Digital Connectedness and Exports Upgrading: Is Sub-Saharan Africa Catching Up?

Joël Cariolle
and
Camille da Piedade

Working Paper GVC-005

Bringing Rigour and Evidence to Economic Policy Making in Africa

AFRICAN ECONOMIC RESEARCH CONSORTIUM
CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

Digital Connectedness and Exports Upgrading: Is Sub-Saharan Africa Catching Up?

By

Joël Cariolle
FERDI

and

Camille da Piedade
FERDI

AERC Working Paper GVC-005
African Economic Research Consortium, Nairobi
July 2022

THIS RESEARCH STUDY was supported by a grant from the African Economic Research Consortium. The findings, opinions and recommendations are those of the author, however, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium
P.O. Box 62882 - City Square
Nairobi 00200, Kenya

Contents

List of tables

List of figures

List of abbreviations and acronyms

2SLS	Two-Stage Least Squares
AAE-1	Asia Africa Europe-1
ACE	Africa-Coast-to-Europe
CERDI	Centre d'Etudes et de Recherches sur le Développement International
CDP	Committee for Development Policy
DVX	Domestic Value-Added Exports
ECI	Economic Complexity Index
EASSy	Eastern Africa Submarine System
EVI	Economic Vulnerability Index
FERDI	Fondation pour les Etudes et Recherches sur le Développement international
FDI	Foreign Direct Investment
FVA	Foreign Value-Added
GDP	Gross Domestic Product
GVCs	Global Value Chains
ICTs	Information and Communication Technologies
IV	Instrumental Variables
LDCs	Least Developed Countries
MENA	Middle East and North Africa
MIT	Massachusetts Institute of Technology
MRIO	Multi-Region Input-Output
OEC	Observatory of Economic Complexity
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
PP	Percentage Points
QOG	Quality of Government
REER	Real Effective Exchange Rate

RoW	Rest of the World
SEAMEWE	Southeast Asia-Middle East-Western Europe
SCI	Shipping Connectivity Index
SCO	Sustainable Competitiveness Observatory
SMC	Submarine Cable
SSA	Sub-Saharan Africa
SITC	Standard International Trade Classification
UNCTAD	United Nations Conference on Trade and Development
TEAMS	The East African Marine Systems
WACS	West Africa Cable System
WDI	World Development Indicators

Abstract

In this paper, we highlight a new dimension of the submarine cable infrastructure network, termed ‘digital connectedness’, reflecting a country's digital proximity to main world markets, and assess its impact on export upgrading. Adopting an instrumental variables approach conducted in a sample of 60 developing countries—including 23 sub-Saharan African countries—over the period 1995–2017, we find that digital connectedness positively and significantly contributes to the export basket complexity, but also points out spatial heterogeneity within our sample. In fact, estimations stress that, compared to the Rest of the World, a 10pp increase in the share of world GDP directly cabled to SSA countries leads to a supplementary increase ranging from 4.6 index points to 5.3 index points in the export complexity index. Moreover, whereas the positive effect of digital connectedness falloffs with distance from global markets everywhere else, in sub-Saharan Africa, an increased benefit is recorded. Last but not least, consistent with the literature improved digital connectedness also materializes into greater exports of differentiated goods and greater participation in the global value chain. Overall, our analysis gives credit to the belief that improved access to information and knowledge, through greater digital connectedness, spurs structural change and export basket upgrading in SSA at a higher pace than in any other developing areas.

Key words: *Economic complexity; Internet; Connectivity infrastructures; Sub-Saharan Africa: exports: Trade diversification.*

Acknowledgements

This paper has been prepared for and with the financial support of the African Economic Research Consortium (AERC). It also benefitted from the support of the French National Research Agency (ANR) under programme ANR-10-LABX-14-01. Results and their interpretation reflect the views of the authors alone.

1. Introduction

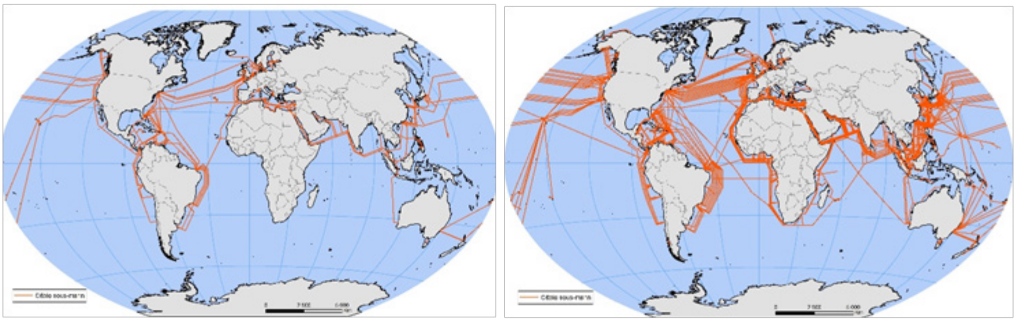
Sub-Saharan Africa (SSA) plays a very marginal role in global trade. Possible reasons for this relative marginalization include high transaction costs due to failing institutions, poor infrastructure network, and structural handicaps related to unfavourable geographical factors. Despite the rapid growth rates recorded over the last two decades, sub-Saharan African countries have not engaged in an industrialization path that has enabled post-independence income levels catch up (Rodrik, 2016). The international context of high commodity prices, low interest rates, and China's increasing appetite for African natural resources has explained the concomitance of high growth rates with slow structural economic transformations, and of increasing and upstream participation to agricultural global value chains with low and stagnant regional value chain (Rodrik, 2016; Balié et al., 2019; de Melo & Twum, 2021). However, beyond the country's position in the global or regional networks of productive activities, to paraphrase Hausmann et al. (2007), what SSA exports matters for its long-term economic growth and industrialization. In this regard, the agricultural and food industries in SSA weight about a quarter of its GDP, employs roughly two-thirds of a population mostly located in rural areas (Balié et al., 2019), and tempering the regional prospects for structural change triggered by industrial sectors development and sophisticated goods and services exporting (Rodrik, 2016; Lim, 2021).

Could an improved access to information and knowledge spur structural change and export basket upgrading in the region? The literature stresses that improved access to information and knowledge produced in different parts of the world has the power to induce structural change in trade patterns, especially for remote low-income countries (Akerman et al., 2015). In particular, various studies have shown that trade is constrained by information frictions, and that these frictions increase with the geographical distance between potential trade partners (Rauch & Trinidade, 2003; Bahar et al., 2014; Akerman et al., 2015; Lendle et al., 2015). In fact, the rapid decay of information and knowledge diffusion with the physical distance makes neighbouring countries more likely to exchange similar products with similar and geographically proximate trade partners (Rauch, 1999; Rauch & Trinidade, 2003; Chaney, 2014; Bahar et al., 2014; Jun et al., 2020). Access to communication networks, by reducing information frictions, facilitates the matching between producers and distributors, assemblers and suppliers, investment need and saving capacity, importers and exporters (Rauch & Trinidade, 2003; Akerman et al., 2015), incites firms to export diversified, differentiated, or more sophisticated products (Rauch, 1999; Jun et al., 2020) and, thereby contributes to the export basket complexification. Without access to these networks, patterns of exports quality upgrading and trade network densification are geographically sticky (Jun et al., 2020). This is particularly true when the knowledge embedded in exports is “tacit” or “multifarious”[1], and, therefore, relies on more direct forms of human interactions (Bahar et al., 2014; Hidalgo, 2021). Therefore, in the light of this literature, African economies' isolation from main world markets, explained by important trade costs and a poor access to information, is a critical obstacle to an increased participation to world exchanges.

However, with the recent and massive deployment of submarine cable (SMC) connectivity infrastructure in SSA and the resulting rise in Internet penetration (Cariolle, 2021) (see Figure 1), information and communication technologies (ICTs) are increasingly seen as a game-changing solution for the region, given its potential for (service) trade in remote areas (Lendle et al., 2015). Empirically, ICT diffusion facilitates catching up with developed countries through the "leapfrogging" process and the rise of mobile telephony in Africa illustrates this point quite well (Aker & Mbiti, 2010). Keeping aside the plentiful, relevant but yet anecdotal evidence on successful African entrepreneurship[2], the empirical literature provides evidence that digitalization improves business performance and foster Internet spillovers (Hjort & Poulsen, 2019; Cariolle & Le Goff, 2021; Paunov & Rollo, 2015, 2016), reduces the size of the informal sector (Jacolin et al., 2021), and facilitates job creation (Hjort & Poulsen, 2019). In relation to trade, Freund and Weinhold (2004), and then Clark and Wallsten (2006), stressed that Internet diffusion has stimulated trade flows and foreign direct investment (FDI). But more recently, Lendle et al. (2015) have shown that the deterrent effect of geographical distance between trade partners was substantially lower (65%) when transactions were made on one of the world's largest online marketplaces, compared to total trade. Their results, therefore, support the “death of distance”, predicted by Cairncross (1997), in that modern digital infrastructures and technologies are now able to carry sufficient information to reduce distance-related international search costs. Interestingly, the authors find that the gap in estimated distance coefficients increases with the size of information frictions, when products are more differentiated, when trade partners do not share common language, and when exporters and importers face higher levels of corruption and other sources of uncertainty in economic transactions.

Figure 1: Submarine cable deployment worldwide, 2000 versus 2017

(a) 2000 (b) 2017



Source: Telegeography.

Looking more specifically at the contribution of the digital infrastructure deployment, the trade dividends are very large according to evidence from industrialized economies (Röller & Waverman, 2001; Czernich et al., 2011), but the research focused on developing countries is scarcer and display more mixed findings. Focusing on an industrialized country like Norway, Akerman et al. (2022) exploit the staggered roll-out of local fiber-optic broadband access-points to estimate the causal effect of Internet adoption on Norwegian firms' bilateral exports. They find that the reduction in information friction induced by Internet access enlarges the choice set of exporters and importers, making demand for traded products more elastic to trade costs and to distance. In developing economies, Hjort and Poulsen (2019) have brought strong evidence that SMC deployment in SSA has spurred trade and job creation, but looking at the separate effect of SMCs' bilateral deployment on firm's participation to bilateral exports in a sample of 48 developed and developing countries over the period 1997–2014, Imbruno et al. (2022) show that this effect is heterogeneous: it increased the number of bilateral exporters from developed countries but reduced this number in developing countries, by 5.4% in sub-Saharan Africa. This finding suggests that exporters from developed and developing areas differ in their ability to undertake information technology upgrading, as previously stressed in the context of Argentinian-Brazilian exports by Bustos (2011).

It is worth noting that establishing a trade relation requires considerable effort to gather information that is not necessarily freely available but assimilated through search and learning efforts. Firms can face some additional obstacles, including non-tariff barriers and issues related to incomplete information or limited capability to process information (Allen, 2014; Dasgupta & Mondria, 2018), to establish a successful trade relationship. Using data from Chilean exporters, Morales et al. (2019) found that extended gravity has a large impact on export entry costs. They estimate that having similarities with a prior export destination in terms of geographic location, language, and income per capita jointly reduce the foreign market entry cost by 69% to 90%. Introducing the principle of relatedness—a measure of the overall similarity between an activity and a location—the economic literature on the process by which countries learn how to produce what they export, has demonstrate how poor knowledge diffusion constrains the ability of countries to penetrate new export markets. Indeed, countries are more likely to start exporting products that are related to their current export basket or that of their geographical neighbours (Hidalgo et al., 2007; Hidalgo & Hausmann, 2009; Bahar et al., 2014; Jun et al., 2020).[3] The importance of knowledge diffusion in the diversification of economic activities has also been observed in the development of regional industries, technologies, and research activities, suggesting that similarity between economic activities enables knowledge diffusion in general (Hidalgo et al., 2018).

In this paper, we keep on questioning the consequences of the recent and rapid deployment of SMCs along African coasts on African trade patterns. In particular, this paper's contribution to the empirical literature is threefold. First, we highlight a new dimension of the SMC infrastructure deployment, termed ‘digital connectedness’, reflecting a country's digital proximity to world markets, and assess its impact on export sophistication. This indicator is the share of world GDP to which a country is connected through direct SMC connections, therefore considering the international connectivity infrastructure from a more qualitative perspective. In fact, we start from the premise that, while the number of SMCs that lay in a country matters, the size of economies to which a country is connected to should matter too. The mechanism emphasized is rather straightforward and is based on the literature on information frictions and export sophistication (Rauch, 1999; Rauch & Trinidade, 2003; Chaney, 2014; Akerman et al, 2015: Jun et al, 2020; Hidalgo, 2021): the greater the digital connectedness, the closer the country to main production and consumption centres, the easier for exporters to gather information on buyers, sellers, production technologies, inputs price and quality, market regulations and institutions, and so on, the larger the incentives and capacity to enter these markets and export more sophisticated products.

Second, we measure export sophistication using a measure of export basket complexity (Hidalgo, 2021). To do so, we rely mainly on the Economic Complexity Index (ECI), calculated using the MIT's Observatory of Economic Complexity trade data set. As defined by Hartman et al. (2017), the ECI assesses the sophistication of the export structure of a country by combining information on the diversity of exported product and the number of countries exporting that product (ubiquity). Studying the effect of digital infrastructure deployment on economic complexity is of primary importance for economic development research, given the recent trends in ICT growth in developing areas, especially SSA, and also because complexity appears to be a strong predictor of a country's future growth path, wealth carbon emission, and income inequality (Hidalgo & Hausman, 2009; Hidalgo, 2021).

Third, to address possible reverse causality between the shape of the SMC network and countries' integration in world markets, we use classical panel data econometrics methods and adopt an instrumental variables framework (2SLS). Our approach consists in regressing the ECI over digital connectedness and a set of controls, and instrumenting the connectedness variable by the number of (indirect) 2nd order SMC connections, that is, the cumulative number of distinct SMC connections a given country's first-order SMC connections have. We also reduce the concern for omitted variable bias by including time and country fixed effects.

