Greasing the Wheels of Regional Integration: Infrastructure as a Catalyst for Trade, Innovation, and Growth in Africa[1]

Akpan Ekpo[21], Anthony Simpasa[1,] and Chuku Chuku[1,]

[1] West African Institute for Financial and Economic Management (WAIFEM)
Lagos, Nigeria
[2]Nigeria Country Department, African Development Bank Group, Abuja, Nigeria
[3]Macroeconomic Policy, Forecasting and Research Department, African Development Bank (AfDB), Abidjan, Cote D'Ivoire

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Abstract

Now, more than ever, infrastructure integration in Africa has become critical to the rebalancing of Africa's growth strategy towards increased intraregional trade. This is particularly so because of the recent wave of protectionism and populism around the world. This paper investigates the extent to which infrastructure development and integration can act as a catalyst for trade, productivity growth, and income improvements in Africa; and examines some important policy issues and challenges related to infrastructure development and integration in Africa. Our findings show that infrastructure does improve trade, productivity, and innovation in sub-Saharan Africa. Specifically, the infrastructure sector with the strongest multiplier effect on economic outcomes is the ICT sector, followed by the transport, electricity, and water sectors, respectively. This ranking informs our recommendation that infrastructure integration and development in Africa should be prioritized according to the ranking of their multiplier effects on the rest of the economy. Furthermore, our findings show that infrastructure has had the strongest impact on economic outcomes in the SADC region, which makes SADC a type of flying-geese leader

1 Corresponding author: Chuku Chuku, c.chuku@afdb.org
2 ahekpo@yahoo.com, a.simpasa@afdb.org, c.chuku@afdb.org

for the other regional economic communities.

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1 Introduction

Infrastructure integration is essential to the realization of Africa's goal of accelerated economic transformation and wealth creation. It has become even more important in view of the recent wave of protectionism and populism around the world. Now, more than ever, the development and integration of infrastructure needs to be accelerated to enhance physical and virtual connectivity for rebalancing Africa's growth towards increased intraregional trade and productivity, and for shared prosperity in the region. To achieve the laudable goals that have been set for Africa by the African Union, the African Development Bank (the High-5 priorities), the United Nations (Sustainable Development Goals) and the goals of the various regional economic communities in Africa, infrastructure development and integration needs to be fast-tracked to promote cross-border trade and investment, improve countries productivity and innovation, and raise regional output and competitiveness. In particular, it is important that regional integration is fast-tracked through better and improved interconnectedness of road, railway, airport, seaport, energy and telecommunications networks.

Although there is general agreement, and with evidence too, that infrastructure integration could allow networks to become smarter, more cost-efficient and guarantee future prosperity for Africa (see Ajakaiye and Ncube, 2010; Ayogu, 2007; Kodongo and Ojah, 2016; Ncube, Faye and Verdier-Chouchane, 2015; Ndulu, 2006), yet it is not clear what infrastructure integration precisely means for sub-Saharan Africa, how to go about it, nor the extent to which it could facilitate trade, innovation, and growth. To better understand what infrastructure integration means, we need to first make a distinction between hard and soft infrastructure. The former refers to physical infrastructures or facilities that support the economy and society, such as transport, electricity, telecommunications and water utilities; while the latter covers non-tangible aspects that support the development and operation of hard infrastructure, such as policy, regulatory governance, institutional frameworks, and mechanisms (Bhattacharyay, 2010).

Regional infrastructure integration, on the other hand, involves executing projects that require physical construction works and coordination of policies or procedures spanning two or more neighbouring countries; and implementing national infrastructure projects that have a significant cross-border impact. Typical examples are projects whose planning and implementation involve cooperation and coordination with one or more countries, projects that seek to stimulate significant amounts of regional trade, and projects that are designed to connect to the network of a neighbouring or third country. By this definition, it means that a large portion of national infrastructure, such as airports, roads, seaports, telecommunications, and railway can be considered as cross-border infrastructure since they constitute the building blocks for infrastructure integration. We focus on infrastructure integration for the two categories of infrastructure: integration of physical amenities and integration of governance amenities.

While African member states have been making steady progress towards stronger economic, financial, monetary and, to some extent, political integration (see AfDB, 2016e; UNECA, 2015), it appears that these efforts and progress seem to be having only a marginal impact in promoting regional integration and intra-regional trade and growth (see Ndulu, 2006). One of the most likely explanations for this marginal impact could be because the progress has not been accompanied by commensurate efforts towards alleviating and integrating both physical (or hard) and institutional (or soft) infrastructure in the region. Although there have been some recent improvements in Africa's infrastructure connectivity, these improvements seem to have progressed in a rather fragmented manner, concentrating particularly within countries and hardly connecting between countries; moreover, the quality of infrastructure in the region still remains at the bottom of global rankings (see Calder/on and Serv/en, 2008; Dethier, 2015; Kodongo and Ojah, 2016). Consequently, the level of integration in Africa has mostly been impeded by a range of non-tariff and regulatory barriers, such as infrastructure

The aim of this paper is to assess the extent to which infrastructure development and integration can act as a catalyst for trade, productivity growth and income improvements in Africa; and to examine some important issues and challenges related to infrastructure development and integration in Africa. The paper uses both the positive approach of economic analysis—that is, an analysis that is based on testable facts through, for example, regression analysis—and the normative approaches to analysis—that is, an analysis that is based on subjective values, anecdotal evidence and experience—to examine the problem. Furthermore, we attempt to shed light on the impact of different dimensions of infrastructure in the regional economic communities (RECs). Our approach is unique in a few ways. First, by examining the cross-regional variations in the impact of infrastructure, disaggregated according to four dimensions, we are able to isolate the impact of specific infrastructure dimensions on economic outcomes in Africa, which helps to set priorities on which infrastructure dimension to fast-track integration. Also, by benchmarking infrastructure impacts based on RECs, we are able to identify the RECs where infrastructure is working best, so that other latecomer regions can perhaps, emulate the governance and operational strategies of the regions with the most significant impact of regional integration. The findings particularly help identify specific areas to focus on in the different subregions and the region-specific bottlenecks that require urgent attention for infrastructure integration.

The remainder of the paper is organized as follows. In Section 2, we conduct a concise diagnostics of Africa's infrastructure endowment and the outlook for Africa's infrastructure. Section 3 asks the question: has infrastructure played its functional role in Africa? It examines three categorizations of infrastructure role: the Keynesian stimulus, the Ricardian stimulus, and the Neoclassical stimulus. Section 4 examines some issues in Africa's infrastructure integration, such as the key challenges, whether it should be market-driven or institutions-driven, and a new paradigm for infrastructure integration—inverse infrastructure. Section 5 contains the empirical analysis of the paper starting from the data, to the econometric model and a discussion of the key results. Section 6 concludes the paper.

2 Africa's Infrastructure diagnostics and prognosis

A thorough diagnostics of the state of Africa's infrastructure and a prognosis of the prospects and outlook for the next three decades was the result of a fruitful collaboration between the African Union Commission (AUC), the African Development Bank (AfDB) and the United Nations Economic Commission for Africa (UNECA), which culminated in the masterplan for Africa's infrastructure development—the Programme for Infrastructure Development in Africa (PIDA) (see AfDB, 2016a,b,c,d; UNECA, 2015). Cursory benchmarking of Africa's infrastructure with other regions show that the state of Africa's infrastructure is abysmal. For example, in Table 1, we present statistics on Africa's infrastructure endowment in relation to other regions of the world. This observation is consistent across all four sectors of infrastructure. The greatest gaps are in the energy sector where SSA power generation capacity is about half the capacity in the second-worst region in the world—South Asia, and about one-tenth of the generation capacity in Europe and Central Asia. The situation for ICT is, however, less severe. For example, in 2016, the density of internet connections per 100 persons was 20 percent in SSA and 26 percent in South Asia only six percentage points higher, and 73 percent for

Europe, the highest region, which is about three times the level in Africa.

The SSA averages presented in Table 1, masks the significant variation in infrastructure endowment within the African region. To see these intra-regional variations, we present the infrastructure endowment benchmarking for four Regional Economic Communities (REC): ECOWAS, EAC, SADC, and CEMAC done in a World Bank study Yepes, Pierce and Foster (2009) in Table 2. The statistics show that the SADC region is significantly more endowed than other regions in all sectors of infrastructure by several multiples. As for the other three regions, there is no consistent pattern for ranking the endowment stocks, some regions are doing better than others in certain sectors while others are better off in other sectors. For example, although the EAC region has the lowest levels of endowment in transport and energy infrastructure, it has the second highest endowment in water and sanitation infrastructure in terms of access.

Table 1: Infrastructure endowments by world regions

Dimensions of Infrastructure and Indicators	**SSA**	**South Asia**	**EAP**	**ECA**	**LAC**	**MNA**
Transport						
Density of paved road network (km/1,000 km2, 2001)	49	149	59	335	418	482
Density of paved road network (km/1,000 arable km2, 2001)	1,087	675	588	1,208	4,826	6,890
Density of total road network (km/1,000 km2, 2001)	152	306	237	576	740	599
Density of total road network (km/1,000 arable km2, 2001)	2,558	1,400	5,385	2,160	8,850	30,319
ICT						
Density of fixed-line telephones (subscribers per 100 people, 2016)	1	1.83	15.57	32.38	16.89	15.17
Density of mobile telephones (subscribers per 100 people, 2016)	74.37	84.83	110	125.11	109	111.24
Density of Internet users (subscribers per 100 people, 2016)	20	26.47	53	73.91	56	47.62
Energy						
Electrical generating capacity	70	154	231	970	464	496

(MW per 1 million people, 2003)						
Access to electricity (% of populattion, 2014)	37.44	80.06	97	100	97	96.99
Water and sanitation						
Water (% of households with access, 2015)	57.54	88.16	94	98.1	96	92.92
Sanitation (% of households with access, 2015)	28.26	46.5	77	96.03	86	89.32

Note: SSA—sub-Saharan Africa, EAP—East Asia and the Pacific, ECA—Europe and Central Asia, LAC—Latin America and the Caribbean, MNA—Middle East and North Africa. The main source of the data is from World Bank, World Development Indicators (WDI) and studies in the Africa Infrastructure Country Diagnostics (AICD), especially Foster and Brice˜no-Garmendia (2010); Yepes et al. (2009)

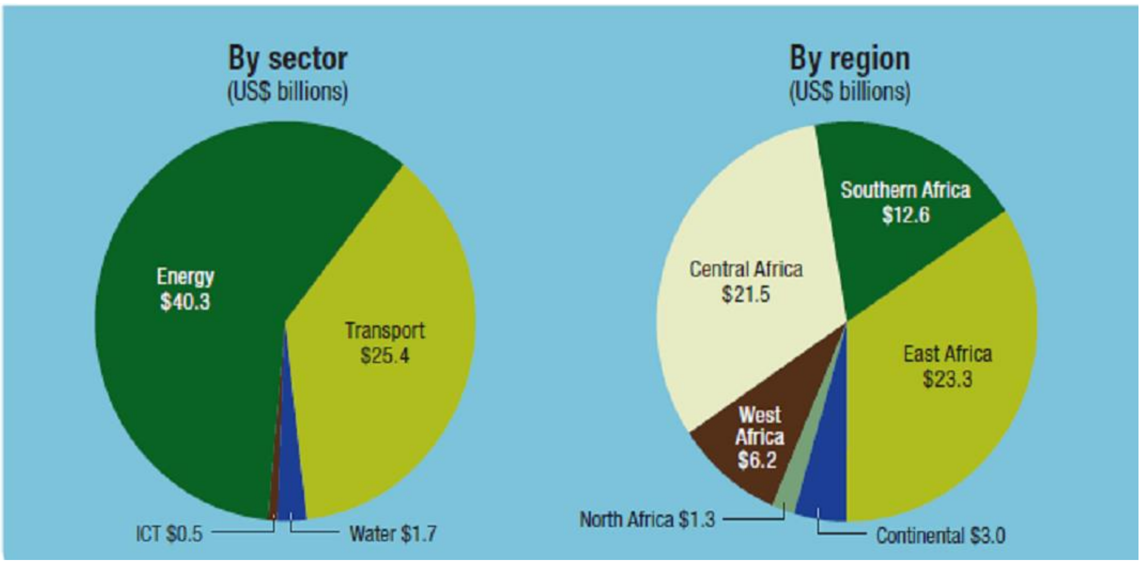
Table 2: Infrastructure endowments by SSA Regional Economic Communities

