
Note: The figure reports the annual cross-country averages for the final sample. The IMF index values are for financial development, financial institutions, and financial markets.

Figure 1. Trends in financial development indicators in Africa, 2002–2020



Note: The figure reports the annual cross-country averages for the final sample. High-technology exports are measured as a percentage of manufactured exports, and ICT service exports are measured as a percentage of service exports.

Figure 2. Trends in technological sophistication in Africa, 2002–2020



Note: The fitted line shows the unconditional association between high-technology exports and the Financial Development Index. The concentration of observations near low high-technology export values reflects the uneven distribution of technological sophistication across African countries.

Figure 3. Technological sophistication and financial development

4.2. Baseline fixed-effects results

The results from the baseline fixed-effects regression are presented in Table 6. The equation (Equation (1)) displayed in the first column estimates the direct effect of technological sophistication on financial development.

We notice that the coefficient of high-technology exports is positive and has statistical significance. This shows that technological sophistication is associated with higher financial development and therefore supports the first hypothesis (H1). In practical terms, what this result suggests is that countries with high participation in intensive technology production and exports tend to achieve stronger financial development outcomes. This observation aligns with the view of Schumpeter (1934). He argued that finance and innovation are closely linked. The observation additionally aligns with more recent evidence (e.g., Azeez et al. (2025) and Edo (2025)). These authors showed that technological advancement and digital transformation positively affect financial development. Observations were made for both African economies and other emerging economies.

In the second equation, in column 2, the Rule of Law is added to the model. We observe stability in the coefficient of high-technology exports. The coefficient remains positive and significant, contrary to the Rule of Law, which appears positive but weakly significant. This supports the second hypothesis (H2) and also suggests that higher institutional quality promotes financial development. This result is consistent with the institutional arguments and law-and-finance arguments. These arguments emphasize that with credible enforcement, legal quality, and governance, financial sector performance is improved (North, 1991; La Porta et al., 1998; Acemoglu et al., 2005). There is, in addition, recent evidence, such as that of Edo (2025) and Chaurasiya and Singh (2026), that aligns with these arguments. In fact,

these authors showed that stronger institutional environments contribute to financial sector development and enhance the benefits of innovation and technology. Altogether, these findings indicate that technological sophistication and institutional quality put together make independent contributions to financial development. These independent contributions come before considering their joint interaction.

Column 3 adds mobile subscriptions and tertiary education as control variables inside the model. The coefficient of high-technology exports remains positive and statistically significant; yet, the Rule of Law remains positive and weakly significant. We observe that Mobile subscriptions are positive and significant, and tertiary education is also positive at the 10% level. These results suggest that several factors are jointly important for financial development. Among these factors, we can name technological sophistication, institutional quality, and human capital. This observation confirms earlier studies (e.g., Chinoda & Kapingura (2024)

Table 6. Baseline fixed-effects results

Variables	(1)	(2)	(3)
	Baseline	Institutional model	Extended controls
hightech	0.0003***	0.0011***	0.0006***
	(0.004)	(0.001)	(0.004)
rule_law		0.0012*	0.0012*
		(0.051)	(0.051)
lngdppc	0.0197	0.0130	0.0057
	(0.0138)	(0.0141)	(0.0121)
inflation	0.0001	0.0001	0.0001
	(0.111)	(0.120)	(0.176)
trade	–0.0001	0.0001	0.0001
	(0.109)	(0.118)	(0.230)
internet	0.0005**	0.0006**	0.0003
	(0.030)	(0.020)	(0.140)
mobile			0.0003***
			(0.004)
tertiary			0.0006*
			(0.051)
Constant	–0.0191	–0.0262	0.0229
	(0.976)	(0.919)	(0.751)
Observations	957	957	957
R-squared	0.3074	0.3273	0.3625
Number of countries	52	52	52
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
SE clustered by country	Yes	Yes	Yes

Note: The *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All models include country and year fixed effects terms. The standard errors are clustered at the country level.

and Saeed et al. (2025)). In these studies, the authors showed that ICT, digital access, and governance can strengthen financial sector outcomes in Africa and developing countries. In our model, the robustness of the specification is further indicated. This can be noticed by the stability of the coefficients across the three specifications. It indicates that the positive nexus between financial development and technological sophistication is robust to the inclusion of additional control variables.

Taken together, the analysis in Table 6 confirms the first two hypotheses (H1 and H2). As stated, technological sophistication is positively associated with financial development, and institutional quality comes in support. However, the above observed baseline results capture only average effects. They do not yet show whether the technological sophistication's effectiveness increases under stronger institutional conditions. This issue is examined in the following analyses: moderation, threshold, and heterogeneity analyses.

4.3. Moderating role of institutional quality

We proceed by testing whether institutional quality has a moderating effect on the relationship between technological sophistication and financial development; the results are presented in Table 7. A look at the interaction term between high-technology exports and Rule of Law shows a coefficient that is both positive and statistically significant in the two specifications. It suggests that the effect of technological sophistication on financial development becomes stronger when institutional quality improves. As such, it indicates that institutional quality has a reinforcing effect on the financial benefits that are associated with technological sophistication rather than the only exertion of an independent effect on financial development.