The first series of regressions conducted on a sample of 60 developing countries over the 1995–2017—of which 23 are from SSA—shows that while digital connectedness is found to increase significantly the export basket complexity in all countries, there is geographical and temporal heterogeneity within our sample. In fact, IV estimations stress that the effect of digital connectedness on export complexity is particularly strong over the period 2006–2015, and point to SSA countries' catch-up. In fact, our results stress that, compared to the Rest of the World (RoW), a 10pp increase in the share of world GDP reached by SSA countries' direct SMC connections[4] leads to a supplementary increase ranging from 4.6 index points (FE–OLS estimations) to 5.3 index points (IV–2SLS estimations). The overall increase in SSA's export complexity resulting from a 10pp increase in its connectedness equals 8.5pp, corresponding to 47% of the ECI sample standard deviation. Our results also point that, in contrast to Latin America and South Asia, there has been no divergence of SSA (together with MENA and South-East Asian countries) with regard to South Korea and China's export complexification path. This effect is also heterogeneous across time, as it is found to be positive and significant starting 2006, which coincides with the deployment of a new generation of cables that brought broadband Internet worldwide (Weller & Woodcock, 2013). Therefore, these estimations suggest that the deployment of SMCs and the resulting increase in digital connectedness has contributed to SSA's catch-up in terms of export basket complexification.

The second strand of estimations is aimed at identifying the factors accentuating or attenuating the effect of connectedness on export complexity. Based on the findings of the literature on information friction and trade patterns (Rauch & Trinidade, 2003; Bahar et al., 2014; Akerman et al., 2015; Lendle et al., 2015), we first test whether the effect of digital connectedness is conditioned by countries' geographical and sea distances to main world markets, and find evidence supporting this hypothesis. Our results stress that the positive effect of connectedness decays with both the geographical and sea distances to world markets; except for SSA where both distances actually increase the benefits of digital connectedness. This finding is reinforced by additional evidence on the positive contribution of decreasing maritime shipping costs in SSA, reflected by increased shipping connectivity, to the positive effect of connectedness on export complexity. These estimations, therefore, bring additional evidence to existing studies on the role of geographical distance in international trade (Blum & Goldfarb, 2006).[5]

Third, we highlight a mediating effect of Internet penetration and human capital, not specific to SSA countries, which is consistent with studies highlighting the importance of digital absorptive capacity to take advantage on the digitalization process (Choi et al., 2020; de Melo & Solleder, 2022). The contribution of critical dimensions of digital absorptive capacity, such has Internet penetration and educational attainment, are investigated and found to mediate the effect of connectedness over long period, but not to explain SSA catch-up in export complexity.

Last, in a series of robustness checks, we extend our analysis to other dimensions of export upgrading. The results show that digital connectedness increases exports of differentiated goods and the participation in global value chains. Regarding the GVCs participation, the impact is much stronger on backward participation and larger for sub-Saharan African countries. This result, therefore, corroborates previous evidence based on the ECI.

The remainder of this paper is structured as follows. Section 2 is devoted to the methodology and data, as well as our identification strategy. In Section 3, we interpret the empirical results. Section 4 is dedicated to robustness checks, and Section 5 concludes on the main messages of the paper.

2. Empirical framework

Our analysis starts from the premise that the reduction in search, replication, transport, tracking, and verification costs resulting from telecommunication SMC deployment has spurred goods and services exports sophistication. We consider that the size of economies to which a country is connected through SMCs is critical for information and knowledge diffusion, and thereby, for the diversification and sophistication of exported products. Therefore, we highlight the contribution of a new dimension of the SMC network, that we term 'digital connectedness', reflecting a country's digital proximity to main production and consumption centres, and assess its impact on export sophistication. In particular, we question the role of distance and other structural determinants of trade, digitalization and industrialization, in channelling this relationship. Considering that digital connectedness and export complexity might be mutually reinforcing, we employ an original instrumental variable approach to identify causal relationships. The next subsections present the data used in this study and our empirical strategy.

Data

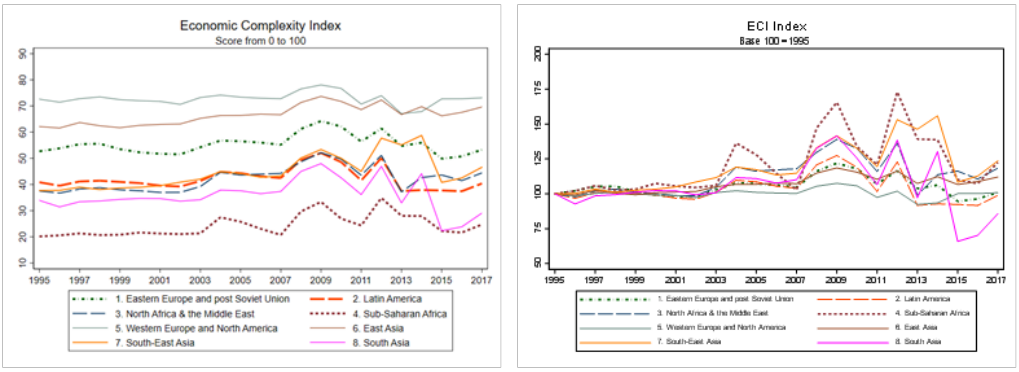
Economic complexity index

The alternative view[6] of the development process provided by research combining the statistical physics of networks and development economics has delivered new analytical tools[7] to quantify the economic relevance of the "historically disregarded productive structure". For this paper, we rely on one of these tools, i.e., the economic complexity index (ECI). As defined by Hartman et al. (2017), the ECI assesses the sophistication of productive structure of a country by combining information on the diversity of exported products and the number of countries exporting these products (ubiquity). The intuition behind ECI is that sophisticated economies are not only diversified, but they export products and services that are exported by few countries (Hidalgo, 2021).

Figure 2 presents the ECI by region. From left-hand side panel, we can easily notice that Western Europe, North America, and East Asia display higher level of complexity, while SSA displays the lowest. The right-hand side panel however indicates sub-Sahara as the region with the greatest increase of complexity between 1995 and 2014, and also the greatest volatility in the index from 2003 to 2015, period corresponding to world geopolitical and financial turmoil and high uncertainty upon commodity markets.

Note that, while the ECI is our main dependent variable, we also mobilize other measures of export upgrading such as the augmented Economic Complexity Index (ECI+), Rauch (1999)'s classification of exports goods, and forward and backward participation in global value chains (GVCs).

Figure 2: ECI evolution by region, 1995-2017



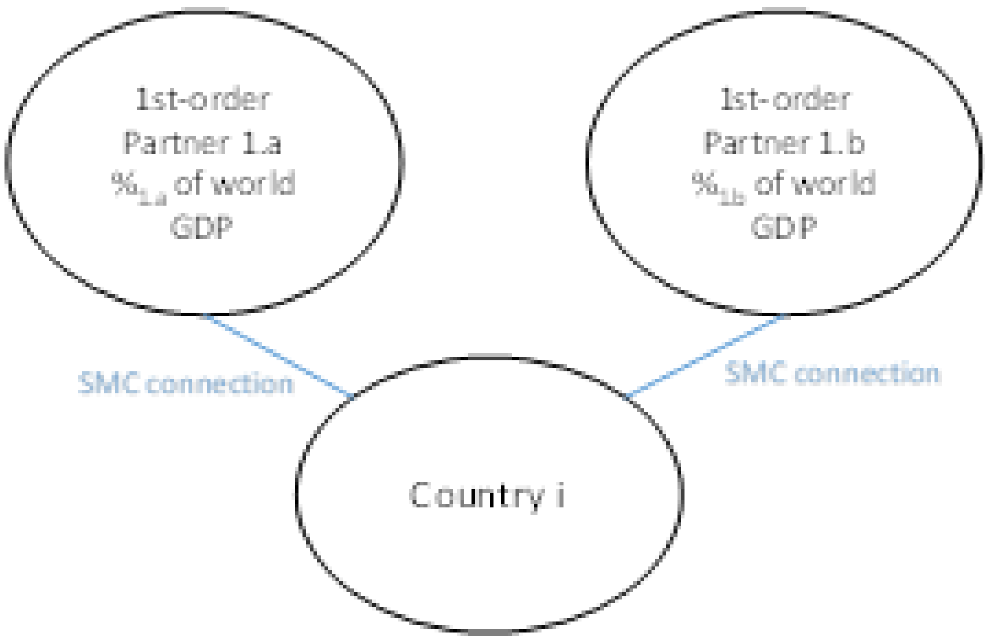
Source: Authors based on raw data from MIT.

Digital connectedness

We use the telecommunication submarine cable (SMC) network as the international infrastructure driving knowledge diffusion, and thereby, as a critical source of economic complexity. To date, SMCs are the cheapest and fastest path for international telecommunications (OECD, 2014)[8], so that more than 95% of international telecommunications passes through this infrastructure. The SMC network is, therefore, a critical determinant of a country's Internet bandwidth, speed, stability, and affordability (Hjort & Poulsen, 2019; Cariolle, 2021; Cariolle & Le Goff, 2021). A direct SMC connection with a partner country will considerably smooth telecommunications and reduce bilateral information and communication costs, compared to non-connected ones. In fact, telecommunications destined to a non-connected partner have to be carried through indirect cable paths, and thereby, will suffer from a slower, narrower, and more expensive bandwidth. The search for low latencies, lower cost, traffic stability, and autonomy, has indeed been a critical incentive for deploying shorter and direct cables connections between OECD countries, and lately, with emerging and developing ones (OECD, 2014).

Therefore, direct cable connections to the largest economies will provide exporters with a better access to information on these markets and facilitate telecommunications between their components. To build a synthetic measure of digital proximity of a country to the main production and consumption centres, we use data on the SMC network worldwide, combine it with worldwide data on GDP, and build an original indicator measuring a country's cumulative share of the world GDP reached by direct—i.e., first-order—cable connections, as schematized in Figure 3. In this figure, country i is directly (or first-order) connected (subscript 1) to countries a and b through SMCs (irrespective of their number), giving a global connectedness indicator consisting in aggregating the weight of countries a and b in world GDP.

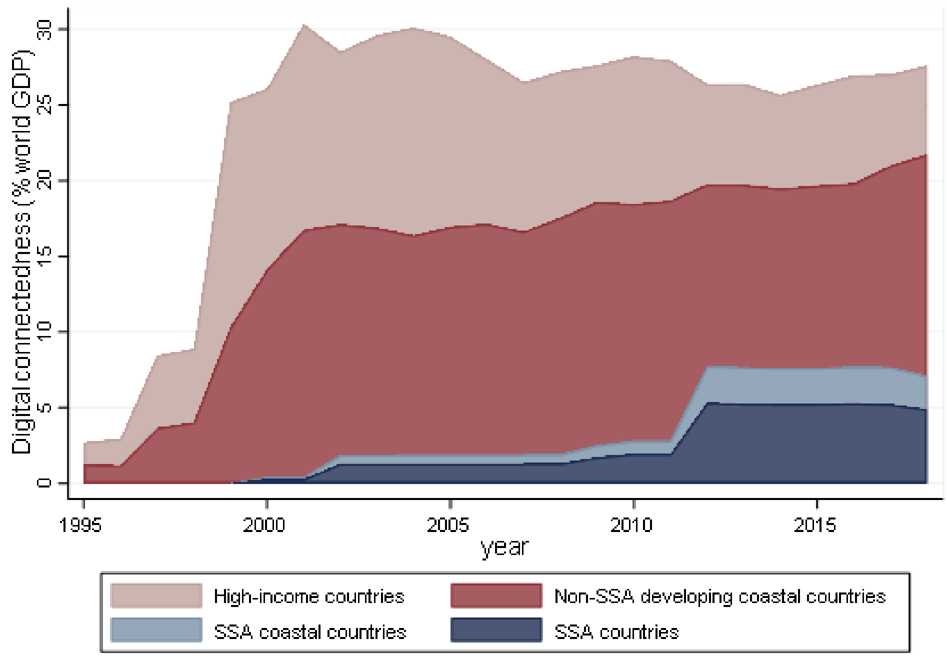
Figure 3: Digital connectedness



Source: Authors' own construction.

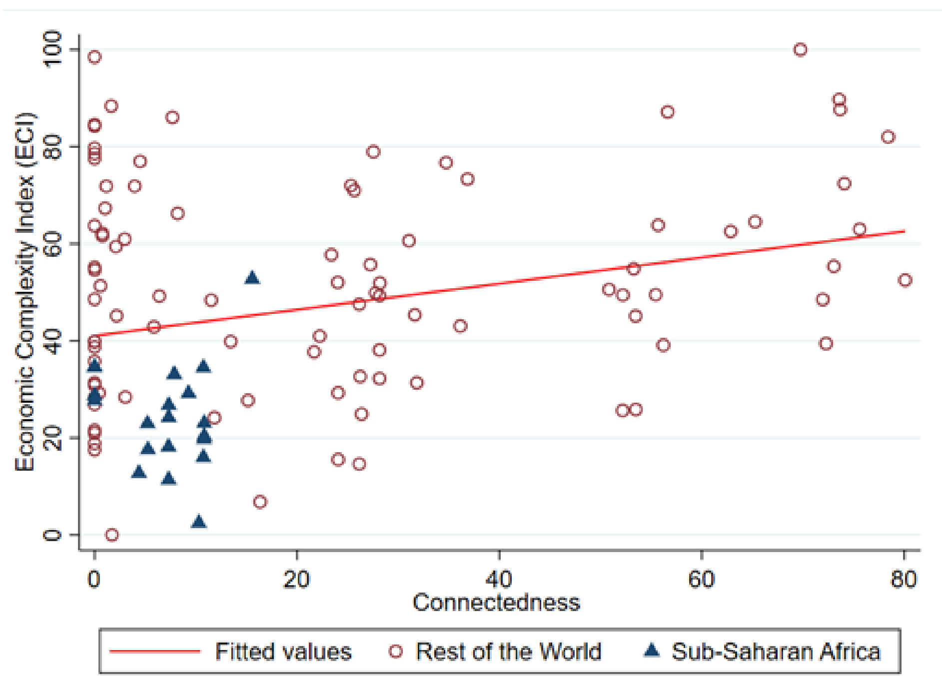
Plotting this indicator average evolution in the world and in sub-Saharan Africa, in particular in Figure 4, we can see that, despite a remarkable jump in the early 2010s, an African country is still, on average, connected to some 5% of the world's GDP in 2017 (7% excluding landlocked countries), against 20% for an average developing non-African coastal country, and 27% for an average high-income country. Acknowledging that trade is limited by information frictions, and that capabilities and knowledge diffusion constrain export complexification, our intuition is that the African very limited digital connectedness to the main world markets may explain a still low export basket's complexity. However, the recent and sharp growth in its digital connectedness to world markets would be expected to have spurred knowledge diffusion and contributed to a rapid catch up for the recent years.

Figure 4: Trends in digital connectedness (% world GDP), 1995–2017



Note: On the X-axis is reported the average cumulative share of world GDP reached by direct (first-order) SCM connections.
Source: Authors' own construction based on raw data from Telegeography and World Development Indicators.