	ECOWAS	EAC	SADC	CEMAC
Transport				
Density of paved road network (km/1,000 km2)	38	8	92	41
Density of paved road network (km/1,000 arable km2)	301	93	3,636	416
Density of total road network (km/1,000 km2)	144	105	214	132
Density of total road network (km/1,000 arable km2)	1,279	1286	6,164	1,790
ICT				
Density of fixed-line telephones (subscribers per 1,000 people)	28	6	74	13
Density of mobile telephones (subscribers per 1,000 people)	72	54	180	74
Density of Internet connections (subscribers per 100 people)	2.4	2.1	6	1.7
Energy				
Electrical generating capacity (MW per 1 million people)	31	24	175	44
Access to electricity (% of households with access)	18	7	21	18
Water and Sanitation				

Water (% of households with access)	63	64	71	58
Sanitation (% of households with access)	35	45	43	28

Note: ECOWAS—Economic Community of West African States, EAC—East African Community, SADC—Southern African Development Commission, CEMAC—Central African Economic and Monetary Community.jkl[] The main source of the data is from World Bank, World Development Indicators (WDI) and studies in the Africa Infrastructure Country Diagnostics (AICD), especially Foster and Briceno-Garmendia (2010); Yepes et al. (2009)

Figure 1: Estimated cost of bridging infrastructure gaps—by region and sector



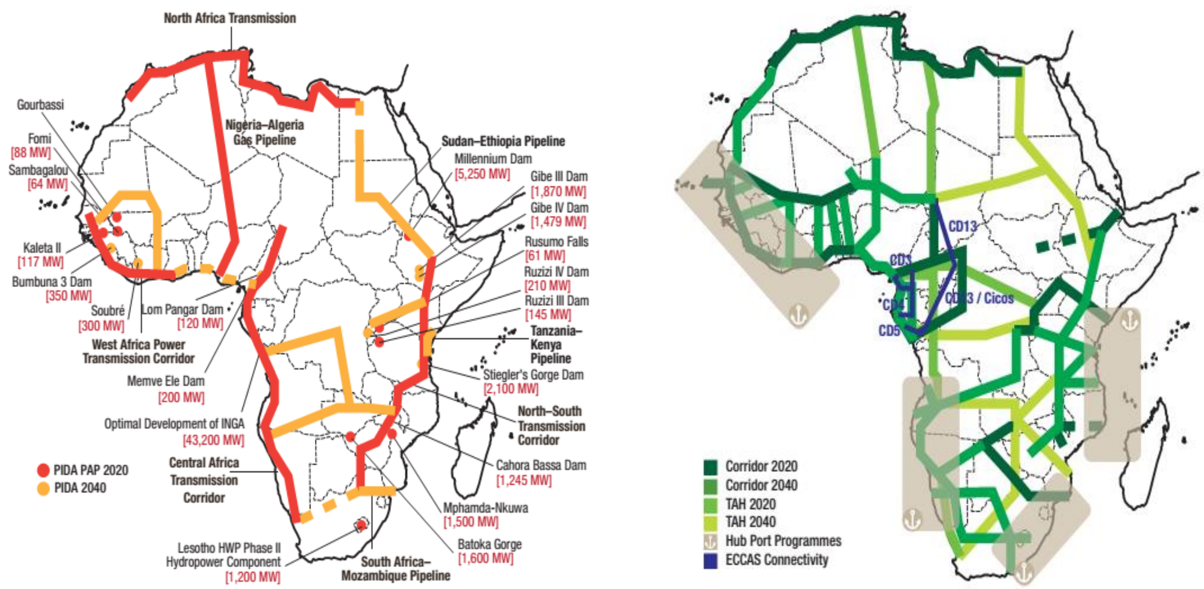
Source: AfDB (2016d)

Although infrastructure endowments are relatively low for the SSA region, it is not altogether a doom-doom situation. The reason is that investments in infrastructure in the region have been shown to yield the highest levels of returns comparatively. Recently, private investors that have ventured into the telecommunications and energy sectors have reported significant value addition in balance sheet terms (see AfDB, 2016b). To close these infrastructure gaps, the joint consultation by the AfDB, AUC, and UNEC which produced the Programme for Infrastructure Development in Africa, arrived at an estimated financial investment requirement of $360 billion for the 2040 outlook. Recognizing that this is an enormous amount of resource to mobilize, the Priority Action Plan (PAP) is a more compact and practical plan to bridge the infrastructure gap in Africa between 2012 and 2020 with an estimated capital cost of $67.9 billion, which requires about $7.5 billion annually for the first decade (see AfDB, 2016c). Of this total investment requirement, energy and transportation projects represent about 95% of the total cost. The breakdown of the proposed investment requirement that would alleviate infrastructure gaps in

Africa by sector and regional blocks is depicted in Figure 1

The infrastructure integration masterplan for Africa in the PIDA document highlights the proposed networks for infrastructure interconnectivity throughout Africa, detailing the proposed optimal path for interconnecting infrastructure through all the subregional blocks and countries in the continent. The plans for infrastructure integration in the four major infrastructure sectors with a significant deficit for Africa are depicted in Figures 2 to 3. In particular, the energy integration plan in Figure 2a focuses on how to link major hydroelectric projects into a power pool to meet the deficit supply and satisfy the forecast increase in demand for electricity in the region. It also seeks to connect regional petroleum and gas pipelines. The objective of the transportation integration master plan in Figure 2b is to connect the major production and consumption centres, to open up land-locked countries, and define the best hubs for ports and railways in order to improve intra-regional trade.

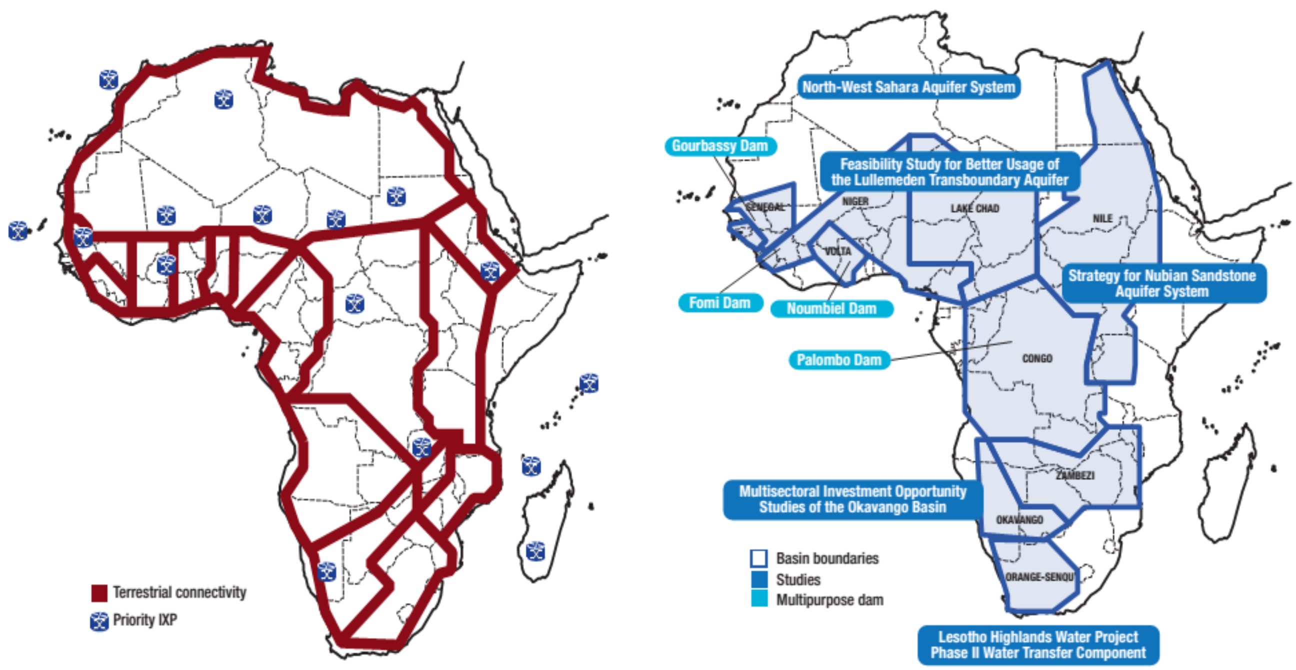
Figure 2: Masterplan for infrastructure integration in Africa: Energy and transport



Panel A: Network for electricity interconnectivity; Panel B: Network for transport integration

Source: AfDB (2016c)

Figure 3: Masterplan for infrastructure integration in Africa: ICT and water



Panel A: Network for ICT infrastructure; Panel B: Network for water connection

Source: AfDB (2016c)

In Figure 3b, we plot the infrastructure integration masterplan for water infrastructure, which seeks to, among other things, develop damps that have multi-purpose services and are capable of providing irrigation to cushion drought effects and boost food sufficiency. Lastly, Figure 3a depicts the masterplan for the integration of information and communication technology across the region. The objective is to fast-track and complete the land fibre-optic infrastructure in the region, and install internet exchange points in countries without them, and also connecting countries to at least two different submarine cables to take advantage of speed and expanded capacity.

3 Has infrastructure played its catalytic role in Africa?

To assess whether or not infrastructure has played its functional roles in Africa, it is instructive to classify infrastructure according to three functional economic roles it plays in an economy: the Keynesian stimulus, the Ricardian stimulus, and the Neoclassical stimulus Roland-Holst (2009).

3.1 Income and employment roles: the Keynesian stimulus

. The Keynesian stimulus of infrastructure is the role that infrastructure development and investment plays in boosting aggregate demand. In particular, it is related to the multiplier effect that infrastructure investment creates on income, output, and employment. It also relates to how infrastructure investments are can be used as a tool for conducting countercyclical economic policies—to boost economic activity during a downturn and to slow down economic activity during a boom.

