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ECONOMIC CONVERGENCE IN AFRICA PUT TO THE TEST OF PRODUCTIVE COMPLEXITY - AN EMPIRICAL ANALYSIS USING SYSTEM GMM PANEL DATA AND MARKOV CHAINS

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ABSTRACT

To assess the phenomena of structural transformation in economies and the phenomenon of the middle-income trap, we have used Hausmann and Hidalgo's conceptualization of economic complexity, a process based on 36 African countries over the period 1995-2023. To eliminate endogeneity errors and the bias caused by the lagged dependent variable as an explanatory factor, we employ the panel data system GMM estimations method. The empirical findings confirm the existence of conditional convergence as well, and the Economic Complexity Index appears to be an important accelerator, especially for countries at intermediate complexity levels. The analysis further uncovers a synergistic effect of institutional quality and economic complexity, whereby strong governance magnifies growth returns (through increased productive capabilities). The Markov chain analysis shows very high levels of structural inertia, most countries in the sample remain stuck in low or intermediate complexity classes over the long term and find it difficult to migrate to the next complexity class. The results agree with the hypothesis that every economy will progress toward a per capita income that captures its unique complexity level. Put simply, the capacity of an economy based on knowledge, expertise and know-how will dictate its processes of structural change. Therefore, sustainable convergence in Africa is not necessarily automatic, but is contingent on the strategic integration of institutional reform and strategic industrial policies targeted toward promoting productive diversification and capability accumulation.

Keywords: *Economic convergence, economic complexity, dynamic panel data, system GMM, Markov chains*

1. INTRODUCTION

One of the most enduring and important questions in the history of development economics concerns the causes of disparities in economic development and growth across countries. Why do some countries achieve sustained economic growth while others do not? And what can be done to foster growth and improve living standards? To answer these questions more convincingly, we must understand the mechanisms that drive differences in income levels across countries, as well as the conditions under which less developed economies are able or unable to catch up. In a large extent these questions involve exploring the causes and consequences of differences in income, as well as the conditions under which a country can adjust its income

distribution (or not) to increase or reduce the gap between its income and poverty. These questions are particularly pertinent for the African continent of today, for it continues to face both enormous challenges and tremendous opportunity for evolution, while changing in an increasingly turbulent and uncertain geopolitical and economic climate. Africa therefore represents a kind of privileged field of observation. The continent comprises middle-income countries (South Africa and Mauritius) that are relatively diversified in their economy and some of the least developed countries on the planet (such as Burundi and Niger) that have severe structural constraints. The stunning growing rate of several nations in Africa, including many of those that have ranked among the world's fastest-growing economies in the last 20 years, turns the region into a laboratory in which to investigate economic resilience under the backdrop of successive crises and external shocks. The ongoing Coronavirus Disease 2019 (COVID-19) pandemic together with the fighting in Ukraine has led to significant disruptions of the commodity, food and energy markets as well as aggravated inflationary pressures and unprecedented food security crises across numerous parts of the world. All that multifaceted crisis has combined for a great scenario that has been further magnified by the protracted consequences of the pandemic. This is a strong affirmation of vulnerable African economies to exogenous shocks and therefore is a powerful reminder to re-think development models to focus more precisely on resilience. The phenomenon of convergence has been the subject of research interest from different theoretical perspectives since antiquity. According to neoclassical exogenous growth theory posited by (Solow, 1956), poorer economies must catch up with richer ones as their returns to capital decrease. Economies with lower capital vis-a-vis labour are expected to grow faster and face low-income gaps because of the marginal return from capital being relatively higher than that for richer economies. Subsequent works advanced this concept with conditional convergence theory. Despite the attractiveness of this theoretical structure in the early years, the shortcoming was highlighted because it could not account for the sources of technical advancement, continuity of income disparities, or failure to converge on several of the world's economies, for instance, Africa and Latin America, especially under conditions of asymmetric shocks such as the war in Ukraine. Endogenous growth theories, particularly those represented by (Mankiw Gregory et al., 1992), highlight innovation and the development of human capital as leading convergence sources. Human capital describes the knowledge obtained either through formal education or through experience and by doing (Arrow, 1962). Furthermore, (Acemoglu et al., 2012a) emphasises the importance of institutional quality. Their work reveals the deep and persistent links between European colonial powers' institution of extractive institutions in numerous colonies, with specific emphasis on Africa, Central America, the Caribbean, and South Asia, and the resulting developmental trajectories. Economic complexity in a world of greater uncertainty represents a new way of understanding development pathways. It moves from measurement of assets held by individual countries to measuring resources realised through collective capabilities in the form of product sophistication and complexity in countries, taking through an iterative assessment of diversity and ubiquity. Hence, the productive knowledge in institutions, firms, and the job market is the basis for a nation's response to crises. (Acemoglu et al., 2012a; Hidalgo et al., 2007; Hidalgo & Hausmann, 2009) offer very solid evidence that a country's Economic Complexity Index, a product of a country's productive capabilities, highly predicts growth for the future. It can be asserted that in the case of many countries, their growth is not as much about old-fashioned factor endowments (such as capital, labour or natural resources), but rather about their ability to build and integrate developed productive capabilities. They also help determine resilience to shocks from external forces. Seen in this light and based on the economic complexity literature, two important factors dictate a country's complexity and consequently its level of development and competitiveness. The first is the existence of a very varied stock of knowledge, know-how and skills within the economy, of which each individual holds only a limited share such as scientific expertise, mastery of specific technologies, design, marketing, logistics, finance, or