Figure 5: Export complexity vs digital connectedness, 2017



Source: Authors' own construction based on raw data from Telegeography and MIT.

Empirical strategy

The model

Combining our original data set on international connectivity with data from MIT's Observatory of Economic Complexity, we construct an unbalanced panel of 60 countries (including 23 sub-Saharan ones) over the period 1995–2017. Table 1 reports descriptive statistics of the variable used in our model, while Table A1 shows the sample composition. Our baseline model is specified as follows:

$$ECI_{i,t} = \alpha_i + \alpha_t + \beta_1 GDP\_connectedness_{it} + (\beta_2 GDP\_connectedness_{it} \times SSA_i) + \beta_3 X_{i,t} + \varepsilon_{it} \quad (1)$$

Where, $\boldsymbol{ECI_{i,t}}$ is the complexity index for country *i* at time *t*; $\boldsymbol{GDP\_connectedness_{it}}$ is the cumulative percentage of world GDP reached by direct cables laid in country *i* at time *t*; SSA_i a dummy variable equal to 1 for sub-Saharan countries and 0 otherwise; $\boldsymbol{X_{i,t}}$ is a set of control variables; α_i and α_t are, respectively, country and time fixed effects; ε_{it} is the error term. Since we are interested in an eventual catch-up of SSA, our parameters of interest are β_1 and β_2. Following the related literature, we control for Internet penetration rates, country size and development level, trade remoteness to world markets (to account to eventual threshold effect in this variable we also control for its squared value), rents from natural resource exports, FDI inflows, trade openness, democracy, electricity access, and real effect exchange rates. The description, expected sign, related literature, and source underlying these control variables are provided in Table A2. These control variables' descriptive statistics are reported in Table 1.

Table 1: Descriptive statistics – Baseline sample: 1,150 observations

	Mean	Std. Dev.	Min	Max	Source
Dependent variable					
ECI	38.25	17.81	0.00	90.84	MIT's OEC
Interest variable					
Digital connectedness	18.10	21.27	0.00	75.59	Authors
Instrumental variable					
2nd order cable connections	32.00	27.84	0.00	102.00	Authors. telegeography

continued next page

Table 1 Continued

	Mean	Std. Dev.	Min	Max	Source
Control variables					
Log (GDP p.c.)	8.09	1.21	5.53	11.15	WDI
log (Population)	16.88	1.41	13.29	21.05	WDI
FDI inflows	3.67	4.52	-6.06	39.46	WDI
Trade (% of GDP)	73.49	48.74	15.64	437.33	WDI
Internet users	17.90	22.19	0.00	97.39	WDI
log (REER)	4.68	0.40	3.04	14.65	FERDI
Remoteness index	53.56	23.19	0.00	100.00	FERDI
Natural rents	9.01	11.24	0.00	58.65	WDI
Polity2	5.81	2.68	0.00	10.00	QOG
Electricity (access)	73.26	30.33	3.44	100.00	WDI
Sea distance	7678.01	2935.01	2494.37	18646.79	CERDI
Shipping connectivity index	26.91	23.30	0.80	141.58	UNCTAD
Absorptive capacity channel					
Internet penetration	17.90	22.20	0.00	97.39	WDI
1ary enrolment rate	102.31	2.63	95.97	105.32	WDI
2ary enrolment rate	78.39	6.65	67.79	90.21	WDI
3ary enrolment rate	34.23	7.26	22.16	47.70	WDI
Value chain participation					
FVA pc	0.79	4.21	0.00	43.10	UNCTAD-Eora
DVX pc	0.46	1.13	0.00	9.96	UNCTAD-Eora
Rauch's exports					
Diff exp. pc	1.23	5.21	0.00	51.43	UN COMTRADE
OE exp. pc	0.78	1.86	0.00	17.94	UN COMTRADE
Ref Pr.exp.pc	0.79	3.38	0.00	39.57	UN COMTRADE

Note: Variable's definitions and related literature are reported in Table A3 (in the appendix).

Instrumental variable

Increased digital connectedness can be a trigger of economic complexity or a consequence of it. The econometric challenge, therefore, consists in solving an eventual reverse causality problem by isolating a causal link going exclusively from GDP connectedness to ECI. To do so, we adopt the IV approach exploiting information on the shape of the SMC network linking partners to whom a country is connected. We specifically use the number of distinct second-order SMC connections (schematized in Figure 6)—excluding duplicates and common partners (i.e., only plain lines considered)—as an instrumental variable (IV) predicting connectedness (Figure 7). We, therefore, estimate the previous (second-stage) Equation 1 with this first-stage equation, using the two-step least-square (2SLS) estimator:

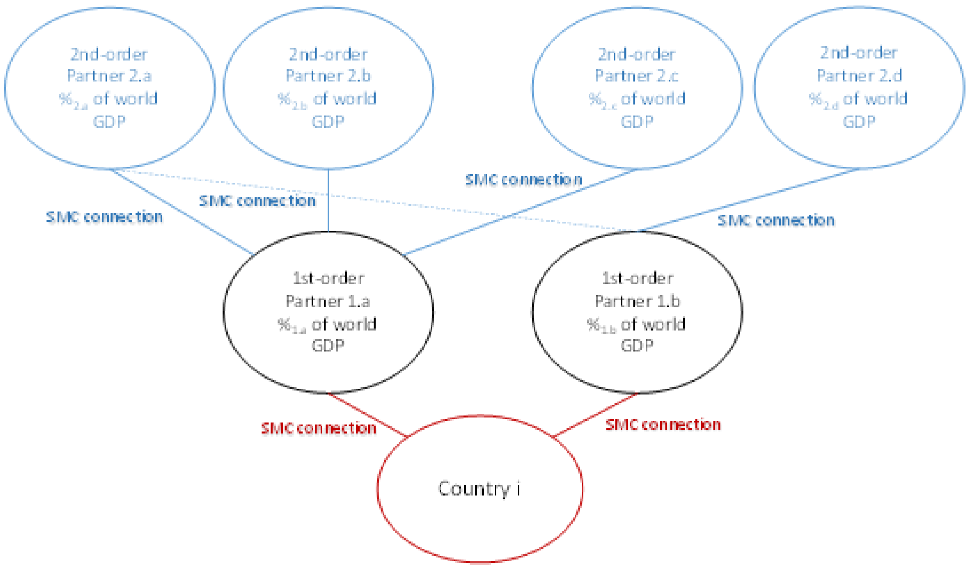
$$Connectedness_{i,t} = \alpha_i + \alpha_t + \gamma_1 2ndorder\_con_{it} + (\gamma_2 2ndorder\_con_{it} \times SSA_i) + \gamma_3 X_{i,t} + \epsilon_{it} \quad (2)$$

Correcting for heteroscedasticity and clustering standard errors at the country-level.

Given its large costs underlying related investments and operations, the ability of a cable to link together a large number of countries depends on served countries/regions/continents' geographical characteristics, in particular, on the possible scale economies induced by bringing Internet to multiple countries, regions, and continents.[9] This is the case for most cables connecting Africa to the rest of the world, such as the Africa-Coast-to-Europe (ACE), WACS, EASSy, WASC or TEAMS cables, deployed in the 2000s and 2010s to serve a large number of countries located in the same regions and/or along the path to connect Africa to other continents. This is also the case of the SEAMEWE-3/4/5 or AAE1 cables, connecting countries located on the path linking far-East Asia to Europe through the Middle-East and North Africa. This characteristic of the cable network, therefore, fulfils the conditions of a good instrument.

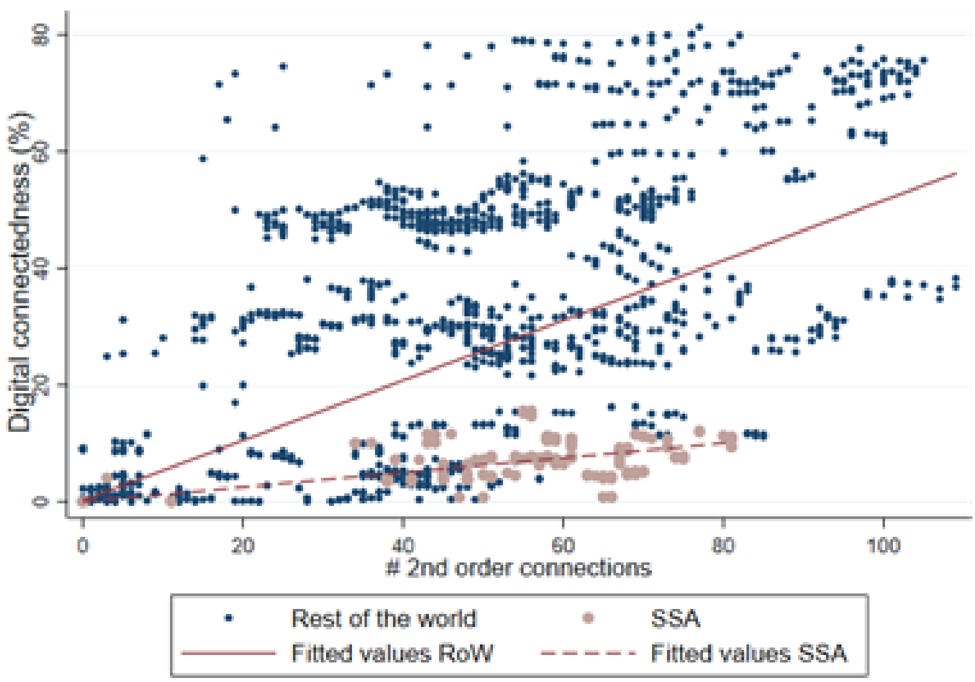
Our IV's rationale is, therefore, quite straightforward: countries that are connected to country themselves poorly (densely) connected world markets will display low (high) connectedness. Our exogeneity claim lies in the fact that the shape and density of the SMC network is determined by historical long-term conditions favourable to western industrialized countries' interconnectedness (which are excluded from the estimation sample), by geographical factors and aggregate economic considerations, independent from a given country's economic situation or policy (Eichengreen et al., 2016; World Bank, 2018; Cariolle, 2021).[10] This claim is plausible for first-order cable connections, but even more likely if we focus on the density of second-order cable connections, which is the rationale of our main instrument (Figure 6). Appendix C reports IV estimates using the number of first-order and second-order cable connections as instruments to test over-identification restrictions.

Figure 6: Second-order SMC connections



Source: Authors' own construction.

Figure 7: Second-order SMC connections and digital connectedness, 1995-2017



Source: Authors' own construction based on data from Telegeography and World Development Indicators.

3. Main results

Baseline estimations and regional effects

Table 2 presents OLS fixed-effect estimates of Equation 1 based on a sample of 60 developing and transition economies (including 23 from sub-Saharan Africa) covering the period 1995–2017. Overall, it appears that digital connectedness is positively related to economic complexity. Suspecting eventual autocorrelation given the large time dimension of our panel, we conduct the Inoe-Solon test for auto-correlated residual and detect the presence of order-1 autocorrelation in residuals (see Appendix B). Therefore, we report in column (3) estimates of Equation 1 with Driscoll–Kraay AR(1) standard errors, and do not find that correcting for AR (1) residuals reduces the significance of estimated relationships.

Table 2: OLS fixed effect estimates

Dep var. ECI	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Period	**1995–2017**					**2000–2017**		**2005–2017**		**2010–2017**		**2006–2015**	
Connectedness	0.223**	0.109**	0.110***	0.128***	0.226***	0.128***	0.317***	0.205**	0.137***	0.240*	3.337***	0.268***	0.126
	(0.108)	(0.0527)	(0.0231)	(0.0470)	(0.0383)	(0.0470)	(0.0477)	(0.101)	(0.0487)	(0.134)	(0.878)	(0.0908)	(0.0945)
SSA x connected				0.340*	0.195	0.340*	0.287	0.436**	0.562**	0.280	-2.947***	0.464**	0.567**
				(0.199)	(0.174)	(0.199)	(0.206)	(0.198)	(0.224)	(0.256)	(0.992)	(0.195)	(0.227)
Lat Am x connected					-0.205***		-0.281**		-0.209		-3.624***		-0.181
					(0.0536)		(0.140)		(0.146)		(0.890)		(0.167)
MENA x connected					-0.131***		-0.125		-0.0376		-3.350***		0.0585
					(0.0341)		(0.0798)		(0.0985)		(0.872)		(0.129)
South-East Asia x connected					0.0239		0.0404		0.240***		-3.009***		0.278**
					(0.0466)		(0.0730)		(0.0803)		(0.924)		(0.112)
South Asia x connected					-0.280***		-0.320***		-0.117		-3.396***		-0.0648
					(0.0560)		(0.0751)		(0.0797)		(0.911)		(0.112)
Control Variables													
log(GDP p.c.)		5.827***	-4.023***	5.851***	6.018***	5.851***	5.071***	4.598*	6.819***	3.326	5.601	1.953	5.887***
		(1.831)	(1.196)	(1.886)	(1.374)	(1.886)	(1.763)	(2.405)	(2.443)	(2.890)	(3.992)	(2.499)	(2.136)
Trade (% of GDP)		0.0796***	-0.0108	0.0763***	0.0482***	0.0763***	0.0321**	0.0779***	0.0244	0.0921***	0.0303	0.0968***	0.0258
		(0.0156)	(0.0119)	(0.0161)	(0.0108)	(0.0161)	(0.0142)	(0.0208)	(0.0211)	(0.0276)	(0.0395)	(0.0226)	(0.0186)
Internet users (% pop)		0.0276	-0.0232	0.0442	0.0217	0.0442	0.0344	0.0568	-0.0190	0.0343	0.0942	-0.0400	-0.0868*
		(0.0347)	(0.0449)	(0.0344)	(0.0332)	(0.0344)	(0.0356)	(0.0398)	(0.0475)	(0.0585)	(0.0871)	(0.0623)	(0.0524)
Remoteness		-0.179*	-0.102	-0.210*	-0.189*	-0.210*	-0.272	-0.346***	-0.465***	-0.498***	-0.467**	-0.536***	-0.451***
		(0.108)	(0.0715)	(0.110)	(0.106)	(0.110)	(0.169)	(0.129)	(0.169)	(0.130)	(0.194)	(0.109)	(0.148)
Remoteness^2		0.0021*	-0.00145	0.0024**	0.00224*	0.00242**	0.00313*	0.00395***	0.00483***	0.00589***	0.00455**	0.00663***	0.00509***
		(0.0012)	(0.0010)	(0.0012)	(0.00122)	(0.00120)	(0.00184)	(0.00148)	(0.00183)	(0.00152)	(0.00210)	(0.00135)	(0.00164)