Through this observation, we confirm that the third hypothesis (H3) is confirmed. Also, this observation suggests that technology alone is not enough for deepening financial systems. Yet, the advantages derived from technological sophistication are dependent upon the institutional environment in which investors, firms, and financial intermediaries operate. In fact, a stronger Rule of Law is capable of improving contract enforcement and reducing uncertainty among the parties. It further strengthens investors' confidence and also enables economic activities related to technology to convert more effectively into financial development. In addition, it implies that the presence of institutions facilitates the reduction of transaction costs and information asymmetry. Also, they reduce enforcement risks. These risks could otherwise prevent technology-intensive activities from receiving formal channel financing.

This outcome shows consistency with Olaniyi and Odhiambo (2023). They demonstrated that, in the African context, institutional quality matters for the finance–economic complexity relationship. This result is also consistent with the findings of Chinoda and Kapingura (2024) and Saeed et al. (2025). In their studies, they emphasize the complementary role of governance in the relationships between finance-growth and digital finance. In addition, the findings align with more recent evidence such as that of Abdulai et al. (2026) and Chaurasiya and Singh (2026). These auhtors demonstrated that stronger institutional environments reinforce the innovation contribution and financial inclusion to economic and financial outcomes.

Table 7. Moderating role of institutional quality

Variables	(1)	(2)
	Main moderation model	Extended controls
hightech	0.0007**	0.0004**
	(0.049)	(0.027)
rule_law	0.0012**	0.0011*
	(0.041)	(0.073)
hightech × *rule_law*	0.0001**	0.0001*
	(0.016)	(0.062)
lngdppc	0.0117	0.0050
	(0.144)	(0.124)
inflation	0.0001	0.0001
	(0.134)	(0.111)
trade	0.0001	0.0001
	(0.141)	(0.101)
internet	0.0005**	0.0002*
	(0.020)	(0.083)
mobile		0.0003***
		(0.004)
tertiary		0.0006**
		(0.033)
Constant	–0.0154	0.0283
	(0.940)	(0.769)
Observations	957	957
R-squared	0.3284	0.3628
Number of countries	52	52
Country FE	Yes	Yes
Year FE	Yes	Yes
SE clustered by country	Yes	Yes

Note: The *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All models include country and year fixed effects terms. The standard errors are clustered at the country level. The interaction term captures the moderating effect of the Rule of Law on the relationship between high-technology exports and financial development.

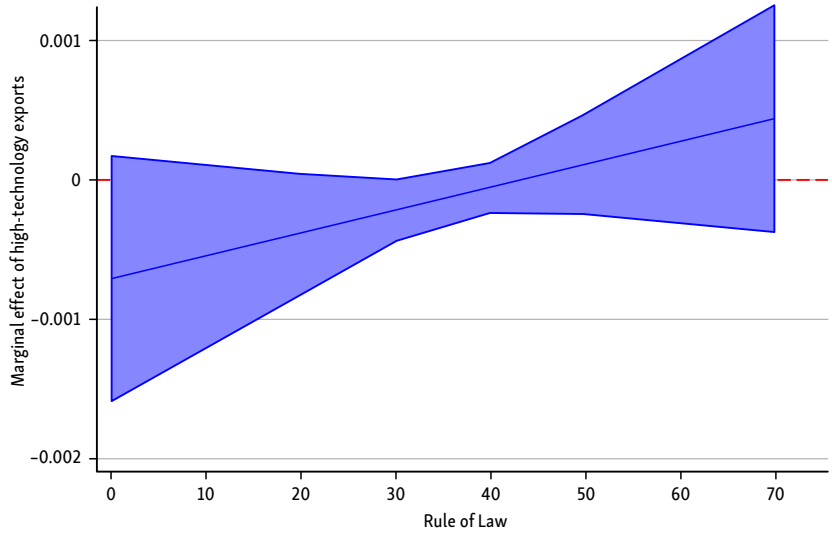
The marginal effects of technological sophistication at different levels of the Rule of Law are presented in Table 8. As can be observed, at low levels of the Rule of Law, the marginal effect is negative and not significant. At the mean level, the effect becomes positive and weakly significant. At high levels of Rule of Law, the effect becomes statistically significant and larger. This pattern confirms that institutional quality has a strengthening effect on the relationship between finance and technology. Thus, the results imply that the technological sophistication effect on financial development appears not uniform across institutional environments. On the contrary, it becomes more economically relevant only when institutional quality is stronger. What this implies is that improvements in institutional quality gradually increase the contribution of technological sophistication to financial development.

Table 8. Marginal effects of technological sophistication

Variables	Marginal effects
Low Rule of Law	–0.0001
	(0.322)
Mean Rule of Law	0.0002*
	(0.061)
High Rule of Law	0.0007**
	(0.020)
Observations	957

Note: The *p*-values are reported in parentheses. ** $p < 0.05$, * $p < 0.1$. Low, mean, and high Rule of Law correspond to the selected values used in the marginal effects estimation. The marginal effect shows the effect of high-technology exports on financial development at different institutional quality levels.