industrial processes. The more advanced a product becomes, the larger its specialized capabilities will be for the time it takes to manufacture one of those products. The second component is the distribution of this knowledge across persons and its interaction and complementarity in complex organisations (firms and markets in particular). The complexity, therefore, of economies and economies to produce, from and to make, advanced, high-value-added goods depends not just on the diversity in the kinds of capabilities people have, but also on how these capabilities can be combined. This article is concerned with a structural transformation as seen through the lens of Hausmann and Hidalgo's theory of economic complexity, in this case the sample is African countries. First, it carries the analysis on to 2023, including the effects from the COVID-19 pandemic, the war in Ukraine and other recent crises which have heavily disrupted the economic paths of the African economies. Second, it applies a robust empirical approach comprising of several complex estimators - fixed effects, random effects and system GMM mixed with standard diagnostic tests for the validity of the findings while considering heterogeneous effects when comparing these as well as the levels of initial development and interaction with geopolitical shocks. Third, it is a method of convergence of complexity of economic system based on a Markov chain method. This article seeks to enhance not only academic knowledge of convergence dynamics in Africa, given the geopolitical convulsions, but also provide evidence for the formulation of more efficient and robust development policies with better comprehension to the processes of structural transition and the ability of African economy to withstand external shocks. To our knowledge, the combination of economic convergence and economic complexity has not been investigated in any original work to explore if productive complexity influences convergence patterns in Africa when considering the post-pandemic phase. This research has a few key contributions. First, it amends the analysis up through 2023 to include global effects of the COVID-19 pandemic, the war in Ukraine and the enactment of the African Continental Free Trade Area, which made an impact on Africa's economic paths. Second, it utilises system GMM estimation to deal with endogeneity and obtain a better approximation of the causal relation between complexity and convergence. Third, it analyses long-term transition dynamics across complexity classes using a Markov chain approach that reveals the structural inertia underlying future convergence possibilities. It offers, finally, new evidence that sustainable convergence in Africa can and should not be accomplished through automatic catchups, but through combinations of institutional reforms and a target industrial policy on stimulating productive diversification and capability accumulation. The rest of the paper is organised as: The theoretical and empirical literature has been reviewed in its respective sections 2 and 3. The methodology and data are presented in Section 4, in addition to the description of the data and an empirical plan. Section 5 presents and discusses the results including robustness checks. The Markov chain analysis is presented in Section 6. Section 7 concludes with concluding remarks and policy recommendations.

2. THEORETICAL LITERATURE REVIEW

According to the Neoclassical exogenous growth theory (Solow, 1956), which forms the theoretical foundation of the convergence analysis, is based upon the law of diminishing factor returns hypothesis, which means that economies with low capital input relative to labour input will have a higher marginal capital input productivity compared with rich economies with lower marginal capital input productivity, and thus will grow faster which implies an adjustment of the gap with wealthy economies. Under the theory of diminishing returns, the trend of beta convergence (when the rate of growth in the poor countries is higher than that of the rich countries) is seen. If so, the inverse relationship of growth at the beginning towards the growth outcome must be true (Islam, 2003). This process is formally described based on the

convergence equation:

$$g_{i,t} = \alpha + \beta \ln(y_{i,t-1}) + \gamma X_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where $g_{i,t}$ is the growth rate of GDP per capita in country i in period t, $y_{i,t-1}$ is the initial level of GDP per capita, and X represents a set of control variables reflecting the steady state specific to each country.

However, as per the endogenous growth model (Barro, 1990; Lucas, 1988; Pack, 1994; Romer, 1997), it is not the case that poor countries will catch up in the long-run to rich countries, because of diminishing law of return, by adding the accumulation of human capital, knowledge externalities and increasing returns to scale it is shown that economies with higher initial levels of knowledge and skills maintain higher growth rates; this shows divergence rather than convergence.

This outlook is especially relevant in the African context, where disparities in the accumulation of human capital and the capacity for innovation may be driving the ongoing existence of income inequalities. Advances in theories of international trade and not least of those of Krugman (1979) and Helpman and Krugman (1985) point to the importance of multi-industry trade models in which each industry produces a mix of differentiated products. The interindustry specialization pattern is formed by factor endowments thus, maintaining a degree of comparative advantage in these models. Simultaneously, economies of scale in production mean that each country can do only a narrow range of products within industries. This implies that intra-industry trade between countries arises because comparative advantage cannot completely explain it. (Hausmann et al., 2007) extended the issue line by finding that export sophistication, as exemplified by the EXPY index, is a powerful predictor of economic growth. Their key discovery is that the countries exporting goods linked to high-income countries tend to grow more quickly. Since it would be empirically infeasible to fully define a country's productive capabilities and to evaluate their inter-relationships, Hausmann and Hidalgo introduced an indirect indicator called the Economic Complexity Index (ECI). Informed by analysis of network theory and utilising product-level export data, they contend that a country's inventory of productive knowledge and skills can be expressed in exports. As a result, the ECI is developed from two essential dimensions: export diversity and product ubiquity. Export diversity is the number of products that a country can export with revealed comparative advantage, assuming, as they do, that economies with a greater amount of knowledge and capabilities can produce and export products of a wider range. Product ubiquity, by contrast, refers to the number of countries able to export a particular product with revealed comparative advantage. The underlying concept is that advanced and complementary capabilities needed for more complex products only exist in a small number of countries. Accordingly, such products are not so common, exports to relatively few economies are in the case of highly complex economies. Two vital indicators that underpin the measurement of economic complexity are the country product matrix:

1. Country diversity: number of products a country exports with revealed comparative advantage.
2. Product ubiquity: the number of countries able to export a product with revealed comparative advantage. By the method of reflections, the Economic Complexity Index is the product obtained with iteratively mixing these two dimensions. It can be expressed as follows:

$$ICE_i = \frac{K_i - (K)}{\sigma_K} \quad (2)$$

Where is the knowledge index for country i, defined as the second eigenvalue of the system of equations linking diversity and ubiquity.

The relationship between economic complexity and level of development is well established

in the literature. (Hidalgo & Hausmann, 2009) show that ECI explains approximately 75% of the variance in GDP per capita between countries.