continued next page

Table 2 Continued

Dep var. ECI	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Period	1995–2017					2000–2017		2005–2017		2010–2017		2006–2015	
Natural rents		-0.379***	-0.297***	-0.354***	-0.343***	-0.354***	-0.294***	-0.319***	-0.383***	-0.400***	-0.574***	-0.317***	-0.273***
		(0.0752)	(0.0791)	(0.0775)	(0.0807)	(0.0775)	(0.111)	(0.0930)	(0.109)	(0.0977)	(0.173)	(0.0873)	(0.0942)
Polity^2		0.246	0.493**	0.0906	-0.0805	0.0906	-0.300	-0.147	-0.580	-0.262	-0.695	-0.403	-0.881*
		(0.346)	(0.180)	(0.357)	(0.326)	(0.357)	(0.397)	(0.433)	(0.422)	(0.449)	(0.718)	(0.473)	(0.527)
Electricity access (% pop)		0.00083	-0.168***	-0.00276	0.0125	-0.00276	-0.00486	-0.0220	-0.0695	-0.0269	-0.129	0.0718	0.0173
		(0.0591)	(0.0563)	(0.0616)	(0.0441)	(0.0616)	(0.0499)	(0.0673)	(0.0679)	(0.0865)	(0.124)	(0.0714)	(0.0537)
log(Population)		1.505	1.406	1.132	0.375	1.132	-0.885	0.398	-1.262	0.274	-0.756	-0.0273	-1.881*
		(1.383)	(2.494)	(1.479)	(1.056)	(1.479)	(1.308)	(1.736)	(1.400)	(1.906)	(1.876)	(1.673)	(1.143)
FDI_inflows		-0.0900	-0.00057	-0.0883	-0.0977	-0.0883	-0.0513	-0.0526	-0.0472	-0.0484	-0.0614	-0.0790	-0.0713
		(0.0823)	(0.0493)	(0.0828)	(0.0684)	(0.0828)	(0.0546)	(0.0710)	(0.0802)	(0.100)	(0.0965)	(0.105)	(0.0869)
log(REER)		-0.800*	-1.029**	-0.698*	-0.712*	-0.698*	-1.064*	-1.048*	-0.856	-0.919	-0.584*	-6.753**	-6.118*
		(0.417)	(0.410)	(0.391)	(0.402)	(0.391)	(0.594)	(0.587)	(0.529)	(0.613)	(0.350)	(3.142)	(3.161)
N	2497	1150	1150	1150	1150	896	896	633	633	363	363	528	528
R^2	0.041	0.652	0.471	0.657	0.693	0.656	0.697	0.661	0.703	0.685	0.729	0.699	0.737

Notes: Standard errors are robust to heteroscedasticity and clustered by country except in column (3) where Driscoll Kraay AR (1) standard errors are reported. *** p<0.01, ** p<0.05, * p<0.1. FE dummy variable estimator, except in column (3) where within FE estimates are reported. Driscoll–Kraay standard errors are robust to very general forms of cross-sectional and temporal dependence when the time dimension becomes large.

Given that the deployment of the SMC has occurred recently in sub-Saharan Africa, we split our sample into four periods in order to properly assess temporal and regional heterogeneity. Column 6, column 8, and column 12 show that the impact of connectivity is larger in sub-Saharan Africa than anywhere else, suggesting a catch-up effect at play on the continent. This effect is noteworthy inasmuch as SSA is compared to the best-performing developing countries in our sample (China and South Korea), which exhibit connectedness levels similar to Western and North American countries (Figure 2). One should also note that the 2006–2015 period is the one in which the highest catch-up effect has been recorded (column 12 and column 13).[11] With respect to controls variables, remoteness and natural rent prove to be detrimental to the export basket complexity while an increase in the income level, in trade openness or a depreciation of the REER is associated with an increase in the complexity of the export basket. All the remaining control variables are statistically not significant.

Table 3 reports FE-2SLS estimates, while Appendix C reports estimates of the same estimator using both first-order and second-order cable connections as instrument set. The statistics regarding the quality of the instruments are satisfactory[12], rejecting the null hypothesis that the equation is under-identified and displaying high first-stage F-statistics, well-above 10. Instrument estimates are positive and statistically significant at 1% in the first-stage regression. The FE-2SLS estimates support a positive causal effect of connectedness on export complexity. IV estimates indicate that the effect is statistically significant at 1% and slightly higher than FE estimates (Table 2). Estimates in column (4) endorse the SSA's technology catch-up over the 2006–2015 period, already documented in Table 2. In magnitude, a ten percentage points (pp) increase in the share of world GDP directly wired to SSA countries leads to an additional 8.4 points increase in the export complexity index. This increase is 5.3 index-points higher than the rest of the developing world, over-performance mainly explained by the lower performance of Latin America and South Asia (column 5). However, contrary to previous FE estimations, IV estimates in column (5) do not show any more SSA catching-up China and South Korea.[13]

Table 3: 2SLS fixed-effect estimates – Regional effects

Dep var. ECI	(1)	(2)	(3)	(4)	(5)
Period:	1995–2017			2006–2015	
(A) Connectedness (con)	0.161**	0.124*	0.304***	0.304**	0.278
	(0.0682)	(0.0657)	(0.0531)	(0.123)	(0.205)
(B) SSA x con		0.265	-0.0779	0.532**	0.250
		(0.223)	(0.194)	(0.258)	(0.292)
(C) Lat Am x con			-0.315***		-0.667**
			(0.0738)		(0.261)
(D) MENA x con			-0.169***		-0.0954
			(0.0603)		(0.358)

continued next page

Table 3 Continued

Dep var. ECI	(1)	(2)	(3)	(4)	(5)
Period:		1995–2017			2006–2015
(E) South-East Asia x con			-0.0721		0.0562
			(0.0586)		(0.136)
(F) South Asia x con			-0.442***		-0.326**
			(0.0907)		(0.153)
			First-stage estimates		
F-stat (A)	63.28***	82.58 ***	117.37***	50.06***	97.92***
F-stat (B)		40.82 ***	19.41***	47.65***	30.14***
F-stat (C)			25.70***		5.42***
F-stat (D)			7.28***		2.02*
F-stat (E)			345.76***		143.67***
F-stat (F)			13.96***		615.46***
Cragg-Donald F-stat	382.685***	503.183	121.077	115.980	6.482
LM-stat	24.113***	31.373	20.245	17.771	10.44
Controls, country FE, year FE			YES		
N	1150	1150	1150	528	528
R^2	0.650	0.657	0.689	0.698	0.731

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. FE 2SLS dummy variable estimator. Control estimates are not reported in the table.

Does distance still matter?

As pointed earlier, the question of whether digitalization of exchanges has spurred the death of distance in international trade is central (Lendle et al., 2016; Goldfarb & Tucker, 2019), and this subsection is aimed at reframing this as problematic within the connectedness–complexity nexus. In Table 4, we test whether the positive effect of connectedness is conditioned by the country's geographical distance to main export markets. To do so, we interact the trade remoteness variable used as control with digital connectedness and SSA dummy variables, applying the same interaction procedure with our instrument set. The results show that the positive effect of connectedness decays with geographic distance to world markets, and this conclusion holds whether we restrict the estimation span to the 2006–2015 period or when we consider only coastal countries in the analysis. However, they suggest, in a 10% confidence level, that the effect of connectedness on export complexity increases with world markets remoteness in SSA coastal countries (column 6). This series of estimations suggest that, despite digitalization and trade digitization, the geographical distance hampers trade complexification, but with a probable exception in SSA. We further this nonlinearity in the next regressions, using more sophisticated measures of distance-related trade costs.

Table 4: Digital connectedness and the geographical distance to main world markets

Dep var. ECI Sample: Period:	(1)	(2)	(3)	(4)	(5)	(6)
	All Countries			Coastal Countries		
	1995–2017		2006–2015	1995–2017		2006–2015
(A) Connectedness (con)	0.330***	0.296**	0.889***	0.321***	0.290**	0.803***
	(0.118)	(0.119)	(0.233)	(0.120)	(0.125)	(0.243)
(B) Con x remoteness	-0.0038**	-0.0038**	-0.016***	-0.0032*	-0.0035*	-0.014***
	(0.00185)	(0.00187)	(0.00424)	(0.00193)	(0.00193)	(0.00426)
(C) Con x SSA		0.570	-0.710		0.540	-0.974
		(0.742)	(0.889)		(0.798)	(0.927)
(D) Con x SSA x remoteness		-0.00538	0.0263		-0.00277	0.0350*
		(0.0119)	(0.0174)		(0.0135)	(0.0192)
Additional controls						
SSA x remoteness		0.0211	-0.0673		0.00723	-0.133
		(0.0577)	(0.0664)		(0.0831)	(0.118)
Remoteness index	0.0758	0.0671	0.323***	0.0477	0.0460	0.252**
	(0.0535)	(0.0619)	(0.0938)	(0.0680)	(0.0685)	(0.111)
	First-stage estimations					
F-stat (A)	30.99	35.72	21.26	22.96	26.37	17.41
F-stat (B)	33.22	33.97	38.19	33.91	28.26	33.07
F-stat (C)		139.04	77.79		144.25	58.62
F-stat (D)		94.45	41.9		102.11	36.96
Cragg-Donald F-stat	220.269	194.980	36.606	156.917	137.18	23.743
LM-stat	24.993***	19.48***	11.42***	21.721***	24.13***	7.726***
Controls, country FE, year FE	Yes					
N	1150	1150	528	1039	1039	484
R^2	0.646	0.655	0.681	0.649	0.663	0.688

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. FE 2SLS dummy variable estimator. Control estimates are not reported in the table. To address the mediating effects of remoteness, the squared term of the remoteness variable has been dropped from the econometric equation.

In a second step, we built an alternative variable reflecting the sea-distance to world markets, using data on bilateral maritime distances from the CERDI-Sea Distance Database (Bertoli et al., 2016). It is likely that the Euclidian distance between capitals, used in the remoteness index, improperly reflects the trade costs related to distance, and that considering sea distances would be more relevant for our problematic since many exports are merchandizes shipped and transported by boats overseas. Based on this data, we compute the average sea distance of country to its ten main trade partners (including imports and exports), and interact this variable with connectedness and SSA variables in Equation 1, and with the instrument in Equation 2. Results, reported in Table 5, are consistent with previous estimations based on the remoteness index.[14] They indeed support that sea distance dampens the positive effect of digital connectedness on export complexity. They also confirm a relationship that was only 10% significant with the trade remoteness variable (Table 4, column 6), stressing that, in contrast to other developing regions the effect of connectedness increases with sea distance in SSA. For example, an increase of 3,000km in sea distance to main trade partners (approximately one standard deviation) reduces the positive effect of connectivity on export complexity in non-SSA countries by 47% but increases by 75% the positive effect of connectivity on export complexity in SSA countries. This effect is not driven by the presence of South Africa in the sample (column 4), and is robust to the exclusion of trade remoteness from control variables (column 5). Moreover, the simple interaction of connectedness with the SSA dummy is associated with a negative and significant sign, suggesting that SSA's complexity catch-up is driven by increased connectedness in countries that are the farthest from world markets. Therefore, (sea) distance to world markets could have been a structural handicap for the complexification of African countries' export basket, which is being offset through the digital interconnection process.

Table 5: Digital connectedness and the sea distance to main trade partners

Dep var. ECI **Period:**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
	1995-2017		**2006–2015**		
(A) Connectedness (con)	0.194	1.201***	1.593***	1.590***	-0.133
	(0.363)	(0.291)	(0.420)	(0.396)	(0.195)
(B) Con x sea distance	-0.000004	-0.000178***	-0.00025***	-0.00025***	0.000015
	(0.00006)	(0.00005)	(0.00008)	(0.00007)	(0.00004)
(C) Con x SSA		-2.437***	-2.612***	-2.695***	-2.417***
		(0.486)	(0.485)	(0.605)	(0.925)
(D) Con x SSA x sea dist.		0.000348***	0.000398***	0.000408***	0.000271***
		(0.0000679)	(0.0000808)	(0.0000909)	(0.0000999)
Additional controls					
SSA x Sea distance		-0.000912	-0.00167	-0.00152	0.000081
		(0.000804)	(0.00115)	(0.00140)	(0.00095)
Sea distance	0.000154	0.000861	0.00203	0.00194	-0.00223**
	(0.00067)	(0.00103)	(0.00146)	(0.00158)	(0.000875)

continued next page

Table 5 Continued

Additional controls					
Dep var. ECI Period:	(1)	(2)	(3)	(4)	(5)
	1995-2017		2006–2015		
	First-stage estimations				
F-stat (A)	10.44	14.8	15.57	20.9	19.42
F-stat (B)	10.68	16.77	18.7	31.19	18.72
F-stat (C)		36.46	38.45	41.85	34.51
F-stat (D)		29.72	29.84	37.32	34.75
Cragg-Donald F-stat	61.486	47.031	28.296	30.515	90.671
LM-stat	17.894***	8.326***	9.080***	8.387***	13.471***
Controls, country FE, year FE	Yes	Yes†	Yes††		
N	737	737	528	518	797
R^2	0.624	0.674	0.707	0.708	0.774

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. FE 2SLS dummy variable estimator. Control estimates are not reported in the table. To avoid potential collinearity with the sea-distance interaction variable and ensure the comparability of results with Table 4, the squared term of the remoteness variable has been dropped from the econometric equation. † In column (4) South Africa was excluded from the sample. †† In column (5), the trade remoteness variable was excluded from the econometric equation.

To further understand the role of distance in our relationship, we investigate whether maritime transport costs could mediate the effect of digital connectedness on export complexity, using the UNCTAD's liner shipping connectivity index as interaction variable. This index measures a country's connectivity to global shipping network based on five metrics: the number of ships, their container-carrying capacity, maximum vessel size, number of services, and number of companies that deploy container ships in a country's ports. Results are reported in Table 6 and stress that shipping connectivity is complementary to digital connectedness, i.e., it increases the contribution of connectedness to export complexity, and that this complementarity is stronger in SSA, especially when South Africa is excluded from the sample (column 4).