Figure 4: Infrastructure development and GDP per capita in Africa

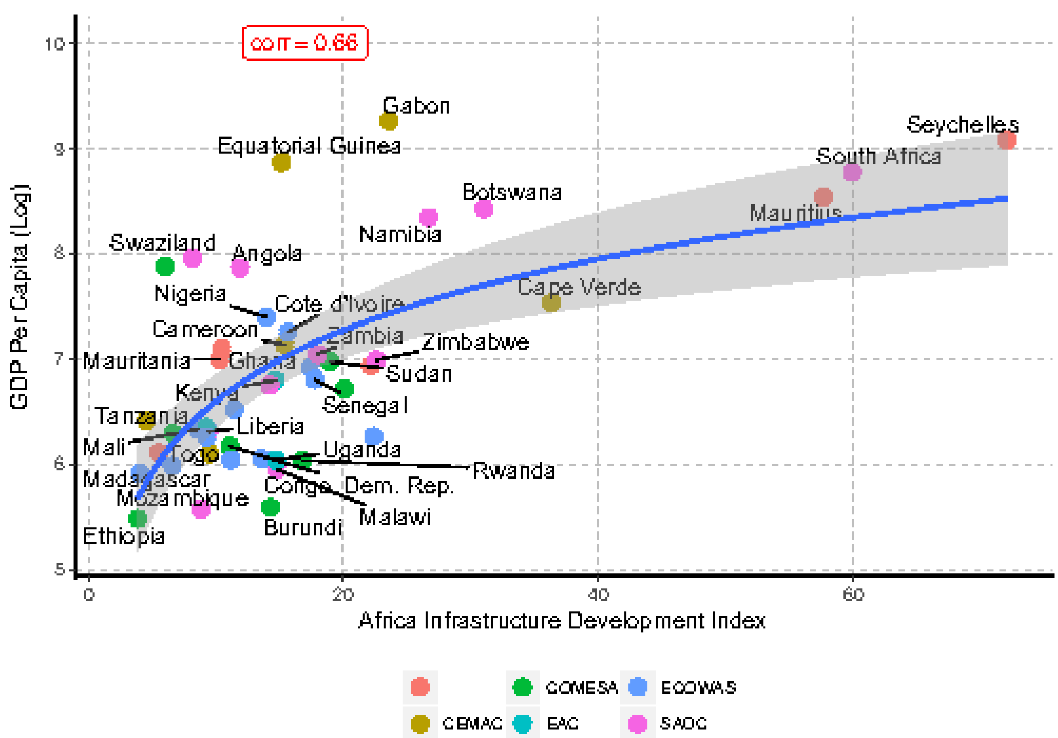
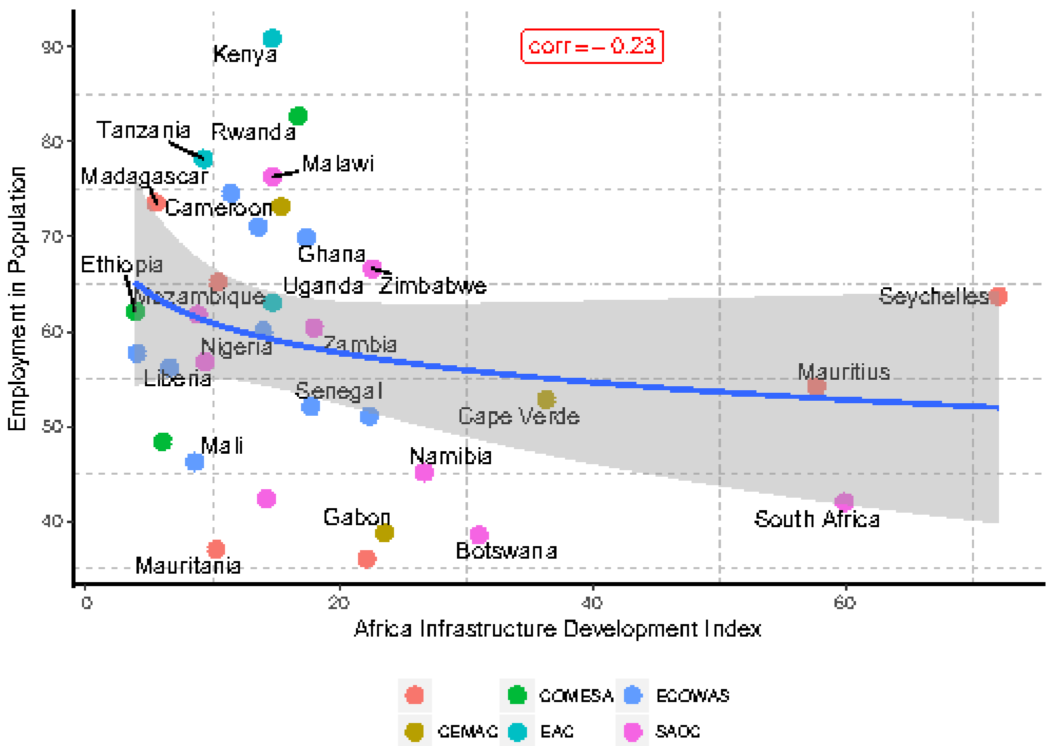


Figure 5: Infrastructure development and employment levels in Africa



In Figure 4 and Figure 5, we plot simple scatter points between our measure of infrastructure, the Africa Infrastructure Development Index (AIDI), and GDP per capita and employment levels along with their unconditional correlations coefficients, respectively. Figure 5, shows clearly that there is a positive relationship between the aggregate level of infrastructure development and the level of GDP per capita, the correlation is high at 0.66 percent and statistically significant too. Thus, infrastructure development is clearly associated with higher levels of GDP per capita. Contrarily, we do not necessarily observe the employment stimulating effect of infrastructure by plotting a scatter of infrastructure and employment levels. Rather, what we seem to observe in Figure 5 is that the relationship between infrastructure development and employment seems to be negative, or at the least neutral. But because data on employment levels in Africa are unreliable, we a weary of attempting to provide an explanation for this observed pattern. We would re-examine this relationship in a subsequent section using conditional regression analysis.

3.2 Trade and trade facilitation roles: the Ricardian stimulus

The Ricardian stimulus role of infrastructure refers to its functional role in improving comparative advantage by reducing the distribution cost of good and services through, for example, making transport and ICT processes more efficient. These reductions in distribution costs lead to reductions in trade margins which work to increase competitiveness, intensify comparative advantage and thus boosting both domestic and international trade.

The main advantage of the Ricardian stimulus is that it helps to increase market participation, expanding the profitable horizon of firms at the extensive and intensive margins. This is particularly the case for many countries in central Africa that are landlocked and other African countries that have significant rural poor communities, where distribution costs are an important source of price distortion that significantly limits market access and reduces economic efficiency. Not only does the Ricardian stimulus role of infrastructure help to increase participation, it also confers growth externalities across the integrated networks that are established. For example, the parallel emergence of light manufacturing in South Africa and Ethiopia are able to confer significant growth externalities across the Southern African and Eastern African regions, respectively.

One of the structural effects that infrastructure exerts on the economy through the reduction of margins is the intensification of comparative advantage. Following classical trade theory, it is price differences create incentives for specialization, international, and inter-regional trade. High distribution margins work to undermine specialization and trade. To see this, consider two prices PH and PF for a homogeneous good from two different locations (home and abroad). Given that trade margins are generally symmetric, the ratio of the home and foreign prices, with margins M taken into account and evaluated as it rises without limit is thus;

$$\frac{PH+\mathcal{M}}{PH+\mathcal{M}} \xrightarrow{\mathcal{M}\to\infty} 1 \tag{1}$$

The implication is that the higher the margin, the lower the potential to take advantage of comparative advantage and specialization between markets in a region. Moreover, falling trade margins that result from infrastructure improvements also work to improve international terms of trade through a double-virtue causation. Consider domestic producer price of an export $PE = PWE - \mathcal{M}$, where PWE is the international price of the export good and M is the margin that must be deducted from the exporter's net revenue. Symmetrically, the domestic purchaser price of an import takes a similar form, $PM = PWM + \mathcal{M}$, where PWE is the corresponding international price of the imported good and $\mathcal{M}$ is the margin that must be added to the purchaser price.

$$\mathcal{M} \downarrow \Rightarrow \frac{PWE-\mathcal{M}}{P_D} \uparrow, \quad \text{and} \quad \frac{PWM+\mathcal{M}}{P_D} \downarrow \tag{2}$$

It can be observed from the expression in Eq. (2) that falling margin induces an improvement in the terms of trade PE/PM. In particular, the double-virtue of falling margins emanate from the higher net revenue for the exporter and lower purchaser prices for the importer, thereby sharpening the incentive for trade from both ends.

Figure 6: Infrastructure development and trade in Africa

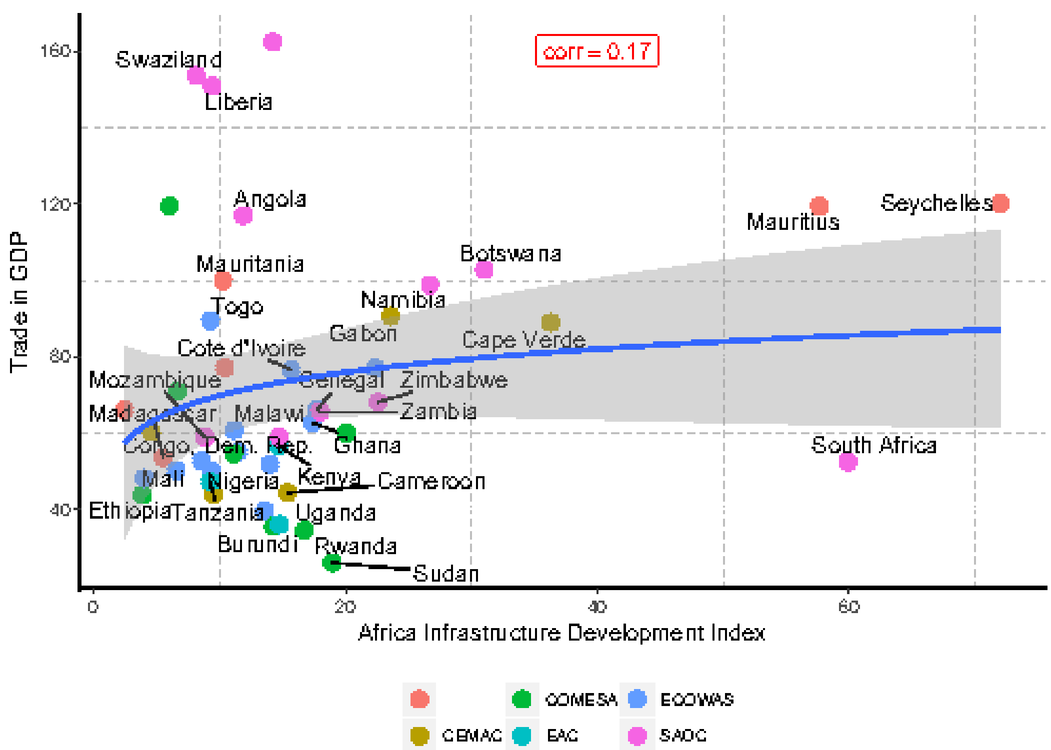
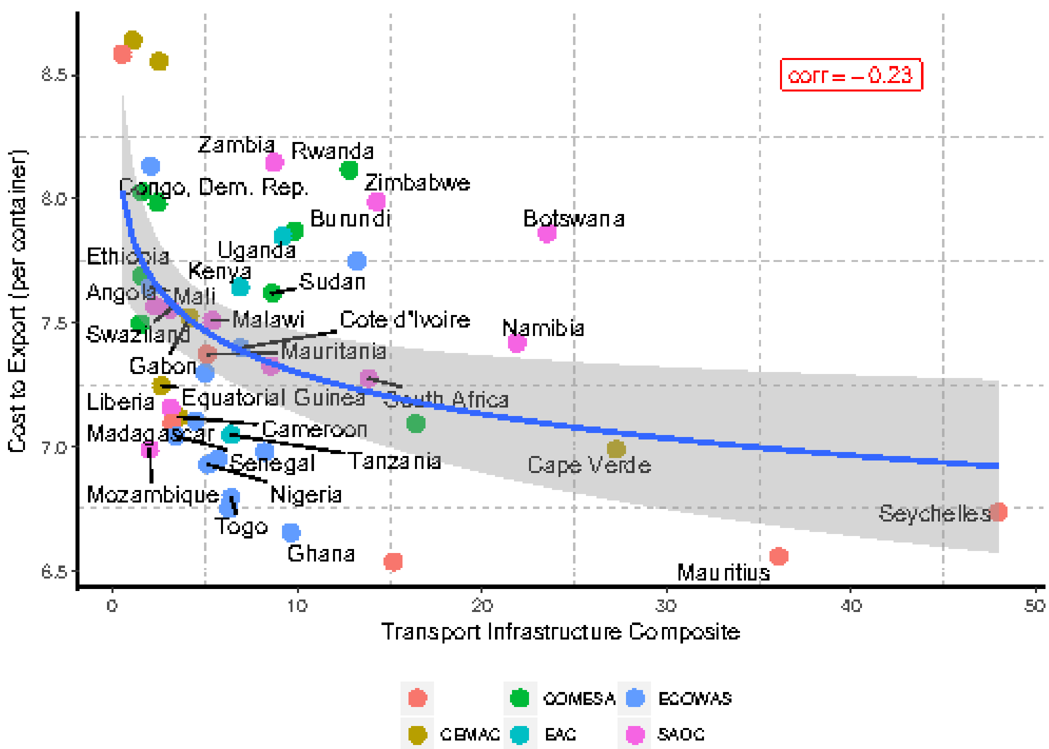


Figure 7: Infrastructure development and trade facilitation in Africa



We now turn to the stylized evidence on the Ricardian stimulus of infrastructure in Africa. In Figure 11, we show a plot of the scatter points of total trade in GDP and the Africa Infrastructure Development Index. The unconditional pattern observed in the figure conforms to the theoretical expectation; that is, infrastructure development, by reducing trade margins help to boost trade—thus, there is a positive association between infrastructure development and trade. In Figure 7, we investigate the direct, first-order Ricardian impact of infrastructure development on trade margins using the average cost to export a container in each African country. The pattern again is consistent with theory; that is, improvements in transport infrastructure is associated with reductions in distribution margins (with a correlation coefficient of 0.23), and specifically, the cost to export a container.