It is evident that a number of mechanisms can provide a rationale for this robust correlation. The generation of learning and technological spillovers is a consequence of complex activities, and the capabilities required to produce complex goods can be transferred to other domains. Furthermore, diversified economies exhibit reduced vulnerability to fluctuations in commodity prices.

3. EMPIRICAL LITERATURE REVIEW

The empirical literature on convergence in Africa has different results. The seminal studies by (Barro & Sala-i-Martin, 1992), however, could provide no strong evidence of convergence in sub-Saharan Africa. Nevertheless, since then, works using dynamic panel methods have suggested slow conditional convergence. (Gbohoui, 2016) observes convergence within the West African Economic and Monetary Union (UEMOA) at around 1.7% per annum over the period 1980-2000. Similarly, Dramani (2007) recorded the development of convergence points in both the UEMOA and CEMAC zones. The conclusions tell us regional integration may lead to convergence. At the same time, other studies emphasise the heterogeneity of African trajectories. (Marrero et al., 2025) find only convergence for homogeneous groups of countries (middle-income countries vs low-income countries), even as a contrast also occurs between these groups. The research on economic complexity in Africa is relatively recent but expanding. (Felipe et al., 2014) investigate the productive structure of African countries across the product space and argue that the majority are ‘stuck’ in unsophisticated and badly interconnected segments. The article by (Stojkoski et al., 2023) further analyses by considering a multiplicity of economic, social and environmental factors. They reveal that countries have opportunities to diversify into ‘green products’ supporting sustainable growth. The literature does not mix convergence with complexity techniques. This is exactly the gap that our research is designed to take care of.

4. METHODOLOGIES AND DATA

4. 1. DATA AND SOURCES

The study includes 36 African countries over the period 1995-2023. The choice of countries is determined by the availability of data for all variables of interest.

Table 1. Data and sources

Variables	Sources
GDP and macroeconomic variables	World Development Indicators (World Bank), and IMF databases
International Trade	UN Comtrade and BACI database
Institutions	Worldwide Governance Indicators (WGI) and International Country Risk Guide (ICRG) for years prior to 1996
Human capital	Penn World Table 11.0, which incorporates data from Barro and Lee (2018) on years of schooling
Economic complexity	Atlas of Economic Complexity (Harvard Growth Lab), with updates through 2023

Source: Authors’ elaboration

4. 2. DESCRIPTIVE STATISTICS

Table 2. Descriptive Statistics for Main Variables

Variable	Mean	Sd	Min	Max	Observations
Per capita	2.05	3.21	-12.34	15.67	1008
Initial	8.17	0.89	6.26	10.12	1008
ECI	0.00	1.00	-2.42	2.15	1008
Hum cap	1.87	0.41	1.05	2.86	1008
Open	65.4	28.3	18.7	156.2	1008
Institution	3.39	0.85	1.63	4.95	1008
Invest	23.5	8.6	5.2	52.6	1008
Pop	2.66	1.08	0.12	6.45	1008
Inflation	8.32	6.75	-4.48	50.59	1008

Source: Authors' elaboration

Time in Which Key Indicators Develop

A look at the time series gives you several key trends:

- Economic growth: At an average of 2.05% for nearly the whole period, it gradually accelerated post-2000 (2.8% 2000-2019) and slowed during the pandemic (0.5% 2020).
- Economic complexity: A slight uplift in the average ECI, from -0.15 in 1995 to 0.08 in 2023, concealing stark regional differences.
- Openness to trade: The trade-to-GDP ratio has increased again from 52% in 1995 to 72% in 2023, as the African continent strengthens its connectivity to the international market.

Heterogeneity among regions

According to the analysis of the subregion, different attributes can be seen:

- North Africa: At a very high average ECI of 0.45, growth 2.2%. Trade liberalisation is very high.
- West Africa: In fact, the average ECI is -0.25, with still rising growth of 3.1% and substantial improvement in institutions.
- East Africa: Low ECI (-0.65), rapid growth (4.0%), improving human capital.
- Central Africa: Very low ECI (-1.05), volatile growth (1.8%), dependency on natural resources.
- Southern Africa: High but concentrated ECI (0.38 in South Africa, –0.12 in other countries), moderate growth (2.5%).

4. 3. ECONOMETRIC MODELS

We follow an empirical strategy, based on three main specifications:

Model 1: Standard conditional convergence

$$g_{i,t} = \alpha + \beta \ln(y_{i,t-1}) + \gamma_1 I_{i,t} + \gamma_2 HC_{i,t} + \gamma_3 Open_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

Model 2: Introduction of economic complexity

$$g_{i,t} = \alpha + \beta \ln (y_{i,t-1}) + \delta\, ECI_{i,t-1} + \gamma\, X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

Model 3: Dynamic specification with GMM

$$g_{i,t} = \alpha + \rho\, g_{i,t-1} + \beta \ln (y_{i,t-1}) + \delta\, ECI_{i,t-1} + \gamma X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (5)$$

Where :

- $g_{i,t}$: GDP per capita growth rate in PPP
- $y_{i,t-1}$: initial GDP per capita
- $ECI_{i,t-1}$: lagged economic complexity index
- $X_{i,t}$: vector of control variables
- μ_i : country fixed effects
- λ_t : year fixed effects
- $\varepsilon_{i,t}$: idiosyncratic errors

Control Variables

Control variables have been chosen based on the literature on growth and convergence models:

- Investment: share of gross fixed capital formation in GDP.
- Human capital: index based on years of schooling (PWT 11.0).
- Trade openness: sum of exports and imports relative to lagged GDP.
- Institutions : composite governance index (WGI).
- Population : population growth rate.
- Inflation: inflation rate (macroeconomic stability control variable).