Therefore, this bunch of estimations stresses that distance still matter to explain the effect of connectedness on economic complexification nexus, but it does in a different way for SSA countries. While increased geographical or sea distance to world markets attenuate the positive effect of digital connectedness on export complexity in most developing economies, an increased distance is, however, found to accentuate this effect in SSA. This means that SSA catch-up in economic complexity is explained by the connectedness of the remotest African countries from world markets (excluding South Africa). These countries probably suffer from the greatest structural handicaps to trade, and therefore it is probably there that the return to increased connectedness (the reduction in information and transaction costs) could be the stronger. This explanation is corroborated by the positive, but less robust, contribution to the connectedness–complexity nexus of shipping connectivity, reflecting decreasing maritime shipping costs in SSA compared to other developing regions.

Table 6: Digital connectedness and the shipping connectivity channel

Dep var. ECI Period:	(1)	(2)	(3)	(4)
	1995–2017		2006–2015	
(A) Connectedness (con)	0.174	0.104	0.0228	-0.0324
	(0.265)	(0.161)	(0.209)	(0.196)
(B) Con x SCI	0.00314	0.00370*	0.00424*	0.00468*
	(0.00262)	(0.00209)	(0.00243)	(0.00240)
(C) Con x SSA		-0.277	-0.333	-0.743
		(0.573)	(0.635)	(0.609)
(D) Con x SSA x SCI		0.0445	0.0568	0.109**
		(0.0423)	(0.0478)	(0.0477)
Additional controls				
SSA x SCI		-0.189	-0.413	-0.973
		(0.485)	(0.514)	(0.596)
Shipping connectivity index (SCI)	-0.328*	-0.304*	-0.258	-0.244
	(0.179)	(0.178)	(0.186)	(0.213)
	First-stage estimations			
F-stat (A)	6.67***	20.24***	23.28 ***	10.47***
F-stat (B)	35.49***	112.35***	88.97***	39.06***
F-stat (C)		144.19***	143.52***	57.20***
F-stat (D)		103.68***	143.09***	49.54***
Cragg-Donald F-stat	19.19	46.389	38.863	40.42
LM-stat	5.034**	8.360***	8.988***	8.972***
Controls, country FE, year FE		Yes		Yes†
N	681	681	492	482
R^2	0.631	0.676	0.706	0.712

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. FE 2SLS dummy variable estimator. Control estimates are not reported in the table. To avoid potential collinearity with the SCI interaction variable and ensure the comparability of results with Table 4 and Table 5, the squared term of the remoteness variable has been dropped from the econometric equation. † In column (4), South Africa is excluded from the sample

The absorptive capacity channel

In a third step, we study other key channel of the connectedness–complexity nexus, namely, the country's digital absorptive capacity. We posit that digital connectedness will trigger structural transformations and export's structure complexification if a country and its driving force are able to absorb technological change and transform access to digital technologies into transaction cost reductions. We consider that this absorptive capacity is reflected by the penetration of the Internet within the whole population on the one hand, and by a country's human capital level on the other hand. While Internet use in the population is a natural proxy for the familiarity of a given population with Internet related technologies, educational attainment has been pinpointed as being a critical factor of technology absorption (Paunov & Rollo, 2015, 2016; Choi et al., 2020), as evidenced by the literature on the skilled-biased technological and organization change (Akerman et al., 2015).

In Table 7, we report estimations of the digital absorptive capacity channel. In columns (1) to (3), the share of population using Internet is used as proxy for this capacity and interacted with the connectedness and SSA dummy variables. Result stress that, in line with our expectation, Internet penetration is found to drive the positive effect of digital connectedness. However, this conditioning effect appears to be less significant over 2006–2015 period (column 3). Moreover, estimation in column (3) suggests that rising Internet penetration rates in SSA are not a factor explaining the observed catch-up in economic complexity, probably because of persistently low Internet penetration rates over the sub-continent.

Another critical dimension of the digital absorptive capacity is human capital, especially education level (Choi et al., 2020). In columns (4) to (12), we proxy educational attainment by the primary, secondary, and tertiary gross enrolment rates[15], and interact separately these variables with the connectedness and SSA dummy variables. First, estimations stress the mediating effect of school enrolment, especially primary enrolment, is significant over the whole 1995–2017 period rather than 2006–2015. Moreover, estimates in column (5) support that increasing primary school enrolment in well-connected SSA countries is particularly beneficial to export complexity. Second, estimates in column (4) and column (5) stress that reaching a minimum primary enrolment rate is necessary for the positive effect of digital connectedness on export complexity to be felt. Based on estimates in column (4), this rate is established at 99%, which corresponds to the first quartile of the sample distribution. Third, the mediating effects of secondary and tertiary enrolment rates are positive and significant, in a 10% or 5% significant level and over long period only, but are not found to differ in SSA.

Table 7: 2SLS fixed-effect estimates – The absorptive capacity channel

Dep var: ECI	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Absorptive capacity var:	**Internet penetration**			**1ary enrolment rate**			**2ary enrolment rate**			**3ary enrolment rate**		
	1995–2017		**2006–2015**	**1995–2017**		**2006–2015**	**1995–2017**		**2006–2015**	**1995–2017**		**2006–2015**
(A) Connectedness (con)	0.0425	0.000369	0.147	-2.932***	-2.552**	-1.900	-0.357	-0.436	-0.292	-0.0947	-0.136	-0.0859
	(0.0758)	(0.0584)	(0.137)	(1.012)	(1.008)	(2.763)	(0.284)	(0.280)	(0.502)	(0.130)	(0.117)	(0.307)
(B) Con x internet	0.00290***	0.00385***	0.00284*									
	(0.00076)	(0.00062)	(0.0016)									
(B) Con x e.r.				0.0297***	0.0257**	0.0210	0.00620*	0.00657*	0.00660	0.00640*	0.00669**	0.00918
				(0.00990)	(0.00997)	(0.0257)	(0.00364)	(0.00367)	(0.00573)	(0.00352)	(0.00325)	(0.00726)
(C) Con x SSA		0.343	0.634*		-28.85**	-2.676		-0.727	0.487		-0.358	-0.505
		(0.289)	(0.343)		(11.68)	(23.94)		(2.191)	(3.641)		(0.942)	(2.175)
(D) Con x SSA x internet		-0.0480***	-0.0233									
		(0.0176)	(0.0280)									
(D) Con x SSA x e.r.					0.281**	0.0304		0.0131	0.000750		0.0141	0.0257
					(0.113)	(0.229)		(0.0264)	(0.0427)		(0.0259)	(0.0538)
Additional controls												
SSA x internet		0.588***	0.214									
		(0.173)	(0.318)									
SSA x e.r.					-0.0119	0.0112		-0.0147	-0.00647		0.0784	0.0251
					(0.0451)	(0.0503)		(0.0647)	(0.0626)		(0.159)	(0.139)
Enrollment rate (e.r.)				-10.40***	-10.46***	14.11**	3.581***	3.299***	-2.120***	5.011***	4.410***	-18.45***
				(1.400)	(1.413)	(5.643)	(0.517)	(0.523)	(0.772)	(0.716)	(0.756)	(6.709)
Internet user (% pop)	-0.0495	-0.0126	-0.0741	0.00241	0.0358	-0.0401	0.0122	0.0395	-0.0405	0.0117	0.0500	-0.0375
	(0.0373)	(0.0439)	(0.0706)	(0.0387)	(0.0364)	(0.0674)	(0.0372)	(0.0369)	(0.0687)	(0.0373)	(0.0402)	(0.0682)

continued next page

Table 7 Continued

Additional controls												
Dep var: ECI	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Absorptive capacity var:	Internet penetration			1ary enrolment rate			2ary enrolment rate			3ary enrolment rate		
	1995–2017		2006–2015	1995–2017		2006–2015	1995–2017		2006–2015	1995–2017		2006–2015
	First-stage estimations											
F-stat (A)	53.98	37.53	27.32	60.15	34.31	16.52	30.66	36.02	34.78	30.81	39.96	41.81
F-stat (B)	97.12	58.14	67.52	59.18	34.8	16.91	30.59	38.24	41.57	30.94	41.12	51.24
F-stat (C)		25.42	33.87		26.86	28.37		25.68	22.99		27.7	23.36
F-stat (D)		7.64	7.63		26.8	28.7		24.38	22.54		23.49	21.04
Cragg-Donald F-stat	122.986	139.992	56.312	131.977	270.721	53.755	186.542	274.393	76.958	185.623	262.082	84.706
LM-stat	26.491***	2.930***	3.524*	29.340***	35.727***	15.763***	27.687***	32.018***	16.930***	27.593***	29.575***	18.200***
Xit, country & year FEs	Yes											
N	1150	1150	528	1150	1150	528	1150	1150	528	1150	1150	528
R^2	0.660	0.657	0.698	0.652	0.663	0.702	0.656	0.665	0.703	0.656	0.665	0.703

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table.

4. Robustness analysis

In this last section, we check the robustness of our results and interpretations using complementary measures of the export sophistication process. First, we test whether previous regional effects in the connectedness–complexity nexus hold for differentiated exports, exports exchanged on organized markets, or exports with reference price, using Rauch's product classification (Rauch, 1999). Second, we investigate whether these relationships are corroborated by increased global value chains participation. Third, we use additional measurements of export upgrading, such as the ECI+ or the Hausman et al. (2007)'s export sophistication index (EXPY).

Digital connectedness and exports according to Rauch's classification

How does the increase in digital connectedness materialize in exports? To answer this question, we use the Rauch (1999)'s classification, which is widely used in empirical work on the relationship between ICT and trade. The Rauch classification consists of three product groups and it presents an important feature in that it allows us to distinguish between products whose exchange faces high information search costs (differentiated goods) and those facing moderate or low information search costs (homogeneous goods sold on an organized exchanges market or with a reference price). Rauch provides two classifications, a "conservative" one that minimizes the number of homogenous products while the "liberal" classification maximizes them. To construct our exports per group's category following the two classifications, we rely on the four-digit level of the Standard International Trade Classification (SITC, revision 2) provided by UN COMTRADE.

Table 8 displays the results based on the conservative classification[16]; columns (1) to (6) show that digital connectedness has a positive and statistically significant effect on exports of differentiated goods, while the impact on the homogenous goods remains not significant. This result is consistent with the literature and meets our expectation inasmuch as differentiated goods are characterized by higher search cost and are intensive in information. When it comes to the heterogeneity analysis, column (7) indicates that the beneficial effect on digital connectedness on exports of differentiated goods is statistically significant at 1% level and in magnitude larger in sub-Saharan Africa than anywhere else—no significant effect is found in MENA countries. Column (8) shows that, organized exchanges are not left out, a positive effect of the digital connectedness being recorded in SSA and the two Asian regions.

Table 8: 2SLS fixed-effect estimates – Digital connectedness and Rauch's exports

Period: 2005-2017 Dep. Var:	(1) Diff exp. pc	(2) OE exp. pc	(3) Ref Pr. exp. pc	(4) Diff exp. pc	(5) OE exp. pc	(6) Ref Pr. exp. pc	(7) Diff exp. pc	(8) OE exp. pc	(9) Ref Pr. exp. pc
(A) Connectedness (con)	0.256**	0.0272	0.0443	0.131*	0.0117	0.0160	-0.193**	-0.0231	-0.0296
	(0.112)	(0.0204)	(0.0368)	(0.0728)	(0.00802)	(0.0164)	(0.0941)	(0.0143)	(0.0357)
(B) SSA x con				0.235	0.0287	0.0526	0.584***	0.0570*	0.118
				(0.165)	(0.0237)	(0.0439)	(0.214)	(0.0317)	(0.0948)
(B) Lat Am x con							0.497**	0.0280	0.00920
							(0.252)	(0.0278)	(0.0486)
(C) MENA x con							0.0141	-0.00718	0.0115
							(0.145)	(0.0162)	(0.0336)
(D) South-East Asia x con							0.272**	0.0344**	0.0403
							(0.128)	(0.0158)	(0.0410)
(E) South Asia x con							0.416***	0.0283*	0.0639
							(0.138)	(0.0145)	(0.0618)
Ref Pr. exports per capita	0.824**		0.236**	0.792**		0.228**	0.694**		0.200**
	(0.333)		(0.107)	(0.332)		(0.0998)	(0.288)		(0.0860)
OE exports per capita	-0.322*	0.0583***		-0.336*	0.0565***		-0.350*	0.0524***	
	(0.179)	(0.00588)		(0.177)	(0.00490)		(0.193)	(0.00818)	
Diff exports per capita		0.0511***	-0.0886		0.0513***	-0.0877		0.0469***	-0.102
		(0.0110)	(0.110)		(0.00984)	(0.108)		(0.0103)	(0.123)
	First-stage statistics								
Cragg-Donald F-stat	58.447	57.215	57.357	195.632	195.335	195.205	19.759	19.699	19.501
LM-stat	10.524***	9.375***	9.595***	21.068***	20.915***	20.977***	14.628***	14.292***	13.758***
Controls, country & year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	773	773	773	773	773	773	773	773	773
R^2	0.816	0.318	0.252	0.847	0.349	0.276	0.857	0.363	0.286

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table.

Digital connectedness and value chain participation

To fully understand the mechanism at play in sub-Saharan Africa, we continue our empirical investigation focusing on global value chain participation. For this purpose, we use the UNCTAD-Eora global value chains data from Casella et al. (2019). Using the EORA Multi-Region Input-Output (MRIO) data set, and following Koopman et al. (2014)'s gross export decomposition, these authors compute various trade-value indicators including the foreign value-added content of exports (FVA) and the indirect value-added exports (DVX). The former measures the part of exports from a country incorporating-value added previously imported from abroad and is widely used as a proxy of the backward GVC participation. The latter captures forward GVC participation and is computed as the portion of gross exports produced in the country that enters as an intermediate input in the value-added exported by other countries including re-imported value-added.

In Table 9, column (1) and column (2) show that digital connectedness induces greater participation in global value chains and that the impact is much stronger in terms of magnitude on backward participation than on forward participation. Regarding the heterogeneity of the effect, column (5) suggests that digital connectivity increases backward participation in all regions except MENA countries. Moreover, the effect is much larger for sub-Saharan African countries, confirming the catch-up effect documented earlier in the sense that more intermediate goods are needed to produce complex goods. The same conclusion applies to a lesser extent when it comes to forward participation, except for MENA and South-East Asia countries where the effect is not significant.