3.3 Productivity and innovation roles: the Neoclassical stimulus

Modern neoclassical growth theories recognize the importance of infrastructure's contribution to increasing productivity. This often works through the diffusion of technology embodied in transport, communication, and distribution systems that help to increase the efficiency of the search and matching stages of trade and the logistical requirements shipment. The neoclassical functional role of infrastructure can be understood from the ideals of endogenous growth theory. That is, factors and conditions that when present in an economy help to facilitate growth in and of themselves. Infrastructure is one of those factors and it also helps other factors other endogenous factors including productivity enhancements, innovation, technology diffusion, information diffusion supply chain articulation, human capital development, and other network externalities (see Roland-Holst, 2009). These are considered among the most important economic contributions of infrastructure.

Figure 8: Infrastructure development and TFP growth in Africa

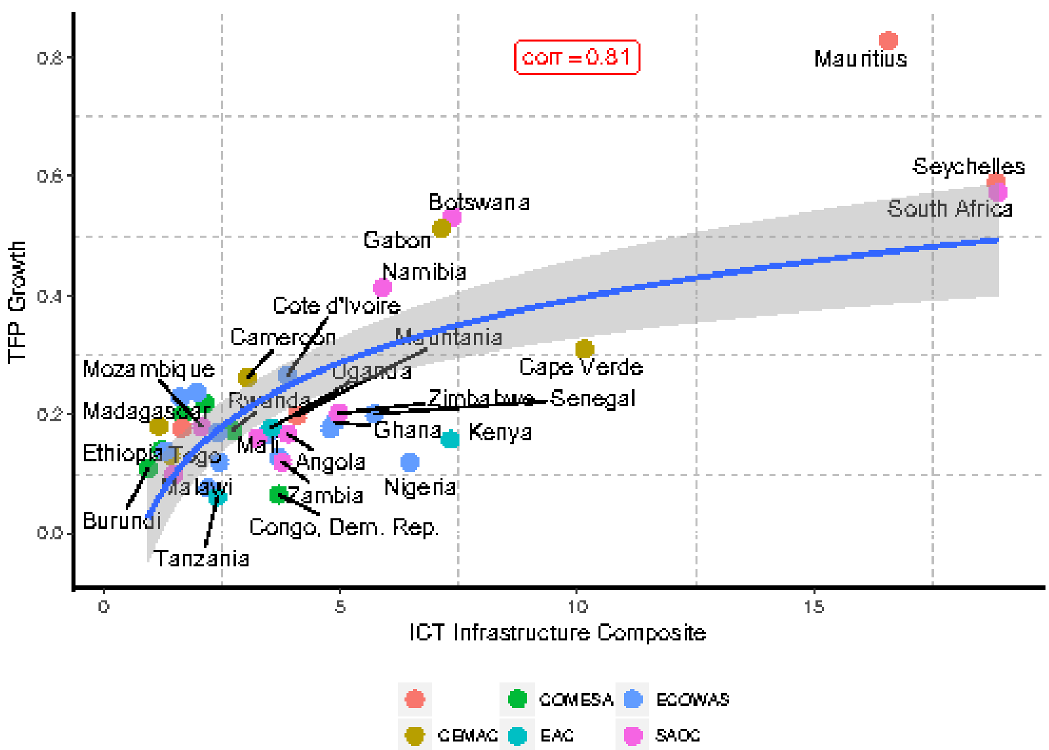
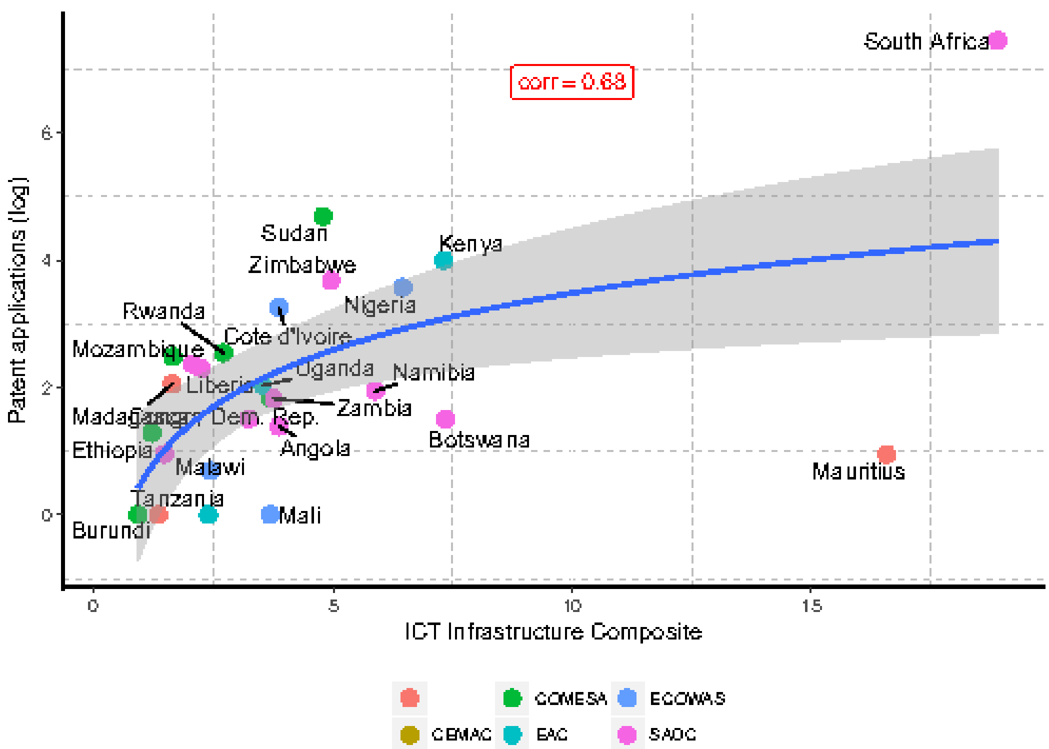


Figure 9: Infrastructure development and innovation in Africa



To examine the stylized facts on infrastructure's role as a neoclassical stimulus, we first plot a scatter chart of the aggregate Africa Infrastructure Development Index against UNIDO's total factor productivity growth for African countries in Figure 8. Although there are a few outliers like South Africa, Mauritius, and Seychelles which tend to drive the pattern of the relationship, there is generally a positive association between ICT infrastructure development and growth in total factor productivity. This pattern of relationship is also very similar to the case of infrastructure and innovation, measured by the number of patent applications by residents, plotted in Figure 9. With regard to patent applications, South Africa is an outlier in Africa—it has the highest level of ICT composite infrastructure and also the highest number of patents applications in Africa. As predicted by the neoclassical theory, infrastructure development is positively associated with innovation; the degree of association is 0.68

percent for sub-Saharan Africa.

4 Some issues in Africa's infrastructure integration

Catalysing infrastructure integration in Africa would involve asking some difficult questions, making some difficult choices, and committing to follow through the choices for as long as is required to achieve the targets. First, there are endogenous conflicts that need to be resolved in order to successfully integrate infrastructure across regions in Africa. The main conflict is related to distributional equity. Building regional and subregional infrastructure involves asymmetric distributional costs and benefits to countries in the region. To understand the extent of these asymmetries, it is important to conduct an objective assessment of the economic (and not only financial) costs, benefits, and externalities arising from cross-border infrastructure projects. So that from the inception of any regional infrastructure project, a mechanism that stipulates the distribution of costs and benefits across countries can be put in place. This pre-emptive measure would help to minimize conflicts and incentivise countries to participate in regional infrastructure projects that can exploit economies of scale and generate externalities that would dominate the distributional disparities in financial and technical contributions by the affected countries. The increasing complexities involved in deploying regional infrastructure continues to affirm the vital role that neutral credible institutions, such as the African Development Bank can play in officiating, coordinating, and implementing regional and cross-country infrastructure projects in Africa.

4.1 Key challenges to Africa's infrastructure integration

Coupled with the challenges that national infrastructure development has to surmount, supranational infrastructure development and integration in Africa faces even more difficult challenges. We highlight a few of them below.

1. Geographical and topographical diversity, which often implies significant differences in the appropriate types and specifications of infrastructure for different areas.
2. Different initial conditions. Different countries are at different levels of infrastructure and economic development.
3. Lack of unifying standards in regulatory policies, legal frameworks, and administrative procedures.

4. Lack of proper assessment of financial implications of cross-border projects; and weak capital markets that could be used to mobilize financing for infrastructure projects, especially by private sector participation through public-private partnerships.

5. Lack of adequate cost-benefit analysis that would show the potential benefits and costs for participating countries. For example, cost-benefit analysis that would show estimates of changes in trade flows, transport costs, tourism, the standard of living, agglomeration effects, scale economies and labour mobility.

6. Lack of proper assessment of negative externalities and environmental impacts, such as the effect of greenhouse gases, displacement of local communicates, forced migration, human trafficking, communicable diseases, smuggling, pollution, etc.

7. Need for effective coordination and consultation among various stakeholders at the local, regional, national, and supranational levels.

Addressing these challenges would require, among other things, concerted effort towards the creation of an enabling environment for cross-border infrastructure investments; effective coordination with a wide range of stakeholders—central governments, state governments, regional government, private sector and civil society; identification and prioritization of commercially viable projects; harmonization and standardization of legal frameworks; and equitable distribution of costs and benefits among participating countries.

4.2 Infrastructure integration: market- or institution-led approach?

One of the most important questions to policymakers on regional integration is how should infrastructure integration in Africa be advanced: should it be through the market-led approach or the institution-led approach. We favour a combination of the two approaches, although there are several reasons why it should be more appropriate to pursue an institution-led approach for infrastructure integration in Africa at the moment. First, intraregional trade in Africa is low. Thus a market-led approach to infrastructure integration in Africa would likewise be low and lacklustre because the required volumes of trade that should make economic sense to invest in regional infrastructure do not yet exist. Second, there is significant heterogeneity in the economic structure of many African countries, from resource-intensive economies to agriculture-intensive economics, and to light-manufacturing, it is difficult to have a coincidence of economic fundamentals that are favourable for infrastructure investments in all kinds of economies. Cultural and colonial historical differences also make it difficult to pursue a market-based approach to infrastructure integration.