This result is supported by Figure 4: The marginal effect of high-technology exports increases as the Rule of Law improves. At low levels of the Rule of Law, the marginal effect that is estimated is negative, and zero is included in the confidence interval. This helps show that the effect is statistically insignificant. With the improvement of institutional quality, the marginal effect experiences a steady rise and crosses into positive territory. With higher values of Rule of Law, the estimated effect becomes positive and statistically significant, since the confidence interval no longer includes zero. Through this clear progression, we see that it is only under sufficiently strong institutional conditions that technological sophistication more strongly contributes to financial development. This fact confirms the central argument of the present study: technological sophistication more effectively promotes financial development when it is supported by credible institutions. Figure 4 thereby visually reinforces the interaction estimates reported in Table 7.



Note: The solid line shows the marginal effect of high-technology exports on financial development across Rule of Law values. The shaded area represents the 95% confidence intervals.

Figure 4. Marginal effect of technological sophistication across levels of institutional quality

4.4. Institutional threshold effects

We extend the moderation analysis by examining whether there is an institutional threshold beyond which technological sophistication is more effective in its ability to promote financial development. The results are reported in Table 9, and as can be seen, the estimated Rule of Law threshold is 55.095. Going below this threshold, the coefficient on high-technology exports turns negative and statistically insignificant across the three financial development indicators. What this fact suggests is that, when facing weak institutional conditions, technological sophistication does not automatically translate into financial deepening. Therefore, it indicates that technological capability alone is not sufficient to bring about meaningful improvements in financial development in a context where institutional quality stays weak.

Above the threshold, a different observation is made. The effect of high-technology exports becomes positive and statistically significant for both the Financial Development Index and the Financial Institutions Index. More specifically, the threshold coefficients above are respectively 0.007 and 0.009 for FD and FI; meanwhile, the corresponding effect for FM is positive but not statistically significant.

Table 9. Institutional threshold effects of technological sophistication on financial development in Africa

	(1)	(2)	(3)
	FD Index	FI Index	FM Index
hightech_low	–0.001	–0.001	–0.001
	(0.110)	(0.134)	(0.103)
hightech_high	0.007**	0.009***	0.003
	(0.012)	(0.009)	(0.102)
lngdppc	0.018	0.034*	0.001
	(0.124)	(0.059)	(0.116)
inflation	0.000	–0.000	0.000
	(0.198)	(0.237)	(0.202)
trade	–0.000	–0.000	0.000
	(0.232)	(0.123)	(0.143)
internet	0.000*	0.001***	0.000
	(0.068)	(0.007)	(0.125)
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	957	957	957
R-squared	0.314	0.507	0.032

Note: The table reports fixed-effects panel threshold regressions for 52 African countries over the period 2002–2020. The institutional threshold (Rule of Law = 55.095) was estimated endogenously using panel threshold regression techniques. *hightech_low* captures the effect of technological sophistication below the threshold, while *hightech_high* captures the effect above the threshold. All models include country and year fixed effects. Robust standard errors clustered at the country level are used. *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

With regard to economic significance, the magnitude of the above-threshold effects is meaningful. The standard deviation of high-technology exports is 6.882 percentage points (Table 3). Using the coefficients above the threshold, an increase of one standard deviation in high-technology exports is associated with an increase of about 0.048 in the Financial Development Index and 0.062 in the Financial Institutions Index, respectively. In relation to the sample means of 0.145 and 0.224 as observed in Table 3, these changes represent approximately 33.2 percent of the mean of the Financial Development Index and 27.7 percent for the Financial Institutions Index. This suggests that the estimated effects are not just statistically significant; they are also economically relevant when met with stronger institutional conditions.

From a policy perspective, these results tell us that investments in technological capability may produce substantially larger financial development gains from the moment countries establish stronger institutional and legal environments. This has a direct implication: technology policies must be complemented by strengthening reforms. Those reforms must aim at reinforcing the Rule of Law, regulatory quality, and governance, so as to help maximize their effectiveness. And in order to implement such reforms, it is necessary to proceed progressively through improvements in targeted areas. The concerned areas include governance quality, regulatory capacity, legal enforcement, and institutional effectiveness. This will result in conditions being created under which technological sophistication can more effectively contribute to financial development.

This result is of great importance as it moves the analysis beyond the statement that institutions solely moderate the relationship. It reveals that technological sophistication promotes financial development primarily when the Rule of Law exceeds a critical threshold, which is consistent with the reported institutional-threshold evidence by Nsiah and Tweneboah (2025).