4. 4. METHODOLOGY JUSTIFICATION

To maximize the power of our findings and minimize the effects of a single estimator, we utilize a variety of panel data methods. The fixed effects (FE) estimator controls for time-invariant unobserved heterogeneity and provides consistent estimates when omitted variables are correlated with the regressors. The random effects (RE) estimator is more efficient when individual-specific effects are uncorrelated with the explanatory variables, and the Hausman test allows us to decide which specification is more appropriate. Nevertheless, both estimators are static and thus do not adequately capture the dynamic nature of economic growth, particularly growth persistence and the potential endogeneity of explanatory variables. To overcome these biases, we apply a System GMM estimator by (Blundell & Bond, 1998). Based on equations formulated in differences and in levels, and by using lagged levels and lagged differences as instruments for endogenous variables, this approach is better adapted to dynamic panel analysis. It responds to these three main concerns: (i) the bias induced by the inclusion of a lagged dependent variable, (ii) reverse causality between growth and its determinants such as investment and trade openness, (iii) potential measurement error.

4. 5. ESTIMATION METHODS

4. 5. 1. STATIC PANEL ESTIMATORS

Hausman test allowed us to make trade-off between fixed effects and random effects model. Standard errors are corrected for heteroscedasticity and autocorrelation (Driscoll & Kraay, 1998) method.

4. 5. 2. DYNAMIC PANEL ESTIMATORS

System GMM developed by (Blundell & Bond, 1998), we leverage it to remove Nickel bias and help control for persistence of lagged endogenous variable, in this approach we combine the level and the difference equations as well as using variable lags as instruments.

There are two required tests of specification:

1. AR (2) autocorrelation test: to check for the absence of second-order autocorrelation in the errors.
2. Hansen and Sargan test: to check the absence of over-identification and the validity of the instruments.

Several robustness tests are also performed:

- Alternative instrumental variables for the ECI.
- Restricted samples excluding oil-producing countries or small island states.
- Alternative specifications including interaction terms and nonlinearities.
- Temporal decompositions to verify the stability of coefficients.

5. RESULTS AND INTERPRETATION

The simple regression between the average growth rate (1995-2023) and the logarithm of initial GDP in 1995 shows a significant negative relationship:

$$Croissance = 7.28 - 0.66 \times Log\,(\,PIB\ initial\,) \qquad (6)$$
$$R_2 = 0.16,\ p\text{-}value = 0.026$$

This result confirms the existence of absolute β-convergence over the entire period. The coefficient of -0.66 implies a convergence rate of approximately 1.4% per year, slightly lower than the usual estimates for developing countries. σ Convergence (Reduction in Dispersion)

Analysis of the evolution of the standard deviation of the logarithm of GDP per capita reveals a complex trend:

Table 3. Evolution of Income Dispersion

	Standard error( )	Coefficient of variation
1995-1999	0.92	0.112
2000-2009	0.88	0.108
2010-2019	0.85	0.104
2020-2023	0.89	0.109

Source: Authors' elaboration

Dispersion declined steadily until 2019 (σ convergence), then increased slightly during the pandemic, suggesting that shocks affect countries differently depending on their economic structure.

5. 1. FIXED AND RANDOM EFFECTS MODELS

Table 4. Comparison of Static Panel Estimators

Variables	(1)	(2)
Initial lngdp	-0.490***(0.002)	-0.452***(0.008)
Investment	1.934***(0.000)	1.867***(0.000)
Population	0.192*(0.083)	0.224*(0.056)
Constante	7.282***(0.003)	6.894***(0.007)
Time fixed effects	YES	YES
R^2 within	0.42	0.39
R^2 between	0.35	0.38
Test de Hausman	$X^2 = 18.76$ [0.004]	
Observations	972	972

*Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. *

Source: Author's estimation

The Hausman test (p-value = 0.004) rejects the hypothesis of no correlation between individual effects and regressors, thus validating the fixed effects model. The initial GDP coefficient (0.490) indicates a convergence rate of approximately 1.6% per year.