Thus, we recommend that the growing political momentum towards regional integration in Africa should be complemented with transnational institution building for infrastructure integration. And although political cooperation (as we have seen in recent times among African leaders) is not always a precondition for progress in regional integration (McKay, Armengol and Pineau, 2004), it provides the platform for advancing infrastructure integration based on transnational institution building. After a proper institution-led framework has been established, then a continuously updated mix of a market-based and institution-based approach could be used to further drive infrastructure integration in Africa. The idea is to pursue a top-down, government-led and market-creating approach, together with a bottom-up, market-driven approach with a multi-paced speed and with multi-track pathways. The role of development partners such as the AfDB, UNECA and the RECs is to ensure coordination and cooperation of its members' infrastructure projects; harness shared resources, such as capital, labour, and technology; harmonize cross-border rules and regulations; and facilitate the exchange of institutional and policy best practices (Bhattacharyay, 2010).

4.3 Inverse infrastructure for infrastructure integration

The paradigm of infrastructure provision is evolving from that of elephant-sized, large-scale projects to that of mushroom-sized small-scale projects that are not owned by governments or large businesses nor centrally controlled by government utility companies in a top-down fashion as, for example, electricity and telecommunications infrastructure have been managed for centuries. Instead, the new paradigm is for individuals and small businesses to own and manage mushroom-sized infrastructure, which would then metamorphose into local, regional and even global infrastructure. Examples of this kind of infrastructure include Google, Wikipedia, networks of privately-owned solar energy systems, and citywide Wi-Fi networks. This self-organizing, user-driven, decentralized infrastructure is what is known as inverse infrastructure (Egyedi, Mehos and Vree, 2009).

These new inverse infrastructure develops independently and outside the realm of centralized control. The key feature of the inverse pattern is that it is being marked by bottom-up investments made by individuals and small firms rather than top-down government funding. What is salient, however, about inverse infrastructure is that they often develop as an afterthought—that is, as an unplanned by-product of an investment or process that is ongoing. In other words, this method of infrastructure integration is not pre-designed as one would have in, for example, GSM mobile telephony or the internet which follow a predefined specification or blueprint. Although this process of evolution does not imply that inverse infrastructure and its integration thereof are without direction, the point is that, given their developmental characteristics, their outcome is less predictable than that of designed infrastructure (Egyedi et al., 2009). It is now the role of policymakers to identify potential investments and activities that are being performed by individuals and small businesses, which can be supported to develop in a decentralized, self-serving, user-driven manner, and not necessarily to invert it to the typical large-scale government controlled model of infrastructure provision.

4.4 Infrastructure integration via incentivization

The United States is often presented as a typical example of a country that drives infrastructure integration through the incentivising method. This method involves providing the supranational macro environment to enable countries, states, and cities to integrate their infrastructure. These kinds of incentives could arise from financial concessions, on, for example, loans from the AfDB or the World Bank, for infrastructure projects that have an element of cross-border integration. The point is that the incentives, whether financial, administrative or technical, arise from a macro level and gets taken up at the micro level, like a top-down approach. That is, creating incentives for infrastructure integration at a region-wide level (for example, from the African Union or AfDB) to a country-wide and state-wide uptake.

Using the incentivising US model, infrastructure integration management can be operated as a combination of differing policies, structures and ownership models, reflecting the various country idiosyncrasies, demography and ideologies. Africa Public Utility Commissions (APUC) could be set up and used to govern cross-border infrastructure. The role of the Africa Public Utility Commissions would include to provide regulatory functions for inter-regional infrastructure markets and offer social oversight to keep consumer prices low and prevent unhealthy monopolistic competition within the infrastructure markets.

4.5 Infrastructure integration via coordination

The approach that Germany has used to integrate its infrastructure and that of Europe at large is often regarded as the coordination method (McLean, 2017). Following the European model, this method would involve integrating infrastructure through interactions between governments at the pan-African level, country level, and local level. This framework provides a framing for coordinating regional infrastructure development through vertical and horizontal interaction by all stakeholders. The idea is to have a coordinated mix of both appropriately regulated public and private providers of regional infrastructure in a free competitive market. Following this German pragmatic approach means that infrastructure integration in Africa should not lean purely toward competitive private markets or to regulated public sector driven monopolies, but on a centrally planned network that is coordinated at the sub-national and country levels.

5 Quantifying the impact of infrastructure

5.1 Data and descriptive statistics

Our main measure of infrastructure is the Africa Infrastructure Development Index (AIDI) from the African Development Bank. This database is particularly preferred because it is comprehensive and assembles data that is usually not publicly available on different components of infrastructure in Africa. The Africa Infrastructure Development Index is based on four major components: (i) the Transport composite index, (ii) the Electricity composite index, (iii) the ICT composite index, and (iv) the Water and Sanitation composite index. These composite indices, in turn, are based on nine different indicators and two sub-indicators. The AIDI series is available for all African countries from 2000 until 2018. To identify the specific infrastructure that has the most catalysing effect on different economic outcomes, we also use the disaggregated component measures of infrastructure.

Although we experiment with all four components of aggregate infrastructure index, the transport and ICT composites are of particular interest to ascertain the effect of infrastructure on trade and productivity growth. The transport composite infrastructure index is a normalized weighted average of the total paved roads in kilometres per 10,000 inhabitants and the total road network in kilometres per square-kilometre of exploitable land area. The ICT composite is more robust, it is constructed from four indicators and two sub-indicators. The indicators are total phone subscription per 100 inhabitants (fixed and mobile cellular), the number of internet users per 100 inhabitants, fixed (wired) broadband internet subscribers per 100 inhabitants, and the international internet bandwidth. The two sub-indicators are fixed-line telephone subscription (percent of population) and mobile cellular subscription (percent of population). The indices are computed as the weighted average of the indicators based on the inverse of the standard deviation of each normalized component. The normalization ensures that the index takes values between 0 and 100, with 100 corresponding to the most developed state of infrastructure.

Data on total factor productivity expressed in relation to US productivity and its growth rate are retrieved from the UNIDO World Productivity Database (see Isaksson, 2009). Barro-type control variables such as initial income, primary enrolment and other variables are obtained from the World Bank, World Development Indicators. Other variables used in the analysis are discussed later.

Table 3 contains descriptive statistics for the main variables used in the analyses; the table shows the statistics for all 48 countries in sub-Saharan Africa. We report the means, standard deviations, minimum, maximum and number of observations for each variable. Two important facts emerge from the summary statistics. First, infrastructure development is significantly different across countries. For example, the average share of individuals in the population using the internet is 3.98 across all countries, but the standard deviation is about double the average at 7.61, and the country with the maximum population of internet users has 51.25 percent of the population using the internet. A similar pattern is also observed for mobile cellular subscription and patent applications. Second, total factor productivity growth seems to be homogeneous across countries, sub-Saharan African countries TFP have been growing at an average rate of 0.23 with a standard deviation of 0.17.

Table 3: Descriptive Statistics

	Mean	SD	Min	Max	Obs.
GDP per capita	1,787.93	2,669.39	115.79	20,333.94	1,560
Total Factor Productivity	0.55	2.84	-25.97	18.94	1,271
Trade Openness	76.65	50.46	6.32	531.74	1,484
TFP Growth	0.23	0.17	0.011	1.53	1,271
Africa Infrastructure Development Index	16.85	14.69	0.369	95.93	720
Transport Infrastructure Index	8.62	9.4	0.38	52.65	720
Electricity Infrastructure Index	7.18	15.06	0	93.56	720
ICT Infrastructure Index	4.39	8.61	0	71.59	720
Water and Sanitation Infrastructure Index	45.36	19.69	6.04	97.56	720
Gross Capital Formation	20.66	15.96	-2.42	219.07	1409
Cost to Export per Container	1,915.14	1,147.77	463	6,615.00	462
Individuals Using the Internet (% of population)	3.98	7.61	0	51.25	990
Mobile Cellular Subscriptions (per 100 people)	14.57	29	0	171.38	1,642
Patent Applications, Residents	273	851	1	5,134.00	244

Control of Corruption, WGI	-0.63	1	-1.87	1.22	846
Rule of Law, WGI	-0.71	1	-2.61	1.08	846

Note: The descriptive statistics are based on an unbalanced panel dataset. The variables with the most available data start at 1980 and those with the most recent data end at 2018.

5.2 Econometric model

Our empirical analysis is based on a simple econometric model that is represented in a general form thus

$$Y_{it} = \alpha Y_{it-1} + \beta \text{Infra}_{it} + \mathbf{X}'_{it}\boldsymbol{\gamma} + \mu_t + \delta_i + e_{it} \tag{3}$$

where Y_{it} is the measure of the outcome variable—trade, innovation and per capita income—for country i in period t. Depending on the outcome variable, the lagged value is also included on the right-hand side to capture persistence and potentially mean-reverting dynamics (i.e., the tendency of the outcome variable to return to some equilibrium value for the country). The main variable of interest in the model is Infra_{it}, the measure of infrastructure at the aggregate or component levels. The parameter β, therefore, measures the causal effect of infrastructure on the outcome variables—trade, innovation, and income per capita. the vector $\mathbf{X}_{it}$ collects all other potential covariates.

Furthermore, δ_i denotes a full set of country-specific effect dummies depending on the estimation technique, and μ_t denotes a full set of time-fixed effect dummies that capture common shocks (or common trends) to the dependent variable; e_{it} is an error term, capturing all other omitted factors, with $E(e_i) = 0$ for all i and t. Below, we present selected results from the estimation of the cross-sectional version of the model, which succinctly captures the average magnitude and pattern of the evidence. Results from the fully fleshed out econometric analysis are contained in a different version of the paper.

5.3 Infrastructure as a Keynesian catalyst: income and employment effects

We begin by showing results for the role that infrastructure plays as a Keynesian catalyst for regional integration in Table 4. The dependent variable in Table 4 is GDP per capita growth rate. In columns (1) to (5) of Table 4, we use different measures of infrastructure; first, is the aggregate infrastructure index (AIDI) and then we incrementally introduce the four different components of infrastructure, respectively. Note first that initial per capita GDP is negative in all regressions but not significant in the Water composite regression (column 5), which denotes convergence in many sub-Saharan African countries conditional on the other variables in the model (also see Ekpo and Chuku, 2017). All the different measure of infrastructure have a positive and statistically significant impact on GDP per capita growth, which illustrates the well-documented positive relationship between infrastructure and income per capita in Africa (see Calderon and Serven, 2010; Ndulu, 2006)

Table 4: Effect of Infrastructure Dimensions on GDP Per Capita Growth

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = GDP per capita growth				
Initial Income	-1.123***	-0.668	-1.471***	-1.173**	-0.624
	(0.435)	(0.430)	(0.433)	(0.521)	(0.432)
Aggregate Infrastructure	0.104***				
	(0.034)				
Transport Composite		0.090***			
		(0.035)			
ICT Composite			0.458***		
			(0.115)		
Electricity Composite				0.099***	
				(0.029)	
Water Composite					0.041**
					(0.018)
Primary enrolment	0.001	0.001	0.007	0.005	-0.001
	(0.012)	(0.013)	(0.012)	(0.015)	(0.013)
Trade openness	0.031**	0.031*	0.031**	0.036**	0.030**
	(0.015)	(0.016)	(0.014)	(0.016)	(0.015)
FDI/GDP	0.049	0.034	0.062	0.028	0.044
	(0.149)	(0.169)	(0.135)	(0.138)	(0.169)
Financial Depth	-0.039***	-0.023	-0.048***	-0.047***	-0.022
	(0.015)	(0.018)	(0.014)	(0.017)	(0.015)
Constant	5.440***	3.009	7.360***	6.497***	1.908
	(1.980)	(1.929)	(2.009)	(2.604)	(1.950)
Countries	44	44	44	44	44
R-squared	0.56	0.48	0.62	0.52	0.45

Notes: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively.