Table 9: 2SLS fixed-effect estimates – Digital connectedness and value chain participation

Period: 2005–2017 **Dep. Var:**	**(1)** **FVA pc**	**(2)** **DVX pc**	**(3)** **FVA pc**	**(4)** **DVX pc**	**(5)** **FVA pc**	**(6)** **DVX pc**
(A) Connectedness (con)	0.202**	0.0398**	0.126*	0.0232*	-0.165*	-0.0237
	(0.0906)	(0.0174)	(0.0661)	(0.0128)	(0.0882)	(0.0198)
(B) SSA x con			0.127	0.0277	0.419**	0.0720*
			(0.102)	(0.0189)	(0.184)	(0.0375)
(C) Lat Am x con					0.344*	0.0641*
					(0.178)	(0.0334)
(D) MENA x con					0.0551	-0.00161
					(0.116)	(0.0256)
(E) South-East Asia x con					0.276**	0.0445
					(0.129)	(0.0276)
(F) South Asia x con					0.322**	0.0492*
					(0.131)	(0.0275)

continued next page

Table 9 Continued

Period: 2005–2017 Dep. Var:	(1) FVA pc	(2) DVX pc	(3) FVA pc	(4) DVX pc	(5) FVA pc	(6) DVX pc
First-stage estimates						
Cragg-Donald F-stat	86.835	86.835	322.281	322.281	28.202	28.202
LM-stat	13.40***	13.40***	25.084***	25.084***	10.541***	10.541***
Controls, country FE, year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	855	855	855	855	855	855
R^2	0.795	0.819	0.826	0.850	0.838	0.865

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table.

Alternative export upgrading variables

This section focuses on the sensitivity of results to alternative measure of export basket sophistication. The results in Table E1 (in the appendix) are based on ECI+, an augmented version of ECI that considers the difficulty of exporting each product. ECI+ is deemed equivalent to the fitness index proposed by Tacchella et al. (2012) and outperforms ECI when used to predict future economic growth (Albeaik et al., 2017). Estimates of column (1) to column (4) show that the use of an alternative measure does not change our results. In Table E2 (in the appendix), we introduce EXPY as an alternative indicator of sophistication. As defined by Hausmann et al. (2007), EXPY indicates the level of productivity associated with a country's pattern of specialization. Compared to the ECI index, EXPY has two limitations (Valette, 2018). First, it includes GDP per capita and is de facto correlated with it. Second, it does not take into account the proximity between products.

Despite these limitations, the estimates leave our conclusions about the positive role of digital connectedness in export sophistication and the negative role of maritime distance unchanged. However, the sub-Saharan Africa exception does not hold anymore, in the usual significance levels.

5. Conclusion

This paper focuses on the impacts of the recent and rapid deployment of SMCs along African coasts on African trade patterns, and makes three contributions to the empirical literature. First, we highlight a new dimension of the SMC infrastructure deployment, termed ‘digital connectedness', reflecting a country's digital proximity to world markets. Second, we assess its impact on export sophistication using the economic complexity index (Hidalgo, 2021). Third, we address possible reverse causality between the shape of the SMC network and countries' integration in world markets, using the number of (indirect) second-order SMC connections as instrument.

From a sample of 60 developing countries, which includes 23 sub-Saharan African countries, and covers the period 1995–2017, our results show that, while digital connectivity significantly increases the complexity of the export basket in all countries, there is geographic and temporal heterogeneity within our sample. Indeed, the effect of digital connectivity on export complexity is particularly strong over the period 2006–2015, and indicates a catching up of sub-Saharan African countries. Compared to the rest of the world, a 10pp increase in the share of world GDP reached by SSA countries' direct SMC connections leads to an additional increase ranging from 4.6 index points (FE estimates) to 5.3 index points (IV estimates). The overall increase in SSA's export complexity resulting from a 10pp increase in its connectedness equals 8.5pp, corresponding to 47% of the ECI sample standard deviation. We also found that the positive effect of connectedness decays with both the geographical and sea distance to world markets; except for SSA where these two types of distances actually increase the benefits of digital connectedness. For example, a 3,000km increase in sea-distance (approximatively one standard deviation) reduces by 47% the positive effect of connectedness on export complexity in non-SSA countries, but increases by 75% the positive effect of connectedness on export complexity in SSA. All these major results hold when using ECI+ as alternative indicator of complexity and thus convey additional evidence to existing studies on the role of geographical distance in international trade (Blum & Goldfarb, 2006).

Focusing on the additional channels through which digital connectivity operates, we document a mediating effect of Internet penetration and human capital, not specific to SSA countries. This result is consistent with those emphasizing the prerequisite role played by digital absorptive capacity in the digitalization process

(Choi et al., 2020). Finally, in exploring how digital connectedness materializes in exports upgrading, we found that digital connectedness increases exports of differentiated goods—that is, goods for which the search cost are higher—as well as fosters backward and forward participation in global value chains. A much stronger impact is seen in backward participation, and the sub-Saharan Africa remains the region with the largest effect.

Notes

1. Tacit knowledge is not codifiable and hard to communicate, while multifarious knowledge is knowledge specific to an economic activity or task (Hidalgo, 2021).

2. See, for example, Ouassi-Olsson, L. “Investing in the exceptional African creativity”, Entreprenante Afrique, 4 October 2021. https://www.entreprenanteafrique.com/en/investing-in-the-exceptional-african-creativity/

3. In this line of research, Regolo (2013) shows that similarly-endowed trade partners tend to exhibit a more diversified trade structure than differently-endowed ones, which is explained by greater competition stemming from identical trade costs. We guess that this mechanism could be extended to information costs.

4. A scenario that is highly plausible since a new connection to China would represent a 15pp increase in this share. This actually happened in 2017 to Djibouti when the Asia Africa Europe-1 (AAE-1) cable was deployed to connect France, Italy, to the Middle East, Central Asia, India, South-East Asia and China.

5. See Goldfarb and Tucker (2019) for a review of researches on the distance–trade nexus in a digitalization context.

6. According to Hidalgo (2009: 2), the main takeaway of this research field can be summed up as follow: “what a country produces matters more than how much value it extracts from its products”.

7. Developing new concept and measures such as Economic Complexity, Product Complexity, Product Relatedness, and Country Fitness (Hidalgo, 2021; Tacchella et al., 2012).

8. In 2014, “A single intercontinental submarine fibre can potentially carry more data, with less delay than could be achieved by combining all the world's active geostationary communications satellites together.” (OECD, 2014: 20).

9. As an illustration of the large costs related to this infrastructure deployment, the WACS connecting South Africa and the West African coast to Europe since 2012 cost US$600 million, while the AAE-1 connecting Asia, Africa and Europe since 2017 cost US$800 million. For more information, see: https://subtelforum.com/submarine-cable-map/

or https://www.submarinenetworks.com/en/insights/a-new-coming-for-submarine-cable-systems-the-independent-infrastructure-developers

10. The concern for a possible influence of policy on SMC network density is further lowered controlling for internet penetration rates, which is the combined outcome of telecommunications policies and a country's digital absorptive capacity. Moreover, estimations additionally controlling for a critical component of the terrestrial infrastructure, i.e., the country number of Internet Exchange Points, remain strictly unchanged. Results can be provided upon request.

11. The period 2006–2015 also corresponds to the episodes of sharp increases in SSA's economic complexity highlighted in Figure 2. The SSA's average ECI score is 27.13, an increase of 11.46% over the average score over the entire 1995–2017period.

12. First-stage F-stat, Cragg-Donad F-stat, LM-weak test, and in Appendix C, Hansen tests.

13. When Latin-America is taken as reference group, interaction terms are positive and significant, except for South Asia, with SSA displaying the strongest marginal effect. Estimates can be provided upon request.

14. We obtain a 23% correlation between these two distance variables in our baseline sample (Table A2 in the appendix).

15. To avoid sample attrition, we filled-in missing values through linear interpolation and extrapolation. It seemed reasonable to us using these technics since we expect these variables to change slowly over time. Estimates using the original primary enrolment rate variable (best documented) shows little difference with those using the inter-extrapolated one.

16. Estimates based on the liberal classification are available in Appendix D.

17. See https://www.un.org/development/desa/dpad/least-developed-country-category/evi-indicators.html and also CDP Secretariat. Note on measuring remoteness for the identification of LDCs. August 2015.

References

Aker, J.C. and I.M. Mbiti. 2010. “Mobile phones and economic development in Africa”. *Journal of Economic Perspectives*, 24(3): 207–32.

Akerman, A., I. Gaarder and M. Mogstad. 2015. “The skill complementarity of broadband Internet”. *The Quarterly Journal of Economics*, 130(4): 1781–1824.

Akerman, A., E. Leuven and M. Mogstad. 2022. “Information frictions, internet, and the relationship between distance and trade”. *American Economic Journal: Applied Economics*, 14(1): 133–63.

Allen, T. 2014. “Information frictions in trade”. *Econometrica*, 82(6): 2041–83.

Albeaik, S., M. Kaltenberg, M. Alsaleh and C.A. Hidalgo. 2017. “Measuring the knowledge intensity of economies with an improved measure of economic complexity”. arXiv preprint arXiv:1707.05826.

Bahar, D. and M.A. Santos. 2018. “One more resource curse: Dutch disease and export concentration”. *Journal of Development Economics*, 132: 102–114.

Bahar, D., R. Hausmann and C.A. Hidalgo. 2014. “Neighbors and the evolution of the comparative advantage of nations: Evidence of international knowledge diffusion?” *Journal of International Economics*, 92(1): 111–23.

Balié, J., D. Del Prete, E. Magrini, P. Montalbano and S. Nenci. 2019. “Does trade policy impact food and agriculture global value chain participation of sub-Saharan African countries?” *American Journal of Agricultural Economics*, 101(3): 773–89.

Bertoli, S., M. Goujon and O. Santoni. 2016. The CERDI Sea-Distance Database. CERDI Etudes & Documents #7.

Blum, B.S. and A. Goldfarb. 2006. “Does the internet defy the law of gravity?” *Journal of International Economics,* 70(2): 384–405.

Brun, J.F., C. Carrère, P. Guillaumont and J. de Melo. 2005. “Has distance died? Evidence from a panel gravity model”. *The World Bank Economic Review*, 19(1): 99–120.

Bustos, P. 2011. “Trade liberalization, exports, and technology upgrading: Evidence on the impact of MERCOSUR on Argentinian firms”. *American Economic Review,* 101(1): 304–40.

Cariolle, J. 2021. “International connectivity and the digital divide in sub-Saharan Africa”. *Information Economics and Policy*, 55: 100901.

Cariolle J. and M. Le Goff. 2021. “Spatial internet spillovers in manufacturing”. FERDI Document de Travail P288, April.

Cariolle, J., M. Goujon and P. Guillaumont. 2016. “Has structural economic vulnerability decreased in Least Developed Countries? Lessons drawn from retrospective indices”. *The*

Journal of Development Studies, 52(5): 591–606.

Carrere, C., J. de Melo and J. Wilson. 2013. "The distance puzzle and low-income countries: An update". *Journal of Economic Surveys*, 27(4): 717–42.

Casella, B., R. Bolwijn, D. Moran and K. Kanemoto. 2019. "Improving the analysis of global value chains: The UNCTAD-Eora database". *Transnational Corporations*, 26(3): 115–42.

Cairncross, F. 1997. "The death of distance: How the communications revolution will change our lives. No. C20-21. Harvard Business School.

Chaney, T. 2014. "The network structure of international trade". *American Economic Review,* 104(11): 3600–3634.

Clarke, G. R., and S. J. Wallsten .2006. "Has the internet increased trade? Developed and developing country evidence". *Economic Inquiry*, 44(3), 465–484.

Choi, J., M.A. Dutz and Z. Usman. (eds.). 2020. *The Future of Work in Africa: Harnessing the Potential of Digital Technologies for All.* Washington, D.C.: The World Bank Publications.

Cristelli, M., A. Tacchella and M. Cader. 2018. "The virtuous interplay of infrastructure development and the complexity of nations". *Entropy*, 20(10): 761. DOI:10.3390/e20100761

Czernich, N., O. Falck, T. Kretschner and L. Woessmann. 2011. "Broadband infrastructure and economic growth". *Economic Journal,* 121: 505–532.

Dasgupta, K. and J. Mondria. 2018. "Inattentive importers". *Journal of International Economics*, 112: 150–65.

de Melo, J., & Solleder, J-M. (2022). Structural transformation in MENA and SSA: the role of digitalization.

de Melo, J. and A. Twum. 2021. "Prospects and challenges for supply chain trade under the Africa Continental Free Trade Area". Journal of African Trade, 8(2). DOI:10.2991/jat.k.210105.001

Dennis, A. and B. Shepherd. 2011. "Trade facilitation and export diversification". *The World Economy*, 34(1): 101–122.

Disdier, A.C. and K. Head. 2008. "The puzzling persistence of the distance effect on bilateral trade". *The Review of Economics and statistics*, 90(1): 37–48.

Eichengreen, B., R. Lafarguette and A. Mehl. 2016. "Cables, sharks and servers: Technology and the geography of the foreign exchange market". NBER Working Paper No. 21884. National Bureau of Economic Research, Cambridge, MA, January.

Falvey, R.E. 1976. "Transport costs in the pure theory of international trade". *The Economic Journal*, 86(343): 536–50.

Frankel, J.A. 2012. "The natural resource curse: A survey of diagnoses and some prescriptions". *Commodity Price Volatility and Inclusive Growth in Low-income Countries,* 7–34.

Freund, C. and D. Weinhold. 2004. "The effect of the Internet on international trade". *Journal of International Economics*, 62(1): 171–89.

Freund, C. and M.D. Pierola. 2012. "Export surges". *Journal of Development Economics*, 97(2): 387–95.

Goldfarb, A. and C. Tucker. 2019. "Digital economics". *Journal of Economic Literature*, 57(1): 3–43.

Hartmann, D., M. R. Guevara., C. Jara-Figueroa., M. Aristarán., and C. A. Hidalgo. 2017. "Linking economic complexity, institutions, and income inequality". *World development*, 93, 75–93.

Hadenius, A. and J. Teorell. 2005. "Cultural and economic prerequisites of democracy: Reassessing recent evidence". *Studies in comparative international development,* 39(4):

87–106.

Hausmann, R. 2016. "Economic development and the accumulation of know-how". *Welsh Economic Review*, 24: 13–16.

Hausmann, R., J. Hwang and D. Rodrik. 2007. "What you export matters". *Journal of Economic Growth,* 12(1): 1–25.

Hidalgo, C. A.2009. "The dynamics of economic complexity and the product space over a 42-year period". *CID Working Paper Series.*

Hummels, D. 2007. "Transportation costs and international trade in the second era of globalization". *Journal of Economic Perspectives*, 21(3): 131–54.