The stronger result for financial institutions is also consistent with the structure of African financial systems. Since banking institutions, microfinance providers, and payment systems remain more central than capital markets in most African economies, technology-related capabilities are more likely to affect financial institutions first. By contrast, financial markets may remain less responsive because they are often shallow, illiquid, weakly integrated, and characterized by quite limited investor participation. Therefore, it (Table 9) supports the institutional-threshold argument as well as the multidimensional nature of financial development. At the same time, it suggests that differences in institutional quality may explain in part why similar technological investments generate unequal financial-development outcomes across African countries.

4.5. Heterogeneity across institutional regimes

Table 10 further examines whether the effect of technological sophistication is different from one African country to another, depending on weak and strong institutional environments. For the analysis, the countries are divided into weak and strong institutional regimes based on the median value of the Rule of Law indicator. The analysis addresses the concern that African economies should not be treated as a homogeneous group. This is because they differ substantially in institutional quality, financial structure, and technological capacity.

The results (Table 10) show that high-technology exports are not significantly associated with the Financial Development Index in institutional environments that are weak. However,

the coefficient becomes positive and significant in strong institutional environments. This therefore confirms that, when the existing institutions are stronger, technological sophistication more clearly contributes to financial development. Further, the observed contrast between the two institutional regimes provides more information. In fact, it implies that, depending on the quality of the institutional environment, even similar technological capabilities generate different financial-development outcomes. For the Financial Institutions Index, the coefficient is small under weak institutions but then turns much larger and significant when in the face of strong institutions. This reinforces the argument that institution quality helps to convert technological capability into formal financial intermediation.

With regard to the financial markets, the results appear to be weaker. High-technology exports show no statistically significant difference whether in weak or strong institutional environments. This shows consistency with the threshold evidence observed earlier and suggests that the technology and finance mechanism operates more strongly through financial institution channels instead of capital markets. This finding reflects the structure of most African financial systems: they are institution-based. In those systems, in fact, banks, microfinance institutions, and payment systems play a more prominent role compared to relatively shallow capital markets.

All in all, the heterogeneity analysis is complementary to both the moderation and threshold results earlier presented. It helps confirm that the financial benefits of technological sophistication are primarily concentrated in countries that are characterized by stronger institutional environments.

Table 10. Heterogeneity in the effect of technological sophistication across institutional regimes in Africa

	(1)	(2)	(3)	(4)	(5)	(6)
	Weak Institutions-FD	Strong Institutions-FD	Weak Institutions-FI	Strong Institutions-FI	Weak Institutions-FM	Strong Institutions-FM
hightech	–0.001	0.009***	0.0004*	0.013**	0.001	0.004
	(0.145)	(0.003)	(0.066)	(0.042)	(0.808)	(0.362)
lngdppc	0.003	0.049	0.015	0.062	–0.008	0.034
	(0.745)	(0.146)	(0.415)	(0.120)	(0.269)	(0.530)
inflation	–0.001	0.001	–0.001	0.001	–0.001	0.001
	(0.259)	(0.353)	(0.436)	(0.916)	(0.902)	(0.271)
trade	–0.001	–0.001	–0.001	–0.001	0.001	0.001
	(0.334)	(0.775)	(0.242)	(0.232)	(0.702)	(0.640)
internet	–0.001	0.010***	–0.002	0.009***	–0.011*	0.001
	(0.185)	(0.004)	(0.784)	(0.001)	(0.071)	(0.271)
Observations	463	494	463	494	463	494
R-squared	0.301	0.408	0.313	0.638	0.097	0.069

Note: The table reports fixed-effects regressions for African countries classified into weak and strong institutional regimes based on the median value of the Rule of Law indicator. Countries with Rule of Law values below the sample median are classified as weak institutional environments, while those above the median are classified as strong institutional environments. All models include country and year fixed effects. Robust standard errors clustered at the country level are used. *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.6. Robustness checks

Table 11 below examines whether the earlier results hold when alternative dependent variables are used. The regression outcomes show that, for the Financial Institutions Index, high-technology exports, the Rule of Law, and their interaction are positive and significant. However, the corresponding effects are not statistically significant in the case of the Financial Markets Index or domestic credit to the private sector. This observation suggests that it is through financial institutions that the technology and institution mechanism operates more strongly. It is through financial institutions rather than through financial markets or private credit. Therefore, the robustness results reinforce the conclusion that technological sophistication does not strengthen all dimensions of the financial system equally. Rather, it primarily strengthens institution-based financial development.

Table 11. Alternative dependent variables

Variables	(1)	(2)	(3)
	fi_index	*fm_index*	*credit*
hightech	0.0012**	0.0002	0.5116
	(0.020)	(0.740)	(0.184)
rule_law	0.0013***	0.0010	0.1188
	(0.002)	(0.322)	(0.572)
hightech × *rule_law*	0.0004*	0.0021	0.0119
	(0.069)	(0.142)	(0.192)
lngdppc	0.0257	–0.0027	–4.0115
	(0.173)	(0.200)	(0.533)
inflation	–0.0001	0.0001	–0.0066
	(0.210)	(0.128)	(0.379)
trade	–0.0001	0.0001	0.0174
	(0.100)	(0.123)	(0.261)
internet	0.0010***	0.0001	0.2548
	(0.003)	(0.130)	(0.197)
Constant	–0.0523	0.0206	34.7747
	(0.248)	(0.192)	(0.349)
Observations	957	957	957
R-squared	0.5201	0.0376	0.1683
Number of countries	52	52	52
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
SE clustered by country	Yes	Yes	Yes

Note: The *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All models include country and year-fixed effects. The standard errors are clustered at the country level. Domestic credit to the private sector is measured as a percentage of GDP, whereas IMF financial development indicators are index values.