Although statistically significant, the effect of different dimensions of infrastructure on income per capita varies by components of infrastructure. The results in column 1 of Table 4 indicate that, overall, a one unit improvement in the aggregate infrastructure index would lead, on average, to a 0.104 improvement in per capita GDP growth. The positive effect of infrastructure on per capita GDP is strongest for the ICT composite with an estimated coefficient of 0.45 and is weakest for the Water composite with an estimated coefficient of 0.04. The control variables yield results that are consistent with theory and the empirical growth literature; primary enrolment, trade openness, and FDI are positive in all regressions, although they are not all statistically significant. Financial depth has a negative effect in all regressions, supporting the idea of the finance-following (and not leading) growth hypotheses in sub-Saharan Africa.

Table 5: Effect of Infrastructure Dimensions on Employment Generation

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = Employment in population				
Aggregate Infrastructure	0.346*				
	(0.212)				
Transport Composite		0.539***			
		(0.205)			
ICT Composite			1.374		
			(0.905)		
Electricity Composite				-0.081	
				(0.277)	
Water Composite					0.129
					(0.147)
log GDP per capita	-9.908***	-9.510***	-10.607***	-5.322*	-7.571**
	(2.795)	(2.655)	(3.794)	(2.729)	(3.065)
Primary enrolment	0.280***	0.291***	0.294***	0.254**	0.256**
	(0.096)	(0.100)	(0.106)	(0.110)	(0.108)
Trade Openness	-0.259***	-0.285***	-0.253***	-0.260***	-0.270***
	(0.083)	(0.069)	(0.087)	(0.084)	(0.096)
FDI/GDP	0.853	0.754	0.956	0.585	0.823
	(0.871)	(0.694)	(0.887)	(1.105)	(1.052)
Financial Depth	-0.042	0.008	-0.068	0.049	0.005
	(0.107)	(0.076)	(0.110)	(0.127)	(0.100)
Inflation	-0.199	-0.585	0.062	-0.071	-0.128

	(1.483)	(1.535)	(1.605)	(1.402)	(1.401)
Constant	114.112***	113.076***	116.656***	89.878***	99.802***
	(15.408)	(13.491)	(19.398)	(16.007)	(17.064)
Countries	31	31	31	31	31
R-squared	0.54	0.59	0.54	0.48	0.50

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5 %, and * for 10% levels respectively

Apart from its growth effect, which can be considered as the indirect effect, most infrastructure investments targeted at the regional, national or local levels often have employment creation as their primary goal, even before other downstream use of the infrastructure that may be considered as a secondary goal. The direct multiplier effect of infrastructure from both employment generation and downstream use can often be substantial (see Roland-Holst, 2009).. We present results for the effect of infrastructure and its components on the level of employment in population for the entire sample in Table 5.

The results show that the effect of infrastructure on employment generation is not as robust as its impact on per capita GDP. In particular, only the Transport composite has a statistically positive effect on employment generation levels, this is true even at the one percent level (see column 2 of Table 5). On average, a one unit improvement in the transport composite index helps to improve employment in population by 0.53 percent. The sign on the electricity composite is negative, but since it is not significant, we do not discuss it further. Again, the control variables yield results that are consistent with theory and the empirical literature: primary enrolment is positive, the effect of inflation is negative but not significant, the other controls variables such as trade openness and financial depth assume negative signs and are difficult to interpret, especially because the literature is inconclusive about their effects on employment.

5.4 Infrastructure as a Ricardian catalyst: Trade and trade facilitation effect

The results for the impact of infrastructure and its dimensions on total trade by African countries is presented in Table 6. The results show that apart from the water composite, aggregate infrastructure, transport infrastructure, ICT infrastructure and electricity infrastructure all work to enhance trade. The impact is not only statistically significant, it is also quantitatively significant. The infrastructure component with the strongest impact on trade is the ICT composite, followed by the transport composite.

Specifically, the results imply that one unit improvement in the ICT infrastructure composite can lead, on average, to a 3.43 percent increase in total trade; and a one unit improvement in the transport infrastructure composite can lead, on average, to a 1.05 percent increase in total trade.

Table 6: Effect of Infrastructure Dimensions on Total Trade

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = Total trade				
Aggregate Infrastructure	0.800***				
	(0.281)				
Transport Composite		1.052**			
		(0.468)			
ICT Composite			3.431***		
			(1.034)		
Electricity Composite				0.664**	
				(0.304)	
Water Composite					0.234
					(0.294)
Log GDP per capita	-4.832	-3.211	-6.900**	-5.252	-3.587
	(3.277)	(3.211)	(3.509)	(3.585)	(3.288)
Cost to export	-0.004	-0.004	-0.003	-0.004	-0.004
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Diversification	0.264	0.273	0.153	0.601	0.647
	(0.569)	(0.616)	(0.557)	(0.504)	(0.593)
Financial Depth	-0.194	-0.096	-0.222	-0.311*	-0.121
	(0.162)	(0.155)	(0.178)	(0.194)	(0.158)
Population density	-0.053	-0.055	-0.053	-0.024	-0.032
	(0.058)	(0.059)	(0.051)	(0.059)	(0.067)
Constant	170.582**	135.813*	220.239**	175.073*	124.780

	(86.389)	(82.232)	(93.141)	(94.449)	(85.332)
Countries	43	43	43	43	43
R-squared	0.78	0.77	0.72	0.78	0.74

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively

It does not come as a surprise that the impact of ICT on trade is stronger than that of transport; with globalization, businesses that hitherto required time and space to consummate transactions no longer have to meet physically or depend on time to do business. ICT infrastructure has helped to surmount these constraints because it facilitates the sharing of information and eliminates the barriers of time and distance required to trade, two factors that transport infrastructure has to deal with.

Table 7: Effect of Infrastructure Dimensions on Trade Facilitation

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = Cost to export a container				
Aggregate Infrastructure	-0.008*				
	(0.004)				
Transport Composite		-0.011*			
		(0.006)			
ICT Composite			-0.031**		
			(0.016)		
Electricity Composite				0.001	
				(0.005)	
Water Composite					-0.003
					(0.004)
Total Trade	-0.200*	-0.202**	-0.192*	-0.210*	-0.200*
	(0.106)	(0.104)	(0.104)	(0.112)	(0.110)
Inflation	0.001***	0.001**	0.001***	0.000**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Control of Corruption	-0.003	0.018	0.002	-0.108	-0.052
	(0.152)	(0.165)	(0.148)	(0.145)	(0.136)
Financial Depth	-0.002	-0.003*	-0.001	-0.004	-0.003
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)

Constant	8.431***	8.448***	8.389***	8.326***	8.451***
	(0.492)	(0.498)	(0.476)	(0.506)	(0.507)
Countries	44	44	44	44	44
R-squared	0.21	0.21	0.22	0.19	0.20

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively

Infrastructure investments serve as a trade facilitation mechanism by reducing the distribution margins of exporters, which then works to expand the profitable horizon of exporting firms and improve their competitiveness. Explicit treatments of infrastructure's role in trade facilitation are relatively few and not easy to synthesize into a general approach (Roland-Holst, 2009). We attempt to gauge the trade facilitation effect of infrastructure by measuring its impact on the cost of export per container.

The results for the effect of infrastructure and its dimensions on trade facilitation are presented in Table 7 to export. Aggregate infrastructure and three other dimensions of infrastructure are appropriately signed, that is better infrastructure reduces the cost to export. The only exception in terms of the sign of the impact is the electricity composite. Despite the negative sign of the infrastructure measures, it is only the coefficient for the ICT composite that is statistically significant. Specifically, a one unit improvement in ICT infrastructure could potentially lead to an average reduction in the cost of export per container of 0.03 units. ICT can particularly help to reduce the cost of administrative fees, documents, customs clearance and inland transport required to export a container.

Two of the control variables in the results for the effect of infrastructure on trade facilitation presented in Table 7to export are worthy of note. First, trade volumes have a cost reduction effect on the cost of export. The coefficient on total trade in all the columns in tab:cost to export are negative, although most of them are only weakly statistically significant (i.e., at the 5 percent level or 10 percent level). Second, inflation is important for explaining trade facilitation. Higher inflation rates imply higher effects on the cost to export, although the quantitative impact is relatively small at 0.001 percent.

5.5 Infrastructure as a neoclassical catalyst: productivity and innovation effects

Infrastructure's role as a neoclassical catalyst can be seen in terms of its presence as an " endogenous growth factor"; that is, those economic factors that when present in an economy, in themselves, facilitate growth. This catalytic role works through productivity enhancements, technology diffusion, innovation, and human capital development. The results for the effect of infrastructure and its dimensions on total factor productivity growth are presented in Table 8. Aggregate infrastructure index and the four composite measure of infrastructure all have a statistically significant and positive effect on total factor productivity growth.

Table 8: Effect of Infrastructure Dimensions on TFP growth

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = TFP growth				
Aggregate Infrastructure	0.008***				
	(0.002)				
Transport Composite		0.011***			
		(0.003)			
ICT Composite			0.029***		
			(0.006)		
Electricity Composite				0.006***	
				(0.002)	
Water Composite					0.005***
					(0.001)
GDP Growth	0.092	0.324*	-0.028	0.040	0.329***
	(0.136)	(0.168)	(0.184)	(0.174)	(0.128)
FDI/GDP	-0.024*	-0.027**	-0.019	-0.023	-0.008
	(0.013)	(0.013)	(0.012)	(0.015)	(0.013)
Inflation	-0.014	-0.005	-0.023*	-0.022*	-0.010
	(0.011)	(0.015)	(0.012)	(0.011)	(0.011)
Trade Openness	0.167***	0.189***	0.162**	0.250**	0.154*
	(0.063)	(0.071)	(0.079)	(0.104)	(0.081)
Constant	-0.545**	-0.662**	-0.467	-0.752*	-0.709**
	(0.255)	(0.312)	(0.323)	(0.402)	(0.327)
Countries	24	24	24	24	24
R-squared	0.85	0.79	0.80	0.75	0.77

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively

The results in column 3 of Table 8 show that the ICT composite has the strongest effect on TFP growth for African economies. Specifically, a one unit improvement in the ICT infrastructure composite could potentially lead to a 0.02 improvement in TFP growth rate. The estimated coefficients of the control variables imply that trade openness is a particularly important driver of TFP growth, as the trade coefficients are both statistically and quantitatively significant in all regressions. For example, for the Transport composite equation in column 2 of Table 8., a one percent improvement in the trade openness measure could potentially lead to improvements in Total Factor productivity growth by 0.18 basis points.

We also use patent applications by residents as a proxy for innovation. The results for the effect of infrastructure dimensions on innovation via patent applications are presented in Table 9.

Table 9: Effect of Infrastructure Dimensions on Patent Applications

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = Patent applications				
Aggregate Infrastructure	0.103***				
	(0.036)				
Transport Composite		0.082			
		(0.083)			
ICT Composite			0.359***		
			(0.114)		
Electricity Composite				0.064***	
				(0.015)	
Water Composite					0.043
					(0.032)
GDP Growth	5.306**	8.668**	2.867	4.243*	7.446***
	(2.274)	(3.196)	(2.416)	(2.197)	(2.606)
FDI/GDP	0.428*	0.297	0.463**	0.189	0.325*
	(0.206)	(0.268)	(0.177)	(0.207)	(0.175)
Rule of Law	-2.667***	-1.961	-1.952***	-1.781**	-1.785
	(0.922)	(1.487)	(0.656)	(0.797)	(1.085)
Inflation	-0.151	0.174	-0.133	0.012	0.064
	(0.276)	(0.328)	(0.217)	(0.294)	(0.347)
Trade Openness	0.343	0.759	-0.563	0.674	0.427
	(0.814)	(0.935)	(0.822)	(1.037)	(0.744)

Constant	-4.787	-6.609	-0.103	-3.964	-5.744
	(3.661)	(4.601)	(3.280)	(4.311)	(3.858)
Countries	18	18	18	18	18
R-squared	0.72	0.52	0.75	0.73	0.58

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively

The results show that apart from the aggregate measure of infrastructure, two other composite dimensions of infrastructure have positive and statistically significant effect on innovation: the ICT composite and the Electricity composite. On average, a one unit improvement in the electricity infrastructure could potentially boost patent applications by 0.06 points, while a one unit improvement in ICT infrastructure could potentially boost patent applications by 0.35 units.