5. 2. SYSTEM GMM MODELS

Table 5. Results of System GMM Models

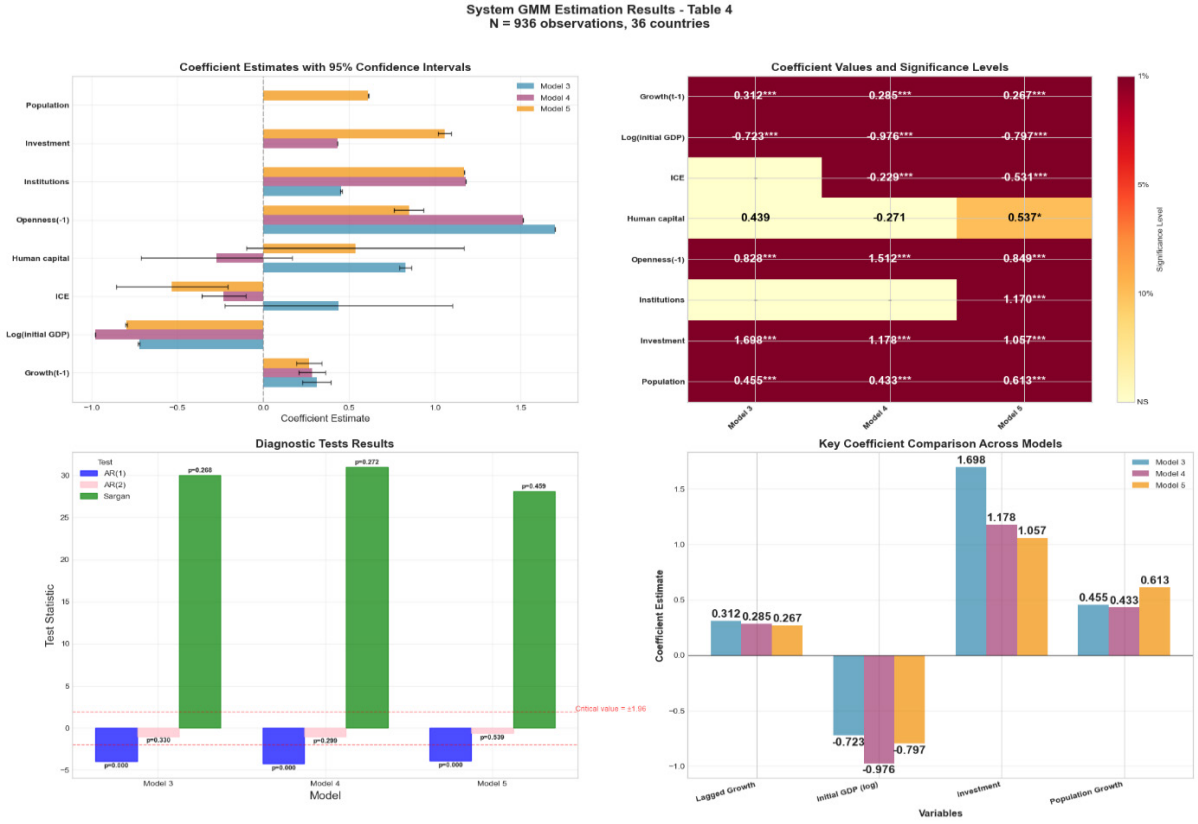
Variables	Model 3	Model 4	Model 5
Growth(t-1)	0.312***(0.042)	0.285***(0.039)	0.267***(0.037)
Initial lngdp	-0.723***(0.002)	-0.976***(0.000)	-0.797***(0.002)
ECI		-0.229* (0.066)	-0.531 (0.165)
Human capital	0.439 (0.338)	-0.271 (0.224)	0.537 (0.323)
Openness (-1)	0.828**(0.018)	1.512***(0.000)	0.849**(0.044)
Institutions			1.170***(0.001)
Investment	1.698***(0.000)	1.178***(0.000)	1.057**(0.020)
Population	0.455***(0.003)	0.433***(0.000)	0.613***(0.001)
AR(1) test	-3.944 [0.000]	-4.193 [0.000]	-3.861 [0.000]
AR(2) test	-0.973 [0.330]	-1.038 [0.299]	-0.615 [0.539]
Sargan test	29.999 [0.268]	30.974 [0.272]	28.102 [0.459]
Observations	936	936	936
Pays	36	36	36

*Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. P-values in brackets. *

Source: Author's estimation

The attached set of graphs shows findings from econometric estimations derived from the generalised method of moments (GMM) for a sample of 36 countries. The documents deal with three different statistical models and explore how investment, human capital and institutions influence economic growth. A horizontal bar chart shows the accuracy of the estimated coefficients with their respective confidence intervals, while a heat map highlights the statistically significant nature of these estimates. In addition, diagnostic tests, including autocorrelation and Sargan tests, ensure the robustness and reliability of the study's models. Finally, a comparative table shows the stability of the impact of initial GDP and population growth between the different specifications.

Figure1. Results of System GMM Models visualisations



Source: Authors' elaboration

INTERPRETATION OF RESULTS

Specification of the 3 dynamic models, estimated using Table 4 2-step system GMM, also confirms history dependence of GDP per capita growth, indicates the robust conditional convergence: negative coefficient of initial GDP implies that low level GDP per capita countries catch up to the case with high level GDP per capita, after controlling for the effect of other structural factors. Development remains robust (autoregressive coefficients of lag dependent variables ~0.27-0.31). Key diagnostic tests are passed by all the models (no AR (2), valid instruments by Sargan test), providing justification for the approach developed to adjust against country fixed costs and endogeneity. Institutions emerge as the ultimate cause: in Model 5 their substantial positive significance plus a magnitude of *1.170* absorbs the weakly negative ECI variable which implies that economic complexity requires good institutions to stimulate economic growth. The highly significant positive coefficients for Investment and Openness (1.057** and 0.849** respectively) have persisted as important growth pillars in the model above and indicate their overall effects even modestly within which institutional is added which means part of that result is operating through institutions. Scale market density is highly significant with the positive coefficient between 0.455*** and 0.613*** in the three models; Human Capital is consistently insignificant in the three models, which may be evidence of measurement or indirect effect biases. In conclusion, Model 5 provide the most detailed specification. It shows that institutions are a base meta-factor that increases the return to investment and trade and may constitute a ground for viable economic complexity. The policy imperative is that the levers used to guide reform are highly powerful as growth tools; without them investments, trade liberalisation, fostering complexity may also give only marginal returns.

VALIDITY AND ROBUSTNESS: THE RELIABILITY OF THE ANALYTICAL FRAMEWORK

System GMM models, structured to alleviate endogeneity problem and to control for country fixed effects, are verified by the most important diagnostic tests (no AR (2) correlation, valid instruments via the Sargan test). This gives us some degree of confidence in our results, the relationships shown here, show structural causation rather than random correlation. Now, we realise economic convergence is not possible through a simple magic solution or one single adjustment, but a coordinated, logical, and proper synthesis of the combined effect of several aspects of: the credible institutionalization of rules of the game; the establishment of complex means of production and efficient integration; not as a simple fourth factor of production, but as a meta-dimension, that is: the efficiency of all the others, i.e., the means of production and institutions, while simultaneously appearing as both the agent and the reflection of successful structural transformation.

5. 3. ROBUSTNESS ANALYSES

Table 6. Analysis by Complexity Groups

Variables	low ECI	medium ECI	high ECI
Initial lngdp	-0.892***(0.005)	-1.245***(0.001)	-0.763***(0.012)
ECI	0.185 (0.142)	0.412** (0.022)	0.287* (0.048)
Convergence rate	1.8%	3.1%	2.2%
Observations	312	312	312

Source: Author's estimation

This analysis reveals a non-linear relationship between ECI and convergence:

- Countries with low ECI: Slow convergence (1.8%), insignificant ECI effect.
- Countries with medium ECI: Rapid convergence (3.1%), strong and significant ECI effect.
- Countries with high ECI: Intermediate convergence (2.2%), moderate ECI effect.