This finding supports hypothesis 4 (H4), which predicts that the effect of technological sophistication differs across the dimensions of financial development. It further aligns with descriptive evidence, which reveals that African financial systems are more institution-based than market-based. From the results, we see that technological sophistication may begin with improvements in banking and institutional financial structures. Only after that will it begin generating stronger effects in capital markets.

Table 12 further investigates heterogeneity across disaggregated financial development indicators. The results show that Rule of Law is positive and significant for financial institutions' efficiency, while Internet use is positively associated with financial institutions' depth and access, as well as financial markets access. Trade openness also shows a positive and significant coefficient for financial institution depth. These results tell us that technology and institutional quality do not affect all dimensions of financial development in a uniform manner. Instead, their effects differ across indicators of financial institutions and markets.

Table 12. Disaggregated financial development indicators

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	fi_depth	*fi_access*	*fi_efficiency*	*fm_depth*	*fm_access*	*fm_efficiency*
hightech	–0.0003	–0.0015	–0.0016	0.0005	–0.0001	–0.0012
	(0.166)	(0.112)	(0.116)	(0.140)	(0.141)	(0.120)
rule_law	0.0004	0.0002	0.0041***	0.0014	–0.0001	0.0015
	(0.150)	(0.177)	(0.003)	(0.150)	(0.122)	(0.140)
hightech × *rule_law*	0.0004	0.0011	0.0002	0.0009	0.0005	0.0010
	(0.194)	(0.146)	(0.209)	(0.211)	(0.124)	(0.143)
lngdppc	–0.0038	0.0350	0.0471	–0.0250	0.0126	0.0082
	(0.127)	(0.241)	(0.418)	(0.326)	(0.102)	(0.358)
inflation	0.0001	–0.0001	–0.0002	0.0001	0.0001	0.0002
	(0.100)	(0.208)	(0.146)	(0.137)	(0.159)	(0.103)
trade	0.0001**	–0.0001	–0.0003	0.0002	–0.0000	0.0002
	(0.013)	(0.322)	(0.102)	(0.211)	(0.156)	(0.287)
internet	0.0005**	0.0024*	–0.0009	–0.0001	0.0004*	–0.0001
	(0.020)	(0.052)	(0.160)	(0.106)	(0.062)	(0.209)
Constant	0.0980	–0.1918	–0.0422	0.1616	–0.0159	–0.1091
	(0.860)	(0.180)	(0.297)	(0.193)	(0.734)	(0.245)
Observations	957	957	957	957	957	957
R-squared	0.3998	0.6224	0.1099	0.0484	0.0595	0.0323
Number of countries	52	52	52	52	52	52
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
SE clustered by country	Yes	Yes	Yes	Yes	Yes	Yes

Note: The *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All models include country and year fixed effects. The standard errors are clustered at the country level. FI denotes financial institutions, and FM denotes financial markets.

The relatively weaker results across disaggregated indicators suggest that complementarities between technology and institutions operate more clearly at the broader financial-system level than through isolated subcomponents. From this finding we draw the conclusion that a prerequisite exists for technological capability and institutional quality before they translate into equally strong effects. In fact, before translating into equally strong effects across each individual component, improvements in technological capability and institutional quality initially strengthen the overall functioning of financial systems. This supports the fourth hypothesis (H4) and is consistent with Azeez et al. (2025), who report heterogeneous effects of technology-related variables across financial development outcomes in Sub-Saharan Africa.

Table 13 tests the robustness of the moderation mechanism using alternative technology and institutional proxies. The interaction between ICT service exports and the Rule of Law is positive and significant at the 10 percent level. Similarly, the interactions between high-technology exports and Government Effectiveness, Regulatory Quality, and Control of Corruption are all positive and weakly significant. Although the direct technology coefficient gets weaker in some specifications, the interaction terms remain positive. This confirms the conditional role of institutional quality. We thus understand that these results suggest the moderating effect is not specific to a single measure of institutional quality or technology. Instead, even across alternative specifications, it remains evident. As such, this proof indicates that the financial-development benefits of technological capability are constantly strengthened by broader governance conditions. This not only further confirms the third hypothesis but also reinforces the argument that governance conditions the financial benefits of technological capability.