The results presented from the stylized regression analysis show indeed that infrastructure has contributed to higher standards of living by boosting per capita income, stimulating employment, trade and innovation for many African countries. The results show that the single most important infrastructure composite that has the greatest multiplier effect on economic outcomes is the ICT sector, followed by the transport sector, the electricity sector, and lastly, the water sector. This observed pattern and ranking of the strength of effects inform our recommendation that infrastructure integration and development commitments in Africa should be prioritized according to the ranking of their multiplier effects: ICT first, transport second, electricity third and water fourth.

5.6 Where is infrastructure working best in Africa?

In this section, we endeavour to unbundle the regional differences in the impact of infrastructure on economic outcomes, identifying regional economic communities (RECs) that have above or below the average impact for the entire region. This strategy helps to identify regions that are lagging behind and hence require additional reforms and effort to boost the role of infrastructure on economic outcomes using the experience from the leading RECs in a flying-geese development type model. We achieve this by interacting the infrastructure variables with dummies for five regional economic blocks in sub-Saharan Africa: (i) Central African Economic and Monetary Community (CEMAC); (ii) Common Market for Eastern and Southern Africa (COMESA); (iii) East African Community (EAC); (iv) Economic Community of West African States (ECOWAS); (iv) Southern African Development Community (SADC).

Table 10: Regional differentials in the effect of AIDI on economic outcomes

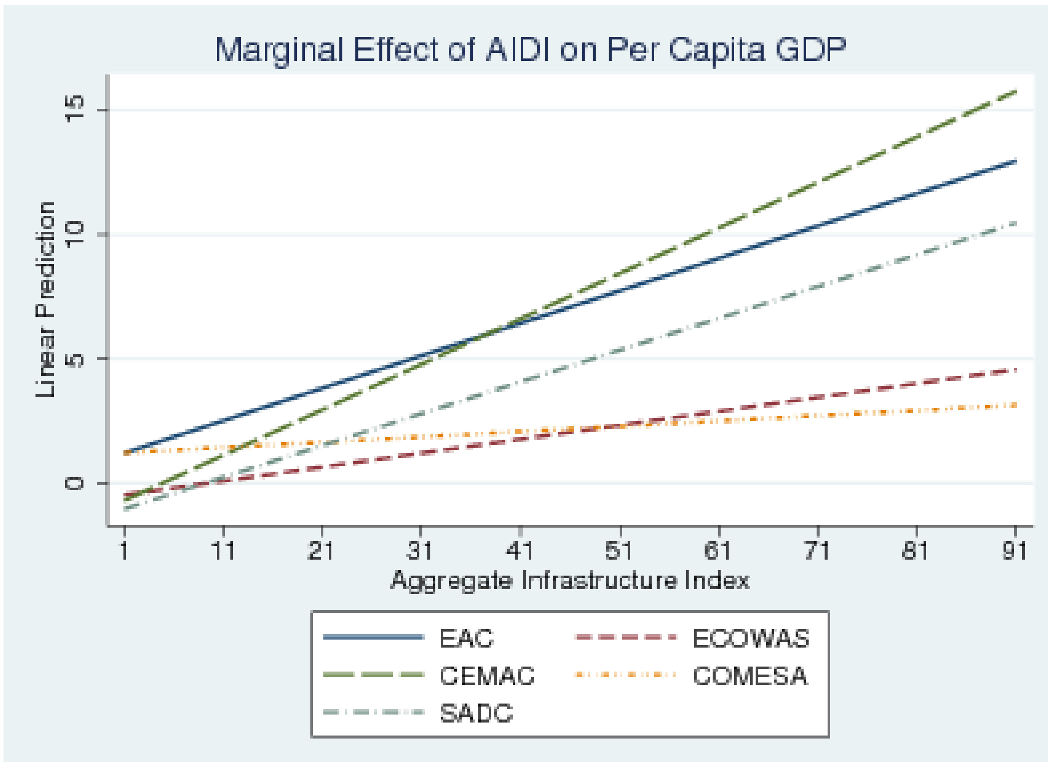
	(1)	(2)	(3)	(4)
	Per capita GDP	Trade	TFP growth	Patents
Aggregate Infrastructure	0.103***	0.438	0.009***	0.061
	(0.035)	(0.517)	(0.001)	(0.055)
EAC*Aggregate Infrastructure	0.088**	-1.575	-0.002	-0.007
	(0.043)	(1.236)	(0.007)	(0.105)
ECOWAS *Aggregate Infrastructure	-0.048	-1.472*	-0.008***	0.049
	(0.053)	(0.848)	(0.002)	(0.115)
CEMAC*Aggregate Infrastructure	0.015	-0.267	0.001	-0.554
	(0.082)	(1.093)	(0.002)	(0.481)
COMESA*Aggregate Infrastructure	-0.002	-0.686	-0.006*	-0.016
	(0.042)	(0.791)	(0.004)	(0.120)
SADC*Aggregate Infrastructure	0.021	0.262	-0.002	0.042**
	(0.028)	(0.662)	(0.002)	(0.018)
Initial Income	-1.122**			
	(0.563)			
Primary Enrolment	-0.011			
	(0.017)			
Trade Openness	0.035**		0.140**	1.718
	(0.016)		(0.060)	(1.353)
FDI/GDP	0.044		-0.028**	-0.068
	(0.146)		(0.012)	(0.472)
Financial Depth	-0.039***	-0.279		
	(0.013)	(0.198)		
Log GDP		-3.106		
		(4.389)		
Cost to Export		-0.006		
		(0.004)		

Diversification		0.471		
		(0.702)		
Population Density		-0.027		
		(0.069)		
GDP Growth			0.091	4.667
			(0.114)	(3.896)
Inflation			-0.004	0.917
			(0.019)	(1.283)
Rule of Law				-2.719*
				(1.327)
Constant	6.377**	141.775	-0.382*	-11.212
	(2.990)	(107.158)	(0.227)	(6.744)
Countries	44	43	24	18
R-squared	0.60	0.28	0.92	0.81

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively

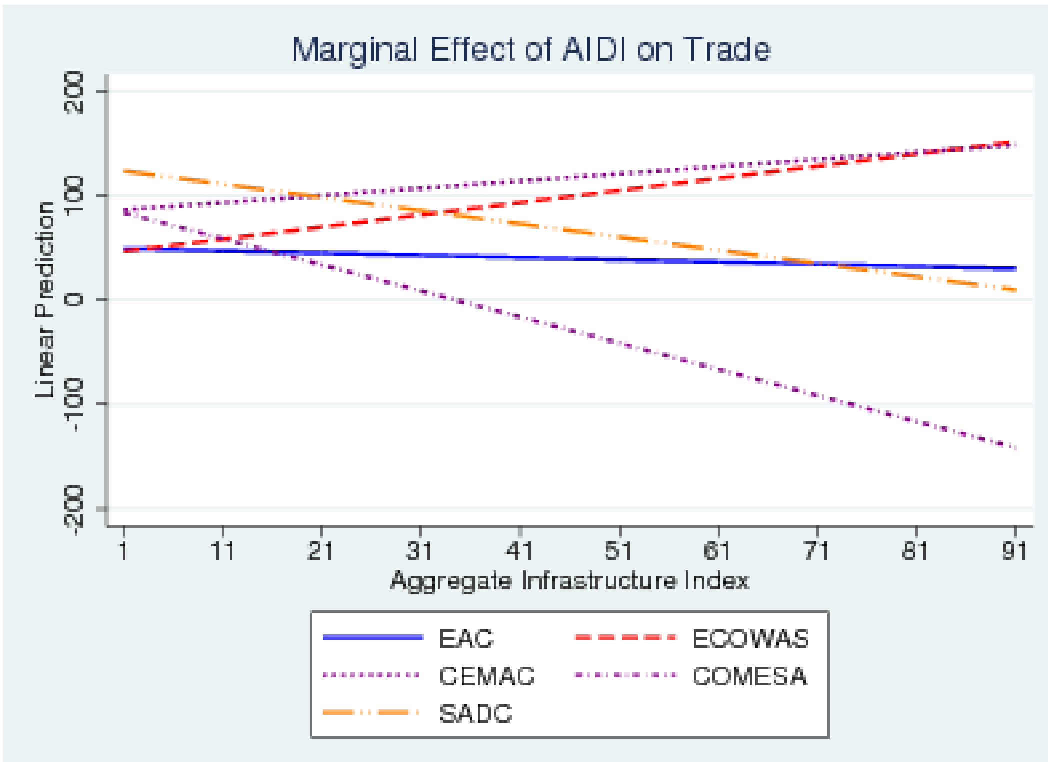
The results for the effect of aggregate infrastructure composite (AIDI) on GDP per capita, trade, TFP growth, and patents are presented in Table 10. Column 1 contains the regional differentials in elasticities of aggregate infrastructure on per capita GDP. The coefficient for aggregate infrastructure is 0.103, which is the impact of aggregate infrastructure for the entire group of countries. The values for the interactions with the regional blocks is the difference in slope between the entire group and the specific regional group that infrastructure is being interacted with. The results show that at the average, the marginal effect of infrastructure on per Capita GDP growth is quantitatively stronger and statistically significant for EAC (0.103 + 0.088 = 0.191); quantitatively stronger but not statistically significant for CEMAC (0.103 + 0.015 = 0.118); and quantitatively stronger but not statistically significant for SADC too (0.103 + 0.021 = 0.124). In contrast, at the average, the marginal impact of infrastructure on income is less than the overall regional impact for ECOWAS (0.103 - 0.048 = 0.055) and for COMESA (0.103-0.002 = 0.101) .

Figure 10: Marginal Effect on GDP per Capita at Different Levels of AIDI



The results from column 1 of Table 10 indicate that infrastructure integration has had the strongest impact on income in the SADC region, with a marginal elasticity of 0.124; followed by EAC, with an elasticity of 0.191; and CEMAC, with an elasticity of 0.118. The impact in CEMAC almost coincides with the sub-Saharan African regional effect of 0.103. More importantly, the results show that the impact of aggregate infrastructure is significantly below the overall regional average for ECOWAS. Therefore, urgent reforms and efforts need to focus on alleviating bottlenecks to infrastructure integration and impact in ECOWAS to enhance its multiplier effect on the rest of the economy. It is important to note, however, that although the joint test for statistical significance of all the interaction terms is robust, some of the coefficients for the individual interaction terms are not statistically significant. Hence, we caution that these results should be taken as indicative, rather than conclusive evidence. Regression results for the regional differential effect of the transport composite and the ICT composite measures of infrastructure are presented in the Appendix to this paper.

Figure 11: Marginal Effect on Trade at Different Levels of AIDI



Two major concerns emerge from the results presented in Table 10. First, because we are using an aggregate measure of infrastructure, it is possible that this aggregate measure is masking the specific marginal effects of different dimensions of infrastructure. Second, the results only show the nature of the relationship at the average level of the infrastructure index. What if the marginal effects are different for different levels of infrastructure development? For the sake of space, we are not able to present results that deal with the first issue, but we present results that show the marginal effect of infrastructure on RECs at different values and levels of infrastructure development.