This non-linearity suggests the existence of a "window of opportunity" where diversification policies are particularly effective.

Table 7. Interaction Effects

Variables	Model with interaction	Model without interaction
ECI	-0.229* (0.066)	-0.187(0.124)
Institution	1.170***(0.001)	1.045***(0.003)
ECI × Institution		0.312**(0.047)
ECI marginal effects	-0.229	0.125

Source: Author's estimation

The positive and significant interaction effect (0.312) indicates that economic complexity and institutional quality are mutually reinforcing. The marginal effect of ICE becomes positive (0.125) for an average level of institutions and increases with the quality of institutions.

Analysis by Sub-periods

Table 8. Temporal Evolution of Coefficients

Variables	1995-2007	2008-2019	2020-2023
Initial	-0.812***(0.003)	-0.921***(0.001)	-1.245***(0.000)
ECI	0.285**(0.032)	0.412***(0.008)	0.318*(0.067)
Convergence rate	1.9%	2.4%	3.7%
Observations	432	432	144

Source : Author's estimation

The acceleration of the convergence rate over time (from 1.9% to 3.7%) and the strengthening of the ICE effect (from 0.285 to 0.412) suggest a gradual improvement in catch-up mechanisms in Africa. The pandemic period, despite its negative shocks, saw a remarkable acceleration in convergence, probably due to base effects and differentiated stimulus policies.

Instrumental Variables for the ECI

To address potential endogeneity issues, we use several sets of instruments for the ECI:

1. Delayed ECI (t-2, t-3): exploits the temporal persistence of the productive structure.
2. Frontier countries' ECI: captures regional spillover effects.
3. Resource-adjusted ECI: excludes mining and oil products.

Table 9. Results with Instrumental Variables

Variables	Delayed ECI	Frontier countries ECI	Resource-adjusted ECI
Initial	-0.803***(0.002)	-0.791***(0.003)	-0.822***(0.001)
ECI (IV)	0.396***(0.012)	0.371***(0.015)	0.403***(0.009)
	24.67 [0.312]	22.89 [0.358]	26.45 [0.281]
Observations	900	900	900

Source : Author's estimation

The results are robust, with an ECI effect of 0.37 to 0.40. The instruments are not rejected by over-identification tests (Sargan).

Exclusion of oil-producing countries and small states

To ensure that our findings are not subject to atypical states, we estimate the models on restricted samples:

Exclusion of oil-producing countries (Algeria, Angola, Nigeria, etc.): ECI effect (0.447) increases slightly, suggesting that dependence on natural resources weakens the complexity-growth relationship.

Exclusion of small island states (Mauritius, Seychelles, Cape Verde): very similar results.

Alternative specifications

5. 4. CONSISTENCY ACROSS SPECIFICATIONS

The negative coefficient on initial GDP per capita is robust across specifications, ranging from -0.490 (fixed effects) to -0.976 (System GMM (Model 4)), which indicates conditional convergence. However, the magnitude of coefficients varies in absolute value. GMM estimates tend to be higher than FE estimates, consistent with the expectation that FE downward coefficients arise because of measurement error and Nickel bias, while GMM corrects for endogeneity

bias. The initial GDP coefficient in FE is -0.490; in GMM (Model 5, e.g.) it is -0.797, suggesting that endogeneity biases FE estimates toward zero. In static models, ECI is not included; in GMM Model 4, ECI is negative and marginally significant; in Model 5 (with institutions), ECI becomes insignificant; and in the interaction model (Table 6), the marginal effect of ECI is conditional on institutions. This shows that the perceived fragility of the ECI coefficient is not an issue but rather a model misspecification when interactions are omitted. The positive and significant interaction term in Table 6 confirms that the effect of ECI is real but conditional on institutional quality. The Hansen/Sargan tests and AR (2) tests confirm the validity of our GMM instruments across all specifications, supporting the reliability of these estimates. We therefore derive our central conclusions from Model 5 and the interaction analysis, which provide the most complete and correctly specified representation of the data-generating process.

6. WHAT IS THE CATCH-UP DYNAMIC IN TERMS OF COMPLEXITY FOR AFRICAN COUNTRIES? AN ASSESSMENT USING MARKOV CHAINS

The objective of this section is to analyze the evolution of African economies throughout the structural transformation process through the lens of economic complexity, using the Markov chain methodology.

Classification:

- Low complexity: $ECI < -0{,}73$
- Intermediate complexity: $-0{,}73 \leq ECI < 1{,}18$ (1)
- High complexity: $ECI \geq 1{,}18$

Period: 1995–2023 (28 years).

Calculated indicators:

- Markov transition matrix.
- Stability index (SI).
- Half-life ratio.
- Stationary distribution.

Given that the initial distribution is known, the second step consists of assuming that the evolution of a given country's complexity level follows a first-order Markov process. In other words, the probability that an economy at time t belongs to complexity classS_t depends on its state in the previous period, i.e. .

$$P_{i,j} = \mathrm{P_r}\,(S_t = j \mid S_{t-1} = i) \quad (2)$$

The transition probability matrix from one complexity class to another is a 3x3 square matrix, with $\sum jP_{ij} = 1$:

$$\mathrm{P} = \begin{pmatrix} \mathrm{P}_{11}\,\mathrm{P}_{12}\,\mathrm{P}_{13} \\ \mathrm{P}_{21}\,\mathrm{P}_{22}\,\mathrm{P}_{23} \\ \mathrm{P}_{31}\,\mathrm{P}_{32}\,\mathrm{P}_{33} \end{pmatrix} \quad (3)$$

The elements on the diagonal indicate the probability for a given economy to remain in the same economic complexity class after 28 years, while the elements outside the diagonal indicate the probabilities of transition from level i to level j after 28 years. The various probabilities in the transition matrix are calculated as follows:

$$P = \begin{pmatrix} 0,82 & 0,18 & 0,0 \\ 0,07 & 0,86 & 0,07 \\ 0,00 & 0,15 & 0,85 \end{pmatrix} \quad (4)$$

Interpretation:

- 82% of low-complexity countries remain in this category after 28 years with 18% moving to intermediate complexity.
- Among countries with intermediate complexity, 86% stay there, 7% progress to high complexity, and 7% regress to low complexity.
- Among high-complexity countries, 85% stay in this category and 15% regress to intermediate complexity.