Hummels, D. and P.J. Klenow. 2005. "The variety and quality of a nation's exports". *American Economic Review*, 95(3): 704–723.

Hidalgo, C.A. 2021. "Economic complexity theory and applications". *Nature Reviews Physics,* 3(2): 92–113.

Hidalgo, C.A., P.A. Balland, R. Boschma, M. Delgado, M. Feldman, K Frenken, K. Frenken, E. Glaeser, C. He, D.F. Kogler, A. Morrison, F. Neffke and D. Rigby. 2018. "The principle of relatedness". In International Conference on Complex Systems, pp. 451–57. Springer, Cham.

Hidalgo, C.A. and R. Hausmann. 2009. "The building blocks of economic complexity". *Proceedings of the National Academy of Sciences*, 106(26): 10570–10575.

Hidalgo, C.A., B. Klinger, A.-L. Barabasi and R. Hausmann. 2007. "The product space conditions the development of nations". *Science*, 317(5837): 482–87.

Hjort, J. and J. Poulsen. 2019. "The arrival of fast internet and employment in Africa". *American Economic Review,* 109(3): 1032–79.

Iacovone, L. and B. Javorcik. 2008. "Shipping good tequila out: Investment, domestic unit values and entry of multi-product plants into export markets". Unpublished Manuscript.

Imbruno M., J. Cariolle and J. de Melo. 2022. *Digital Connectivity and Firm Participation in Foreign Markets: An Exporter-Based Bilateral Analysis.* CEPR Discussion Paper No. DP17318. Centre for Economic Policy Research, May.

Imbs, J. 2004. "Trade, finance, specialization, and synchronization". *Review of economics and Statistics,* 86(3): 723–34.

Jacolin, L., J. Keneck Massil and A. Noah. 2021. "Informal sector and mobile financial services in emerging and developing countries: Does financial innovation matter?" *The World Economy*, 44(9): 2703–2737. https://doi.org/10.1111/twec.13093

Keller, W. 2010. "International trade, foreign direct investment, and technology spillovers". In *Handbook of the Economics of Innovation,* Vol. 2, pp. 793–829). Amsterdam: Elsevier (North-Holland Publishing Co.).

Jun, B., A. Alshamsi, J. Gao and C.A. Hidalgo. 2020. "Bilateral relatedness: Knowledge diffusion and the evolution of bilateral trade". *Journal of Evolutionary Economics*, (30): 247–77.

Koopman, R., Z. Wang and S.J. Wei. 2014. "Tracing value-added and double counting in gross exports". *American Economic Review*, 104(2): 459–94.

Krautheim, S. 2012. "Heterogeneous firms, exporter networks and the effect of distance on international trade". *Journal of International Economics*, 87(1): 27–35.

Lapatinas, A. 2019. "The effect of the Internet on economic sophistication: An empirical analysis". *Economics Letters*, 174: 35–38.

Lendle, A., and P.L. Vézina. 2015. “Internet Technology and the Extensive Margin of Trade: Evidence from eBay in Emerging Economies”. *Review of Development Economics*, 19(2), 375–386.

Lendle, A., M. Olarreaga, S. Schropp and P.L. Vézina. 2016. “There goes gravity: eBay and the death of distance”. *The Economic Journal*, 126(591): 406–41.

Lim, S. 2021. “Global agricultural value chains and structural transformation”. NBER Working Paper No. 29194. National Bureau of Economic Research, Cambridge, MA, August.

Makhlouf, Y., N.M. Kellard and D. Vinogradov. 2015. “Trade openness, export diversification, and political regimes”. *Economics Letters*, 136: 25–27.

Morales, E., G. Sheu and A. Zahler. 2019. “Extended gravity”. *The Review of Economic Studies*, 86(6): 2668–2712

Organization for Economic Co-operation and Development (OECD). 2014. “International cables, gateways, backhaul and international exchange points”. OECD Digital Economy Paper No. 232. OECD Publishing, Paris, February. http://dx.doi.org/10.1787/5jz8m9jf3wkl-en

Parteka, A. and M. Tamberi. 2008. “Determinants of export diversification: An empirical investigation”. *Universita Politecnica delle Marche, Dipartimento di Economia Quaderno di Ricerca,* No. 327. DOI:10.2139/ssrn.1345728

Paunov, C. and V. Rollo. 2015. “Overcoming obstacles: The Internet's contributions to firm development”. *World Bank Economic Review*, 29(Suppl.1): S192–S204.

Paunov, C. and V. Rollo. 2016. “Has the Internet fostered inclusive innovation in the developing world?” *World Development*, 78: 587–609.

Rauch, J.E. 1999. “Networks versus markets in international trade”. *Journal of international Economics*, 48(1): 7–35.

Rauch, J.E. and V. Trindade. 2003. “Information, international substitutability, and globalization”. *American Economic Review*, 93(3): 775–91.

Regolo, J. 2013. “Export diversification: How much does the choice of the trading partner matter?” *Journal of International Economics*, 91(2): 329–42.

Rodrik, D. 2016. “Premature deindustrialization”. *Journal of Economic Growth*, 21(1): 1–33.

Röller, L.-H. and L. Waverman. 2001. “Telecommunications infrastructure and economic development: A simultaneous approach”. *American Economic Review*, 91(4): 909–23.

Ross, M.L. 2004. “How do natural resources influence civil war? Evidence from thirteen cases”. *International Organization*, 58(1): 35–67.

Ross, M.L. 2015. “What have we learned about the resource curse?” *Annual Review of Political Science*, 18: 239–59.

Ross, M.L. 2017. “What do we know about economic diversification in oil-producing countries?” EEG State-of-Knowledge Paper Series No. 5.2. Oxford Policy Management Center for Effective Global Action, December.

Rostow, W.W. 1990. *The Stages of Economic Growth: A Non-Communist Manifesto.* Cambridge, MA: Cambridge University Press.

Saadi, M. 2020. “Remittance inflows and export complexity: New evidence from developing and emerging countries”. *The Journal of Development Studies,* 56(12): 2266–92.

Starosta de Waldemar, F. 2010. “How costly is rent-seeking to diversification: An empirical approach”. In Proceedings of the German Development Economics Conference, Hannover

2010 (No. 4).

Tacchella, A., M. Cristelli, G. Caldarelli, A. Gabrielli and L. Pietronero. 2012. “A new metrics for countries' fitness and products' complexity”. *Scientific Reports*, 2(1): 1–7.

Tang, H. and Y. Zhang. 2012. “Exchange rates and the margins of trade: Evidence from Chinese exporters”. *CESifo Economic Studies*, 58(4): 671–702.

Valette, J. 2018. “Do migrants transfer productive knowledge back to their origin countries?” *The Journal of Development Studies*, 54(9): 1637–56.

van der Ploeg, F. 2011. “Natural resources: Curse or blessing?” *Journal of Economic literature*, 49(2): 366–420.

Venables, A.J. 2016. “Using natural resources for development: Why has it proven so difficult?” *Journal of Economic Perspectives*, 30(1): 161–84.

Weller, D. and B. Woodcock. 2013. “Internet traffic exchange: Market developments and policy challenges”. OECD Digital Economy Paper No. 207. OECD Publishing, Paris, January. https://doi.org/10.1787/5k918gpt130q-en

World Bank Group. 2018. *Innovative Business Models for Expanding Fiber-Optic Networks and Closing the Access Gaps*. Washington, D.C.: The World Bank.

Appendixes

Appendix A: Additional tables

Table A1: Sample composition

Country	Region	Obs	Country	Region	Obs
AGO	Sub-Saharan Africa	15	KAZ	Eastern Europe and post-Soviet Union	23
CIV	Sub-Saharan Africa	23	BOL	Latin America	23
CMR	Sub-Saharan Africa	22	BRA	Latin America	23
COD	Sub-Saharan Africa	13	CHL	Latin America	23
COG	Sub-Saharan Africa	11	COL	Latin America	23
GAB	Sub-Saharan Africa	16	CRI	Latin America	23
GHA	Sub-Saharan Africa	23	DOM	Latin America	23
GIN	Sub-Saharan Africa	18	ECU	Latin America	23
KEN	Sub-Saharan Africa	23	GTM	Latin America	23
LBR	Sub-Saharan Africa	3	HND	Latin America	23
MDG	Sub-Saharan Africa	23	MEX	Latin America	23
MLI	Sub-Saharan Africa	3	PER	Latin America	23
MOZ	Sub-Saharan Africa	21	PRY	Latin America	23
MRT	Sub-Saharan Africa	13	SLV	Latin America	22
MUS	Sub-Saharan Africa	3	URY	Latin America	23
NGA	Sub-Saharan Africa	23	VEN	Latin America	19
SEN	Sub-Saharan Africa	22	DZA	North Africa & the Middle East	9
TGO	Sub-Saharan Africa	17	EGY	North Africa & the Middle East	22
TZA	Sub-Saharan Africa	23	IRN	North Africa & the Middle East	13
UGA	Sub-Saharan Africa	3	ISR	North Africa & the Middle East	23
ZAF	Sub-Saharan Africa	22	JOR	North Africa & the Middle East	18
ZMB	Sub-Saharan Africa	23	MAR	North Africa & the Middle East	23
ZWE	Sub-Saharan Africa	13	OMN	North Africa & the Middle East	23
CHN	East Asia	18	QAT	North Africa & the Middle East	18
KOR	East Asia	23	SAU	North Africa & the Middle East	23
IDN	South-East Asia	23	TUN	North Africa & the Middle East	22

continued next page

Table A1 Continued

Country	Region	Obs	Country	Region	Obs
KHM	South-East Asia	20	TUR	North Africa & the Middle East	8
PHL	South-East Asia	23		**Total**	**1150**
SGP	South-East Asia	23			
THA	South-East Asia	18			
BGD	South-East Asia	21			
IND	South-East Asia	23			
LKA	South-East Asia	17			

TableA2: Correlation table

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(1) ECI	1.000																							
(2) Connectedness	0.520	1.000																						
(3) 2nd order	0.305	0.675	1.000																					
(4) log (GDP p.c.)	0.629	0.365	0.309	1.000																				
(5) Trade (% of GDP)	0.287	0.186	0.110	0.279	1.000																			
(6) Internet users	0.483	0.449	0.551	0.618	0.216	1.000																		
(7) Remoteness	-0.081	-0.281	-0.338	-0.132	-0.039	-0.153	1.000																	
(8) Sea distance	-0.316	-0.308	-0.066	-0.098	-0.174	-0.155	0.234	1.000																
(9) Shipping connectivity index	0.599	0.724	0.501	0.433	0.247	0.509	-0.198	-0.179	1.000															
(10) Natural rents	-0.298	-0.090	-0.034	0.171	0.029	-0.058	-0.130	0.367	-0.171	1.000														
(11) Electricity (access)	0.605	0.497	0.365	0.814	0.123	0.507	-0.205	-0.350	0.438	-0.065	1.000													
(12) log (Population)	0.139	0.376	0.269	-0.220	-0.370	-0.040	-0.110	-0.019	0.431	-0.208	-0.009	1.000												
(13) FDI inflows	0.089	-0.001	0.067	0.064	0.542	0.103	0.093	-0.001	0.051	0.049	-0.047	-0.223	1.000											
(14) log (REER)	-0.091	-0.026	0.010	-0.042	-0.061	0.036	0.108	0.002	-0.008	-0.026	-0.034	0.028	-0.046	1.000										
(15) Internet penetration	0.483	0.449	0.551	0.618	0.216	1.000	-0.153	-0.155	0.509	-0.058	0.507	-0.040	0.103	0.036	1.000									
(16) 1ary enrollment rate	0.083	0.319	0.582	0.095	0.076	0.478	-0.105	-0.016	0.068	0.143	0.116	0.064	0.145	0.056	0.478	1.000								
(17) 2ary enrollment rate	0.043	0.255	0.614	0.125	0.033	0.645	-0.113	-0.005	0.176	0.037	0.153	0.073	0.115	0.124	0.645	0.775	1.000							
(18) 3ary enrollment rate	0.045	0.273	0.623	0.123	0.040	0.646	-0.114	-0.002	0.175	0.053	0.151	0.073	0.131	0.126	0.646	0.805	0.975	1.000						
(19) Oil rents (%GDP)	-0.154	0.041	0.046	0.368	0.047	0.017	-0.212	0.211	-0.063	0.914	0.172	-0.185	-0.033	-0.031	0.017	0.086	-0.008	0.005	1.000					
(20) FVA pc	0.402	0.276	0.197	0.348	0.788	0.344	-0.005	-0.162	0.446	-0.116	0.159	-0.143	0.440	0.004	0.344	0.056	0.065	0.065	-0.066	1.000				
(21) DVX pc	0.449	0.282	0.277	0.610	0.637	0.555	-0.142	-0.078	0.390	0.142	0.311	-0.251	0.305	-0.010	0.555	0.159	0.163	0.167	0.201	0.802	1.000			
(22) Diff exp. Pc	0.425	0.270	0.206	0.411	0.793	0.394	-0.040	-0.150	0.429	-0.061	0.187	-0.168	0.424	-0.006	0.394	0.078	0.080	0.081	-0.013	0.935	0.834	1.000		
(23) OE exp. Pc	0.117	0.080	0.102	0.561	0.194	0.334	-0.152	0.194	0.019	0.644	0.272	-0.338	0.068	-0.012	0.334	0.151	0.106	0.115	0.672	0.148	0.607	0.244	1.000	
(24) Ref Pr.exp.pc	0.296	0.152	0.172	0.456	0.553	0.405	-0.086	-0.031	0.218	0.138	0.189	-0.250	0.273	-0.007	0.405	0.096	0.098	0.099	0.159	0.649	0.872	0.664	0.561	1.000

Table A3: Dependent and control variables, expected sign, and associated literature

Variable	Definition	Source
ECI	Economic Complexity Index.	Observatory of Economic Complexity (OEC, MIT).
ECI+	Augmented Economic complexity Index taking into account the difficulty of exporting each product.	
Connectedness	Cumulative share of the world GDP reached by direct—that is, first-order—cable connections.	Author's computation using SMC network worldwide.
Trade (% of GDP)	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.	WDI
Internet users (% of pop)	Internet users are individuals who have used the Internet (from any location) in the last three months. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV, etc.	WDI
Remoteness	Remoteness from world markets, adjusted for landlocked-ness is the trade weighted average distance from world markets.	UN-CDP and FERDI's retrospective EVI series.
Sea distance	Average sea distance of country to its 10 main imports and exports trade partners	Author's computation using CERDI-Sea Distance Database (Bertoli et al., 2016).
Shipping connect index	Liner Shipping Connectivity Index score indicates how well countries are connected to global shipping networks based on the status of their maritime transport sector.	UNCTAD
Natural rents	Total natural resources rents (% of GDP) are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents.	WDI
Polity 2	Polity2 is a revised and combined version of the POLITY score indicator, which captures the spectrum of political regime authority on a scale of -10 (hereditary monarchy) to 10 (consolidated democracy).	QOG
Electricity access (% of pop)	Access to electricity is the percentage of population with access to electricity.	WDI
FDI inflows (% of GDP)	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10% or more of voting stock) in an enterprise operating in an economy other than that of the investor.	WDI

continued next page

Table A3 Continued

Variable	Definition	Source
REER	The Real Effective Exchange Rate is calculated as the weighted geometric average of the nominal exchange rate indices vis-a-vis the ten main partners, total imports and exports excluding oil of the country under consideration adjusted for relative prices.	FERDI's Sustainable Competitiveness Observatory (SCO) data.
FVA pc	Foreign Value-Added per capita used as indicator of backward participation in GVCs.	UNCTAD-Eora global value chain data from Casella et al. (2019).
DVX pc	Indirect ValueAdded per capita widely used as indicator of forward participation in GVCs.	
Diff exp pc	Per capita exports of differentiated goods	Author''s computation using UN COMTRADE Database and following Rauch (1999)'s classification.
OE exp pc	Per capita exports of Organized Exchange goods.	
RefPr exp Pc	Per capita exports of reference price goods.	