Table 13. Alternative technology and institutional proxies

Variables	(1)	(2)	(3)	(4)
	ICT exports × Rule of Law	Hightech × Gov. effectiveness	Hightech × Reg. quality	Hightech × Corruption control
ict_exports	0.0002*			
	(0.076)			
rule_law	0.0012**			
	(0.016)			
ict_exports × rule_law	0.0010*			
	(0.062)			
lngdppc	0.0124	0.0171	0.0157	0.0143
	(0.142)	(0.148)	(0.146)	(0.137)
inflation	0.0001	0.0001	0.0001	0.0001
	(0.210)	(0.109)	(0.165)	(0.100)
trade	0.0001	0.0001	–0.0001	–0.0001
	(0.170)	(0.198)	(0.221)	(0.101)
internet	0.0005**	0.0005**	0.0005**	0.0005*
	(0.016)	(0.020)	(0.012)	(0.053)
hightech		–0.0005	–0.0012	–0.0003
		(0.217)	(0.188)	(0.322)

End of Table 13

Variables	(1)	(2)	(3)	(4)
	ICT exports × Rule of Law	Hightech × Gov. effectiveness	Hightech × Reg. quality	Hightech × Corruption control
gov_eff		0.0002		
		(0.140)		
hightech × gov_eff		0.0019*		
		(0.055)		
reg_qual			0.0004	
			(0.160)	
hightech × reg_qual			0.0023*	
			(0.070)	
corr_ctrl				0.0004
				(0.244)
hightech × corr_ctrl				0.0007*
				(0.078)
Constant	–0.0207	–0.0061	–0.0090	0.0059
	(0.129)	(0.101)	(0.187)	(0.163)
Observations	957	957	957	957
R-squared	0.3282	0.3089	0.3121	0.3109
Number of countries	52	52	52	52
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
SE clustered by country	Yes	Yes	Yes	Yes

Note: The *p*-values are reported in parentheses. ** $p < 0.05$, * $p < 0.1$. All models include country and year fixed effects terms. The standard errors are clustered at the country level. Each column replaces the main technology or institutional proxy to assess the robustness of the moderating mechanism.

The fourteenth table (Table 14) presents the diagnostic tests conducted. The modified Wald test rejects the null hypothesis of homoskedasticity, and the Wooldridge test rejects that of first-order serial correlation. The Pesaran CD test indicates cross-sectional independence because it fails to reject the null hypothesis. Based on these results, it logically follows to use country-clustered standard errors in the main specifications and to conduct additional robustness checks using the Driscoll–Kraay standard errors.

The results of the Driscoll–Kraay robustness are presented in Table 15. The Rule of Law is seen to be positive and significant, and the interaction between it and high-technology exports remains positive and significant as well. The persistence of these coefficients, under an alternative covariance estimator, indicates that the moderation effect is not driven by serial correlation, heteroskedasticity, or other specification issues. As such, we can confirm that the moderating role of institutional quality shows robustness to alternative standard error corrections.

Table 14. Diagnostic tests

Diagnostic test	Null hypothesis	Test statistic	*p*-value	Decision
Modified Wald test	Homoskedasticity	$\chi^2(52) = 7624.9100$	0.0000	Reject
Wooldridge test	No first-order serial correlation	F(1, 51) = 28.963	0.0000	Reject
Pesaran CD test	Cross-sectional independence	CD = 1.6100	0.1070	Do not reject

Note: The table reports the diagnostic tests for heteroskedasticity, serial correlation, and cross-sectional dependence. The rejection of the null hypothesis indicates the presence of the corresponding diagnostic issue.

Table 15. Driscoll–Kraay robustness

Variables	Driscoll–Kraay
hightech	0.0002
	(0.168)
rule_law	0.0012***
	(0.002)
hightech × *rule_law*	0.0006*
	(0.075)
lngdppc	0.0117***
	(0.005)
inflation	0.0001
	(0.128)
trade	0.0001
	(0.290)
internet	0.0005**
	(0.016)
Constant	–0.0154
	(0.222)
Observations	957
Number of groups	52
Country FE	Yes
Year FE	Yes

Note: The *p*-values are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Driscoll–Kraay standard errors are robust to heteroskedasticity, serial correlation, and cross-sectional dependence. Country and year fixed effects were included.

In order to lower simultaneity concerns, the results in Table 16 use one-year-lagged explanatory variables. The coefficient on lagged high-technology exports is positive and significant. The interaction between lagged high-technology exports and lagged Rule of Law also shows a similar pattern (positive and significant). These results suggest that the main findings are not driven by contemporaneous relationships, thus providing additional support for the first (H1) and third (H3) hypotheses.

Table 16. Lagged (L) explanatory variables

Variables	Lagged explanatory variables
L.hightech	0.0008*
	(0.065)
L.rule_law	0.0009
	(0.140)
L.hightech × *L.rule_law*	0.0005*
	(0.078)
L.lngdppc	0.0144
	(0.154)
L.inflation	–0.0001
	(0.201)
L.trade	0.0001
	(0.178)
L.internet	0.0005**
	(0.016)
Constant	–0.0197
	(0.101)
Observations	907
Number of countries	52
R-squared	0.2980
Country FE	Yes
Year FE	Yes
SE clustered by country	Yes

Note: The *p*-values are reported in parentheses. ** $p < 0.05$, * $p < 0.1$. All explanatory variables were lagged by one year to reduce simultaneity concerns. Country and year fixed effects are included, and the standard errors are clustered at the country level.