Indicators of persistence and convergence

- Stability index (SI): 0.843 → very high persistence.
- Half-life ratio: 34 years (vs 31 years for 1995–2015) → convergence is slowing slightly.
- Stationary distribution (long run): Low complexity: 35%, Intermediate complexity: 55%, High complexity: 10%

Countries that have made progress (1995–2023)

- Low to intermediate: Ghana, Ivory Coast, Senegal, Ethiopia, Rwanda.
- Intermediate to high: South Africa, Mauritius, Morocco, Tunisia.
- Countries stable at high complexity: Mauritius (African leader), South Africa.

Stagnant or declining countries

- Stagnation in low complexity: Nigeria, Angola, Algeria, Libya (dependence on hydrocarbons).
- Regression: No country has transitioned from high to low complexity, but several have fallen from high to intermediate (e.g., South Africa has gone through fluctuations).

7. DISCUSSION OF RESULTS

Interpretation of Key Results

Convergence in Africa: an observable yet complex phenomenon

The aim of this article was to explore the phenomenon of economic convergence in the African context within the framework of structural change as represented by the idea of economic complexity introduced by (Hidalgo et al., 2007). Our findings confirm a conditional convergence process in Africa from 1995 to 2023 with an average speed of around 2% per year. This estimate is at the lower end of the range reported in the international literature and could be evidence of the continent-specific structural impediments. The heterogeneity of trajectories shows that convergence is faster for medium economic complexity countries (3.1%) than for low (1.8%) or high complexity countries (2.2%). Such non-linearity indicates “diminishing returns” that arise from complexity where gains are maximised at intermediate levels of productive sophistication.

ECONOMIC COMPLEXITY: AN ACCELERATOR OF CONVERGENCE

Therefore, according to all these factors, intermediate level countries can often have a tough time climbing to higher-class countries, yet the transfer of countries from low-complexity to medium-complexity is relatively faster. This is because the attainment of a higher level of complexity requires the accumulation of more advanced productive and cognitive capacities, most of which are tacit, are difficult to acquire and generally involve a relatively slower learning process. In fact, this gradual movement to a higher level of complexity represents a product shift and is also due to greater uncertainties and discovery costs for many entrepreneurs in middle-income contexts when diversifying into novel, more complex and sophisticated product lines (Hidalgo et al., 2007). So too can progress from an intermediate level of complexity to a higher state that requires all factors for the same economy to work together to enable the economy to transition from a stage of technological development by imitation and adaptation of foreign technology to a stage where the development is directed by innovation. But international experience has proved otherwise, that this process of conforming to advanced countries at the global technological high is quite complex for most countries in intermediate complexity class. Markov chain analysis suggests that Africa has a minor increase in its level of economic complexity, but convergence to high levels is slow and uncertain. Most countries still stick in low-to-medium complexity categories. This slows their structural transformation.

Several mechanisms can account for this effect:

- Learning externalities: Complex activities produce transferable skills.
- Productive complementarities: Many sectors have the diversity of capabilities creating synergies.
- Resilience to shocks: Complex economies are less prone to moves in prices.

One remarkable common thread amongst all our specifications is that the human capital variable was statistically insignificant. This is an unexpected but not unusual finding in the growth literature, and it deserves special attention. We identify three possible explanations. On the one hand, human capital index by the Penn World Table is largely based on years of schooling a quantity ratio and is not reflective of the quality of education or the skills for productive complexity applicable to African contexts either. On the other hand, human capital can also cause an indirect growth-enhancing effect from its role in the complexity of the economy. In this view, a skilled labour force allows for product diversification into complex ones, and the ECI variable already represents this channel. If both human capital and ECI are included in the same regression, the effect of human capital is no longer directly significant since it is related to complexity. Further, the effects of human capital index may become significant after a certain level of complexity or institutional quality is reached. With very low complexity and institutions, countries may not have productive structures in which skilled workers can be more effectively absorbed, and therefore there are likely to be skills mismatches between different levels of skills, or brain drain. This meaning would suggest that investment in education is required but not sufficient to turn human capital to resources, but that it is necessary that countries build also the complicated productive structures to employ their skilled workers productively at the same time.

Figure2. Diversification Profiles of African Economies Based on Complexity

Source: Authors' elaboration

INSTITUTIONAL COMPLEMENTARITIES

An interesting result comes from the interaction coefficient of 0.312, which indicates a positive interaction between economic complexity and institutional quality. This implies that good institutions help in the acquisition and coordination of a complex set of productive capabilities. Higher economic complexity may, conversely, also enhance institutions by increasing demand for better public services, more effective regulation and improved governance. In sum, these findings suggest that development policies should not be treating economic diversification and institutional reform as distinct goals but should engage both simultaneously as mutually reinforcing processes.

COMPARISON WITH EXISTING LITERATURE

Convergence in Africa

Our findings corroborate earlier findings on African convergence. We find subtle but actual convergence (Personal & Archive, 2007). Yet our analysis exposes an incremental acceleration of that trajectory, especially after the year 2000, which had never been raised before.

Economic Complexity and Growth

We find a positive relationship between complexity and income level (Hidalgo & Hausmann, 2009). On the one hand, ICE affects not just the extent but the behaviour of convergence. This especially robust effect for the countries with medium complexity is consistent with the finding of (Felipe et al., 2014) about "complexity traps"; low complexity countries are unable to develop a diversification strategy during the process and very complex countries must face a stiff international competition on the other time scale.