Figure 12: Marginal Effect on TFP Growth at Different Levels of AIDI

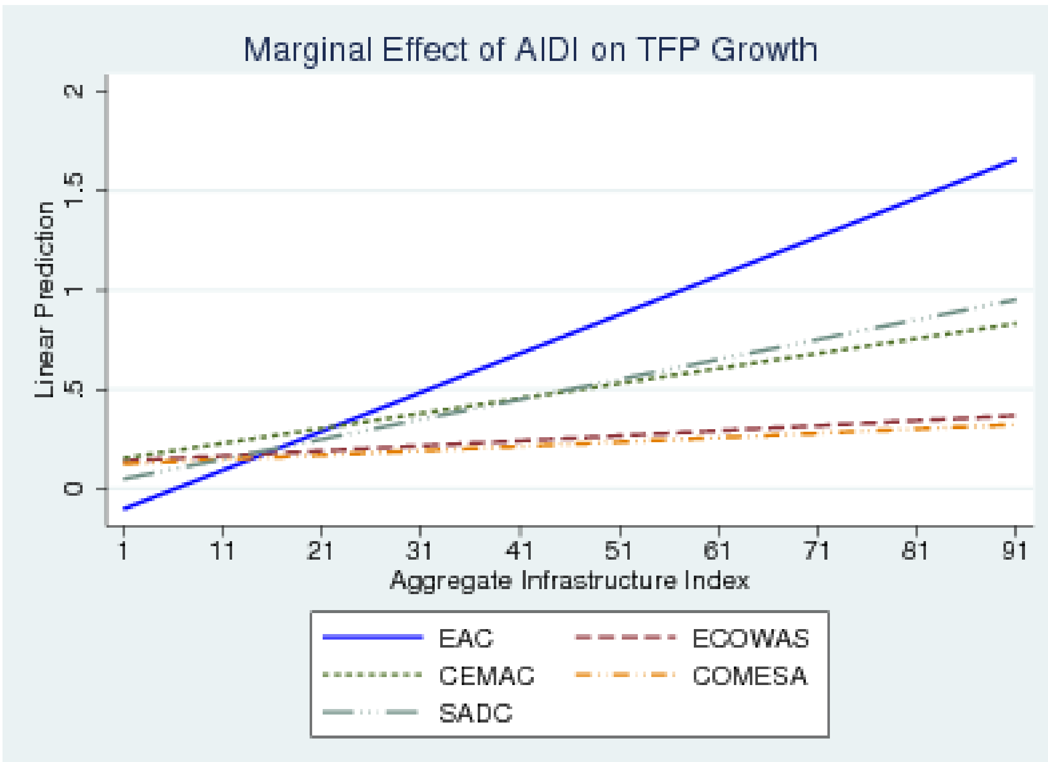


Table 10 displays the marginal effect of aggregate infrastructure on per capita GDP growth for the five regional economic blocks. The pattern in the figure is consistent with the results reported in column 1 of Table 10. In particular, for values of aggregate infrastructure less than 21, the marginal effect for all five regions are closely clustered and slightly positive. But as soon as the level of infrastructure development starts to exceed 21 units, the differences in the marginal impact of infrastructure start to become obvious and significant. The slope of the marginal effect is steeper for EAC, CEMAC, and SADC; and it is seemingly flat, if not negative, for ECOWAS and COMESA.

The marginal effect of infrastructure on trade, presented in Table 11, is quite revealing. The results show that the higher the level of infrastructure development, the higher the impact on trade in EAC, CEMAC, and ECOWAS regions. This increasing effect is not particularly observed for COMESA and SADC regions. Rather, and surprisingly too, the marginal effect of infrastructure on trade in significantly falling as the level of infrastructure increases. This result is difficult to explain, it may be that there are other dimensions of infrastructure that may be driving this relationship. For example, what is the state of the available "soft" infrastructure for trade in these regions—i.e., customs administration, documentation procedures, trade-related bureaucracies and governance structures, and so forth.

6 Concluding remarks

This paper set out to assess the extent to which infrastructure development and integration can act as a catalyst for trade, productivity growth, and income improvements in Africa; and to examine some important policy issues and challenges related to infrastructure development and integration in Africa. Our analysis has shown that infrastructure does improve trade, productivity, and innovation in sub-Saharan Africa. In particular, the results show that the single most important infrastructure composite that has the greatest multiplier effect on economic outcomes is the ICT sector, followed by the transport sector, the electricity sector, and lastly, the water sector. This observed pattern and ranking of the strength of effects lead us to recommend that infrastructure integration and development commitments in Africa should be prioritized according to the ranking of their multiplier effects on the rest of the economy: that is, ICT first, transport second, electricity third, and water fourth.

In searching for regions with more effective infrastructure networks, our findings show that infrastructure has had the strongest impact on economic outcomes in the SADC region. Perhaps, there are other variables outside the model that explain the higher than average impact of infrastructure in the SADC region (these factors are considered in a more technical version of the paper). Therefore, the SADC regional economic community is identified as the flying-geese, which should provide the exemplary leadership for other RECs to emulate in other to help make the impact of infrastructure more effective. One important change in paradigm that we have advocated here is the utilization of "inverse" infrastructure techniques for integrating African infrastructure.

Appendix

Table 11: Pairwise correlation matrix of key variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
GDP per capita (1)	1															
TFP ratio of US (2)	0.209	1														
Trade Openness (3)	0.5089*	0.177	1													
TFP Growth (4)	0.7857*	0.4848*	0.3578*	1												
AIDI (5)	0.6697*	0.3119*	0.170	0.8386*	1											
Transport Infrastructure (6)	0.4733*	0.298	0.139	0.7180*	0.8722*	1										
Electricity Infrastructure (7)	0.6635*	0.251	0.0863	0.7292*	0.8497*	0.5554*	1									
ICT Infrastructure (8)	0.6809*	0.3194*	0.176	0.8164*	0.9468*	0.7541*	0.8728*	1								
Water Infrastructure (9)	0.5808*	0.214	0.201	0.7197*	0.8705*	0.7685*	0.5969*	0.7388*	1							
Gross Fixed Capital Formation (10)	0.4712*	0.0718	0.6958*	0.206	0.143	0.118	0.0733	0.138	0.186	1						
Cost to Export (11)	-0.168	-0.245	-0.194	-0.270	-0.2911*	-0.2882*	-0.188	-0.276	-0.263	-0.176	1					
Internet Users (12)	0.6560*	0.4051*	0.270	0.7815*	0.8889*	0.8171*	0.6986*	0.8796*	0.7196*	0.212	-0.3063*	1				
Mobil Subscription (13)	0.7862*	0.3415*	0.3238*	0.8224*	0.7793*	0.6112*	0.7031*	0.8310*	0.6614*	0.175	-0.240	0.7371*	1			
Patents (14)	0.5831*	0.0518	-0.122	0.403	0.6306*	0.122	0.9062*	0.6885*	0.3921*	-0.0121	-0.157	0.4419*	0.5025*	1		
Control of Corruption (15)	0.2945*	0.3175*	0.102	0.5845*	0.6200*	0.6837*	0.4479*	0.5576*	0.5383*	0.0794	-0.284	0.5710*	0.5554*	0.262	1	
Rule of Law (16)	0.3550*	0.4263*	0.107	0.6075*	0.6252*	0.6348*	0.4470*	0.5968*	0.5640*	0.121	-0.3306*	0.5839*	0.6122*	0.213	0.9107*	1

Table 12: Regional differentials in the effect of transport infrastructure on economic outcomes

	(1)	(2)	(3)	(4)
Dependent Variable	Per capita GDP	Trade	TFP growth	Patents
Transport Composite	0.094**	0.559	0.013***	-0.073
	(0.041)	(0.666)	(0.003)	(0.096)
EAC*Transport Composite	0.159**	-2.526	-0.012	-0.311
	(0.079)	(1.943)	(0.013)	(0.240)
ECOWAS*Transport Composite	-0.057	-2.950*	-0.010*	0.219
	(0.101)	(1.527)	(0.006)	(0.132)
CEMAC*Transport Composite	0.166	-1.278	0.031*	-4.776**
	(0.437)	(5.701)	(0.017)	(1.777)
COMESA* Transport Composite	0.031	-2.247*	-0.005	0.029
	(0.083)	(1.177)	(0.008)	(0.203)
SADC*Transport Composite	0.020	1.020	-0.001	0.016
	(0.050)	(0.969)	(0.003)	(0.074)
Initial Income	-0.676			
	(0.556)			
Primary Enrolment	-0.012			
	(0.017)			
Trade Openness	0.036*		0.109	3.662*
	(0.019)		(0.068)	(1.737)
FDI/GDP	0.010		-0.023	-0.578
	(0.181)		(0.018)	(0.393)
Financial Depth	-0.021	-0.160		
	(0.019)	(0.188)		
Log GDP		-2.762		
		(3.868)		
Cost to Export		-0.005		
		(0.004)		
Diversification		0.202		
		(0.625)		
Population Density		-0.006		
		(0.059)		
GDP growth			0.322**	9.725**
			(0.129)	(3.368)
Inflation			-0.008	2.516**

			(0.023)	(0.977)
Rule of Law				-0.740
				(1.611)
Constant	3.657	141.705	-0.317	-20.251**
	(2.894)	(93.908)	(0.260)	(7.710)
Countries	44	43	24	18
R-squared	0.51	0.34	0.88	0.77

Note: All regressions are cross-sectional with one averaged observation per country. Standard errors are in parenthesis, and significance levels for rejection of null hypothesis are: *** for 1 %, ** for 5% , and * for 10% levels respectively

Table 13: Regional differentials in the effect of ICT composite on economic outcomes

	(1)	(2)	(3)	(4)
	Per capita GDP	Trade	TFP growth	Patents
Composite ICT	0.460***	3.152**	0.029***	0.281**
	(0.133)	(1.503)	(0.005)	(0.091)
EAC* Composite ICT	-0.043	-4.854	-0.016	-0.035
	(0.220)	(4.695)	(0.023)	(0.196)
ECOWAS* Composite ICT	-0.156	-3.850	-0.034***	0.011
	(0.152)	(2.709)	(0.006)	(0.216)
CEMAC* Composite ICT	-0.014	-0.131	-0.002	-0.563
	(0.341)	(3.029)	(0.008)	(1.100)
COMESA* Composite ICT	0.036	0.893	-0.023	0.259
	(0.219)	(4.117)	(0.019)	(0.361)
SADC* Composite ICT	0.079	0.441	-0.010**	0.190**
	(0.100)	(2.590)	(0.005)	(0.073)
Initial Income	-1.516**			
	(0.635)			
Primary Enrolment	0.001			
	(0.015)			
Trade Openness	0.030**		0.152**	-0.245
	(0.015)		(0.069)	(1.469)
FDI/GDP	0.081		-0.027***	0.321
	(0.128)		(0.009)	(0.391)
Financial Depth	-0.052***	-0.296		
	(0.013)	(0.214)		
Log GDP		-5.709		
		(5.176)		
Cost to Export		-0.006		
		(0.004)		
Diversification		0.188		
		(0.630)		
Population Density		-0.050		
		(0.059)		
GDP Growth			0.129	0.609
			(0.149)	(2.670)
Inflation			-0.003	-0.140

			(0.020)	(0.756)
Rule of Law				-2.000*
				(1.070)
Constant	8.307**	205.076*	-0.408	-0.678
	(3.400)	(127.650)	(0.276)	(6.475)
Countries	44	43	24	18
R-squared	0.64	0.29	0.91	0.87

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