Further, a system GMM regression is estimated, and the results in Table 17 show that the lagged dependent variable is positive and significant. This indicates persistence in the relationship between financial development and economic growth. A look at the Rule of Law shows a positive and significant coefficient, and the interaction between high-technology exports and the Rule of Law remains positive and significant. The related diagnostic tests give acceptable results: AR (1) is significant compared to the AR (2) test, which is insignificant, while the Hansen test does not reject instrument validity, etc. With these results, we further confirm that, after accounting for persistence and potential endogeneity, the institutional moderation effect remains robust. These two methods, despite the confidence in the findings being strengthened by the lagged specifications and system GMM, cannot totally eliminate the possibility of residual endogeneity that arises from omitted variables or reverse causality. Therefore, the results are to be interpreted as empirical relationships that are robust; they are not to be considered definitive evidence of causality.

Table 17. System GMM robustness

Variables	System GMM
L.fd_index	0.0658**
	(0.017)
hightech	0.0004
	(0.689)
rule_law	0.0002**
	(0.046)
hightech × *rule_law*	0.0002*
	(0.089)
lngdppc	0.0016
	(0.374)
inflation	–0.0001
	(0.243)
trade	–0.0001
	(0.179)
internet	0.0001
	(0.254)
Constant	–0.0158
	(0.111)
Observations	907
AR(1) *p*-value	0.004
AR(2) *p*-value	0.522
Hansen *p*-value	0.242
Number of instruments	34
Number of countries	52

Note: The *p*-values are reported in parentheses. ** $p < 0.05$, * $p < 0.1$. The model was estimated using the system GMM. AR(1) and AR(2) are the Arellano–Bond serial correlation tests. The Hansen test assesses the validity of the instruments. The number of instruments is kept below the number of countries to limit the proliferation of instruments.

Taken together, the section on robustness checks provides support for the main findings of the study. As observed, first, technological sophistication has a positive association with financial development. Second, institutional quality directly contributes to this association. Third, it is observed that the positive impact of technological sophistication is enhanced through the presence of stronger institutions. However, the results from the section also indicate that this effect is more prominent with financial institutions compared to financial markets. This confirms that financial development is of a multidimensional nature. The evidence on robustness therefore supports the central argument. This argument states that, when supported by credible institutional conditions, technology policy is more likely to boost financial development.

4.7. Summary of empirical findings

The results of the empirical analysis confirm all four hypotheses of this study. As stated in H1, the results reveal that high-technology exports are positively associated with financial development. H2 is confirmed by the Rule of Law being positively associated with financial development. As the interaction between technological sophistication and institutional quality is positive and significant in the main model and robust with several complementary checks, this supports H3. The fourth hypothesis (H4) is confirmed since the results differ across financial institutions, markets, access, depth, and efficiency. This indicates that the impact of technological sophistication is not uniform across the different dimensions of financial development.

The empirical findings of the study, taken together, suggest that Africa is on a good track toward financial development through technological sophistication, as the latter can indeed contribute to it. However, its effect strongly depends on the quality of available institutions. In fact, as shown, in a weak institutional environment, technology-related capabilities may not be fully converted into financial deepening. However, in stronger institutional environments, technological sophistication is more likely to support financial development. This support will manifest through improved trust and reduced transaction friction. It will also manifest through expanded demand for better, more advanced financial services. The evidence brings further information on how these effects operate. In fact, they operate through financial institutions more clearly and effectively than through financial markets. This reflects the African financial systems' institution-based structure.

In a nutshell, the combined analyses (threshold, moderation, heterogeneity, and robustness) kept indicating that stronger institutional environments play a very essential role in the translation of technological capability into sound and sustained financial development.

5. Conclusions

In this study, we attempt to examine the nexus between technological sophistication and financial development in the African region. More specifically, the analysis aims to verify whether technological sophistication promotes financial development. The study also tries to check if institutional quality plays a moderating role in this relationship. Using a set of panel data for 52 African countries from 2002 to 2020, fixed-effects models and various robustness checks are applied in this study. Among other models applied, there were alternative dependent variables, institutional-threshold regressions, lagged explanatory variables, Driscoll–Kraay standard errors, system GMM estimations, etc. Through the integration of moderation, threshold, heterogeneity, and multiple robustness analyses, the present study provides a comprehensive assessment of how technological sophistication and institutional quality together influence financial development in the African economies setting.

The results show a positive association between technological sophistication and financial development. This result supports the view that productive and technological capabilities help strengthen financial systems. The rule of law also appears positively associated with financial development, and thus confirms how important institutional quality is. Yet, more importantly, the interaction between the rule of Law and high-technology exports shows

statistical significance. This observation is made in the main models and remains robust broadly across additional specifications. Therefore, it indicates that technological capability alone is not enough, and that its contribution to financial development is mainly dependent upon institutions that help in the enforcement of contracts, the protection of investors, the regulation of markets, and the reduction of uncertainty. These findings highlight that institutional quality and technological sophistication are to be viewed as complementary drivers of financial development; they are not to be viewed as policy instruments.