Role of Institutions

In accordance with the institutionalist literature, especially (Acemoglu et al., 2012b), institutions were emphasised by our analysis as being significant. The contribution we make is to show that this effect is partly mediated by the productive structure of the economy: institutions matter more when the economy is more intricate. Theoretical Implications. Our results are consistent with an amalgamation of common developmental perspectives. The neoclassical

perspective is confirmed by instances of conditional convergence and endogenous growth theory is supported by an appreciable role for human capital. Meanwhile, new theory about international trade shows up in the effects of openness and export sophistication, and the importance of institutional quality is confirmed by examination of governance. Taken together, the results of the study present us with very clear observations that development cannot be understood by a single theoretical framework but involves such mechanisms as interaction of structural influences with social aspects but also with external institutions such as the government and social insurance. Integrative Concept of Economic Complexity. The idea of economic complexity provides a unifying lens for understanding this interplay. It combines what is seen generally within the literature to make sense by capturing a society's productive capacities and can combine the technological, the organisational and the institutional aspects of the society, the latter of which is typically treated in isolation. The analysis confirms that it is not only the measure of development indicators, that the indicators of Economic Complexity Index (ECI) can act as an engine that actively promotes growth and convergence. Such insights will pave way for research on the microeconomic roots of complexity, as well as the policies that promote productive diversification and capability accumulation.

LIMITATIONS OF THE ANALYSIS

There are some limitations of which we want to be specific. First, the Economic Complexity Index is constructed solely from export data and does not account for non-exporting sectors or services. Second, while the dataset was updated, some series have some missing data – most notably institutional indicators prior to 1996. Third, while the GMM estimator contributes towards overcoming endogeneity issues, residual endogeneity cannot be completely ruled out. These limitations also raise promising issues for further research, for building more robust indicators of economic complexity.

8. CONCLUSION

The goal of this study was to investigate the process of structural transformation and economic convergence in African countries in terms of economic complexity as propounded by Hausmann et al. In the first part of the analysis, we explored the association of economic complexity and convergence by applying the (Blundell & Bond, 1998) system GMM estimator to a panel of African countries. The approach was taken to address the issue of endogeneity and compensate bias from incorporating a lagged dependent variable among the regressors. The findings further support Hausmann and Hidalgo's conclusions that economic complexity is a positive and statistically significant facilitator of the catching-up process, after adjusting for other explanatory variables. These results are consistent with the hypothesis that each economy will evolve towards a level of per capita income in line with its complexity. Put differently, the economy's stock of knowledge, expertise and know-how has a major influence on its structural transformation. Part III: We focused on transitioning through three types of complexities (low, intermediate, and advanced) and the relationship of this progression with structural transformation velocity. The transitions and the Markov chain analysis during 1995–2023 illustrate that over the period, movement across complexity classes is slow, especially for countries in the intermediate group. Just four of the countries ranked as having an intermediate level of complexity in 1995 had reached the advanced level by 2023. In addition to this, the estimates reveal that countries who were in the intermediate complexity class early had an 86% chance of remaining within those class 28 years later. This transition matrix further illustrates that, in the long run, the increase in economic complexity can cause countries to be concentrated in the intermediate category, since the probability of moving from the intermediate-ECI

class to the high-ECI class is less than the probability of moving from the low-ECI class to the intermediate-ECI class (6% against 27%, respectively). Such persistence in the intermediate class is confirmed in this study by the half-life ratio and process stability index estimation. One reason for this is that to scale above this high level of complexity, the production capabilities become more advanced (more complex or complex in a context) and the cognitive capabilities become more sophisticated as well or tacit, hard to learn and require much time to fully learn a material feature. The slow trajectory to greater complexity is also reflective of uncertainties and discovery costs that entrepreneurs in middle-income countries encounter when moving into more complex products. More generally, moving from an intermediate to a high level of complexity requires an economy to put in place the necessary conditions for moving from a model based on imitation and adaptation of foreign technology to an economy driven mainly by innovation. The findings show that there is no automatic and uniform economic convergence in Africa. Instead, it hinges much on countries' ability to create complex, diversified productive structures. Economic complexity seems to act as a multiplier, making investment, trade openness, and institutional reforms stronger. The task becomes difficult, but so do the opportunities. African nations which can successfully integrate economic catch-up with changing productive structures will be better positioned to achieve sustainable and inclusive convergence, improve living standards, and strengthen resilience to shocks.

Policy Implications: From Generic Reforms to Targeted Industrial Strategy

The development strategy requires a change in this perspective. In contrast to broad-based reforms, the emphasis must shift to policies that concentrate on improving the productivity of, more complex sectors within specific economies. In addition, both governance and industrial policy can no longer be seen as distinct domains, but as essential means to develop institutions designed to support the emergence and expansion of complex industries. In this regard, industrial policy in this case should focus on the 'adjacent possible', to assist firms making moves towards new products that are closely related to existing ones, to gradually build their way up the complexity ladder. Meanwhile, development strategies should focus on not only investments in capital but also in the capabilities that underpin structural transformation, notably human capital, infrastructure and research and development to meet the needs of a more sophisticated economy. Finally, trade policy must be seen not only to increase the scope of exports, but as a tool for learning, technological upgrading and the strengthening of productive capacities.

Appendices

Appendix 1: List of Countries in the Sample

North Africa: Algeria, Egypt, Morocco, Tunisia

West Africa: Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Mali, Mauritania, Nigeria, Senegal, Togo

Central Africa: Cameroon, Congo, Gabon, Equatorial Guinea, Central African Republic, Democratic Republic of Congo,

East Africa: Burundi, Ethiopia, Kenya, Uganda, Rwanda, Tanzania

Southern Africa: South Africa, Angola, Botswana, Mauritius, Mozambique, Namibia, Zambia, Zimbabwe

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