Further, the study shows that the nexus between technology and finance is conditional and nonlinear. In fact, the analysis of the institutional threshold reveals that technological sophistication more effectively contributes to financial development only after a critical level is reached in institutional quality. More practically, a one-standard-deviation increase in high-technology exports leads to economically meaningful improvements in both the Financial Development Index and the Financial Institutions Index. This observation is made under stronger institutional conditions. This implies that the measured effects are not just statistically significant but also economically relevant for policy and structural transformation. Thus, they show that better institutional quality has the capability to increase the financial development benefits connected with technological sophistication.

The regression results also show some variations across the different dimensions of financial development. We see that the effects are weaker for financial markets than for financial institutions. This implies that, in Africa, technology and institutional quality have a closer association with institutional finance than with capital market development. The disaggregated results also vary across access, depth, and efficiency. Therefore, they show that financial development has several dimensions. The heterogeneity analysis also provides a similar picture. The positive effect of technological sophistication is mainly found in countries with stronger institutions, while the effect remains weak where institutional conditions are poor. This means that countries with similar technological capabilities may experience quite different financial-development outcomes depending on the strength of their institutions. All of this depends on the quality of the institutional environment.

Overall, the empirical evidence of the study provides us with strong support for the four hypotheses initially stated. It first confirms that technological sophistication promotes financial development. Second, institutional quality directly contributes to financial development. The third confirmation is that stronger institutions reinforce the technology–finance relationship. Last, these effects are different across the various dimensions of financial development.

With this study come several clear policy-related implications. The continent of Africa has a vast and untapped potential. African countries should act and integrate important measures into their agendas without delay. Among these measures must be technology policies, institutional reforms, and financial sector development. In addition, the threshold analysis suggests that technology policies alone are not likely to generate substantial financial-development gains in countries with institutional quality remaining below the estimated threshold. Therefore, complementary investments should be made by governments. These investments should target areas such as digital infrastructure, technological capability, ICT services, and high-technology production. Practical institutional reforms are also needed. These include improving regulatory quality and strengthening judicial effectiveness. African

governments should also consider enhancing transparency and anti-corruption mechanisms. Investor rights and the enforcement of commercial contracts also need greater attention. Such reforms would help countries move progressively toward technology-friendly institutional conditions. In other words, institutional conditions in which technological sophistication is able to generate larger financial-development benefits.

Governments and policymakers should also revise their targets and give priority to banks and microfinance institutions. While payment systems and digital financial channels are equally important, capital markets, however, should be gradually deepened. This is because the observed effects tend to be stronger for financial institutions than for financial markets. Also, trying to expand Internet access, mobile connectivity, and human capital would help further reinforce the financial benefits of technological sophistication.

Despite our efforts to bring the best of this study to the literature, there still remain some limitations. While High-technology and ICT service exports capture very important aspects of technological capability, they may not fully reflect other aspects. Examples are domestic innovation, fintech adoption and digital entrepreneurship, or firm-level technological upgrading. In African economies, this limitation is particularly relevant. In those economies, high-technology exports may partly reflect foreign-owned production or enclave activities, which may not fully capture technological capability that is domestically generated. Also, this study uses annual country-level data, and as such, it may limit the ability to identify micro-level mechanisms. Further, the study has addressed endogeneity concerns through the use of several methods. These are fixed effects, lagged regressors, and system GMM. Even though the results of these techniques are sound, the findings are not to be interpreted as definitive causal evidence. Instead, they should be simply regarded as robust empirical associations.

It follows that there is enough available ground for future research. Future studies could use firm, bank, or household-level data to analyze the mechanisms that link technology to financial access, credit allocation, and investment. Also, other studies may include direct measures of fintech adoption, mobile money, digital payments, innovation capacity, and even digital regulation. Another interesting area to be explored would be that of comparative research across African subregions. Last but not least, future work should extend the threshold approach in the nexus between technological sophistication and financial development. This can be done by examining dynamic nonlinearities and multiple institutional thresholds. Such research would help contribute to a deeper understanding of the way Africa is impacted by institutional quality and technological capability. In fact, the way they shape financial development together across different stages of Africa's economic transformation remains to be deeply studied.

Taken together, the present study helps demonstrate that technological sophistication can become a central driver of financial development in the African context. Yet, this can truly manifest only when it receives support from institutional environments that are sufficiently strong. Through the integration of varied empirical techniques, this study provides a very comprehensive empirical framework. This framework helps contribute to the literature on institutions, technology, and financial development. At the same time, it provides insights, based on clear evidence, for policymakers. These insights are intended to help policymakers who strive for the promotion of sustainable financial development across African economies.

Declaration of the use of Artificial Intelligence

We declare that no generative artificial intelligence tools were used in the writing, analysis, or preparation of this manuscript.

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