Remoteness from world markets. Transportation costs and geographic distance have a crucial impact on international trade (Falvey, 1976; Hummels, 2007). Several empirical studies of bilateral trade have emphasized the negative relationship between distance and trade flows (Brun et al., 2005; Disdier & Head, 2008; Krautheim, 2012; Carrere et al., 2013)—and diversification is not an exception. Dennis and Shepherd (2011) found that a reduction in export or international transport costs is associated with a gain in export diversification. In line with results from Parteka and Tamberi (2008) that positing remoteness form major markets as a robust determinant of export diversification, we resort to Remoteness Index for our empirical investigation. This index, sub-component of the United Nations' Economic Vulnerability Index (EVI) (Cariolle et al., 2016), is the normalized minimum average distance to 33% of the world markets.[17] We expect export complexity to decrease with greater remoteness from world markets, but to account to eventual threshold effect in this variable, we also control for its squared value.

Country size and development level. Country size and development level, in particular through human capital development, are favourable to the enhancement of the size of export basket and the countries' diversification possibilities (Hummels & Klenow, 2005; Parteka & Tamberi, 2008; Starosta de Waldemar, 2010). To capture the role played by a large domestic market in increasing product variety and quality, we control for the logarithm of the population. We also use the logarithm of GDP per capita as a global proxy of the level of development. We expect these factors to exert a positive effect on export complexity.

Natural rents. While natural resource abundance was once considered a source of development Rostow (1990), a vast literature on "resource curse" has highlighted the negative impact of natural resources on economic growth (Frankel, 2012; van der Ploeg, 2011; Ross, 2015; Venables, 2016). An abundance of natural rents and a low level of economic diversification characterize resource-rich countries. Indeed, natural resources dominate export earnings and government revenues (Ross, 2017; Bahar & Santos, 2018). This results in a low level of economic diversification, making them vulnerable to economic shocks and conflicts (Ross, 2004; Venables, 2016). To account for the role of natural resources on the economic complexity, we include an indicator of total natural resources rents expressed as a share of GDP, provided by the WDI (and also rely on a decomposition of this indicator into oil, gas, mineral, and forest rents). We expect a negative sign for this variable.

FDI inflows. Export complexity is more likely to be affected by FDI. By facilitating the transfer of knowledge, technology and managerial skills, FDI may promote the production and the export of more complex goods and services (Hausmann, 2016). We draw upon FDI inflows retrieved from World Development Indicators. We expect this variable to have a positive impact on export complexity.

Trade openness is often associated with greater specialization (Imbs, 2004), diversification (Dennis & Shepherd, 2011; Makhlouf et al., 2015), or greater complexity in export structure (Keller, 2010). We use trade as a percentage of GDP, derived from the World Bank's WDI, as a measure of openness. Since the literature show that countries that are more open benefit most from technology diffusion, we expect a positive effect of openness on complexity.

Institutional quality. Institutions are important for the sophistication and complexity of the economy (Makhlouf et al., 2015; Saadi, 2020). To capture this impact, we use the Freedom House imputed polity 2 index provided by the Quality of Government Institute (QOG) and deemed to perform better in terms of validity and reliability (Hadenius & Teorell, 2005). The index ranges from 0 to 10, 0 characterizing a less democratic country and 10 for the most democratic. We expect that an increase in the Polity 2 index will improve the complexity of the export.

Internet and energy access are central for exports sophistication (Cristelli et al., 2018). We control for internet users (Lapatinas, 2019) and access to electricity. Both data are derived from the World Bank's WDI database and are expected to influence positively exports complexity.

Real Effective Exchange Rate. The exchange rate is at the heart of the diversification strategy in developing countries. Studying export surges in developing countries, Freund and Pierola (2012) show that export accelerations are preceded by episode of large real devaluations and a reduction in exchange rate volatility. Thus, exchange rate depreciation increases entry into new products and markets and these new flows account for 25% of growth during surges. In the same vein, Iacovone and Javorcik (2008) find that devaluations precede export "breakthroughs" in Mexican firms, while Tang and Zhang (2012) highlight the negative impact of exchange rate appreciation on firms' extensive margin. To account for the role of REER on complexity, we draw upon FERDI's Sustainable Competitiveness Observatory (SCO) data. The REER index is calculated as the weighted geometric average of the nominal exchange rate indices vis-a-vis the 10 main partners, total imports, and exports excluding oil of the country under consideration adjusted for relative prices. The weights are calculated according to the relative share of the partners over the period 2009–2013. A change below 100 reflects a real depreciation, and thus a tendency to undervaluation. In line with Freund and Pierola (2012) findings, we expect the REER to affect negatively the complexity of the export basket.

Appendix B: Inoue and Solon (2006) LM-test on residuals

Lags	IS-stat	p-value	N	Max T
K=1	44.16	0.003	60	23
K=2	52.76	0.146	60	23

Notes: H0: No auto-correlation of any order. Ha: Auto-correlation up to order k.
Source: Inoue, A. and G. Solon. 2006. "A portmanteau test for serially correlated errors in fixed effects models". Econometric Theory, 22(5): 835–51.

Appendix C: Multi-instruments set-up

Period: 2005–2017. Var dep: ECI	(1)	(2)	(3)	(4)
(A) Connectedness (con)	0.304***	0.202*	0.300**	1.549***
	(0.114)	(0.115)	(0.132)	(0.308)
(B) SSA x con		0.416*	0.290	0.000347***
		(0.222)	(0.287)	(0.000111)
(C) Lat Am x con			-0.438*	
			(0.253)	
(D) MENA x con			-0.00930	
			(0.211)	
(E) South-East Asia x con			0.0524	
			(0.152)	
(F) South Asia x con			-0.340**	
			(0.167)	
(G) Con x sea distance				-0.000230***
				(0.0000548)
(H) Con x SSA x sea dist.				0.000347***
				(0.000111)

continued next page

Appendix C Continued

Period: 2005–2017. Var dep: ECI	(1)	(2)	(3)	(4)
Additional controls				
Sea distance				0.00213***
				(0.000819)
Sea distance x SSA				-0.00166**
				(0.000828)
	First-stage statistics			
F-test (A)	67.56***	110.57***	105.43****	43.44***
F-test (B)		103.17***	93.45***	42.46***
F-test (C)			2.67**	
F-test (D)			2.51**	
F-test (E)			183.22***	
F-test (F)			240.83***	
F-test (G)				93.36***
F-test (H)				85.14***
Cragg-Donald F-stat	74.249	312.249	18.974	79.47
LM-stat	11.385***	24.673***	8.115***	11.65***
Hansen test p-val	0.69	0.12	0.20	0.35
Controls, country & year FEs	Yes	Yes	Yes	Yes
N	633	633	633	633
R^2	0.643	0.660	0.698	0.690

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table. The baseline instrument set (column 1) is: the number of first-order cable connections, the number of second-order cable connections, and the product of the two instruments. Instrument set in column (2) to column(4): conditional variables are interacted with the number of second-order cable connections and added to the number of first-order cable connections and the product of the two instruments in the set of instruments.

Appendix D: Rauch's exports – Liberal classification

2SLS fixed-effect estimates – Digital connectedness and Rauch's exports									
Period: 2005-2017 **Dep. Var:**	**(1)** **Diff exp. pc**	**(2)** **OE exp. pc**	**(3)** **Ref Pr. exp. pc**	**(4)** **Diff exp. pc**	**(5)** **OE exp. pc**	**(6)** **Ref Pr. exp. pc**	**(7)** **Diff exp. pc**	**(8)** **OE exp. pc**	**(9)** **Ref Pr. exp. pc**
(A) Connectedness (con)	0.143**	0.0303	0.114*	0.0684	0.0129	0.0591	-0.122*	-0.0233	-0.0785
	(0.0707)	(0.0211)	(0.0625)	(0.0462)	(0.00854)	(0.0402)	(0.0722)	(0.0148)	(0.0483)
(B) SSA x con				0.138	0.0321	0.104	0.352**	0.0609*	0.267**
				(0.114)	(0.0241)	(0.0656)	(0.152)	(0.0323)	(0.133)
(B) Lat Am x con							0.336*	0.0308	0.129
							(0.172)	(0.0295)	(0.0885)
(C) MENA x con							-0.0304	-0.00788	0.0545
							(0.0988)	(0.0165)	(0.0729)
(D) South-East Asia x con							0.146*	0.0361**	0.133*
							(0.0847)	(0.0168)	(0.0768)
(E) South Asia x con							0.267***	0.0289*	0.164*
							(0.104)	(0.0153)	(0.0844)
Ref Pr. exp. per capita	-0.00288	0.0611***		0.00717	0.0631***		-0.0472	0.0569***	
	(0.357)	(0.00860)		(0.365)	(0.00639)		(0.349)	(0.00775)	
OE exp. per capita	0.608***		0.388***	0.582***		0.373***	0.546***		0.328***
	(0.212)		(0.122)	(0.208)		(0.118)	(0.200)		(0.108)
Diff exp. per capita		0.0562***	0.0155		0.0548***	0.0124		0.0518***	-0.0150
		(0.0127)	(0.201)		(0.0117)	(0.197)		(0.0117)	(0.210)

continued next page

Appendix D Continued

	2SLS fixed-effect estimates – Digital connectedness and Rauch's exports								
Period: 2005-2017 **Dep. Var:**	**(1)** **Diff exp. pc**	**(2)** **OE exp. pc**	**(3)** **Ref Pr. exp. pc**	**(4)** **Diff exp. pc**	**(5)** **OE exp. pc**	**(6)** **Ref Pr. exp. pc**	**(7)** **Diff exp. pc**	**(8)** **OE exp. pc**	**(9)** **Ref Pr. exp. pc**
	First-stage estimates								
F-stat (A)	10.39***	10.12***	11.03***	55.07***	51.06***	53.44***	52.52***	58.40***	58.33***
F-stat (B)				20.86***	21.04***	20.88***	26.54***	28.50***	28.77***
F-stat (C)							2.78**	2.64**	2.79**
F-stat (D)							2.55**	2.56**	2.52**
F-stat (E)							62.83**	62.58***	59.44***
F-stat (F)							279.85**	270.43***	273.52***
Cragg-Donald F-stat	56.536	56.806	59.392	192.569	194.370	197.599	19.830	19.724	19.462
LM-stat	10.539***	9.569***	10.014***	21.255***	21.033***	21.029***	14.292***	14.353***	13.814***
Controls, country & year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	773	773	773	773	773	773	773	773	773
R^2	0.805	0.328	0.620	0.824	0.365	0.654	0.832	0.379	0.664

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table.

Appendix E: Augmented Economic complexity index and Export sophistication index

Table E1: ECI+ index

Period: 2005–2017	(1)	(2)	(3)	(4)
Var dep: ECI+	**2nd stage estimations**			
(A) Connectedness (con)	0.996*	0.338**	0.172	1.168***
	(0.560)	(0.135)	(0.299)	(0.383)
(B) SSA x con		0.855*	1.124*	-2.946***
		(0.450)	(0.613)	(1.144)
(C) Lat Am x con			0.116	
			(0.560)	
(D) MENA x con			0.598	
			(0.560)	
(E) South-East Asia x con			0.293	
			(0.238)	
(F) South Asia x con			0.0952	
			(0.240)	
(G) Con x sea distance				-0.000191***
				(0.0000670)
(H) Con x SSA x sea dist.				0.000485***
				(0.000142)
Additional controls				
Sea distance				0.00284**
				(0.00113)
Sea distance x SSA				-0.00329***
				(0.000838)
	First-stage statistics			
F-test (A)	4.69**	49.66***	116.72***	17.06***
F-test (B)		48.68***	30.36***	30.52***
F-test (C)			5.68***	
F-test (D)			2.07*	
F-test (E)			144.61***	
F-test (F)			845.20***	
F-test (G)				19.66***
F-test (H)				39.45***
Cragg-Donald F-stat	21.053	116.295	6.332	31.58
LM-stat	5.049**	17.410***	10.600***	8.827***
Controls, country & year FEs	Yes	Yes	Yes	Yes
N	521	521	521	521
R2	0.595	0.811	0.805	0.838

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table.

Table E2: Export sophistication index (EXPY)

Period: 2005–2017	(1)	(2)	(3)	(4)
Var dep: EXPY score	**2nd stage estimations**			
(A) Connectedness (con)	0.255*	0.0422	0.200*	1.074***
	(0.134)	(0.113)	(0.115)	(0.348)
(B) SSA x con		0.326	-0.0806	0.184
		(0.232)	(0.209)	(0.554)
(C) Lat Am x con			-0.771***	
			(0.192)	
(D) MENA x con			-0.121	
			(0.127)	
(E)South-East Asia x con			-0.0700	
			(0.113)	
(F) South Asia x con			-0.545***	
			(0.124)	
(G) Con x sea distance				-0.000159***
				(0.0000612)
(H) Con x SSA x sea dist.				0.0000588
				(0.0000642)
Additional controls				
Sea distance				0.00195**
				(0.000957)
Sea distance x SSA				0.0000316
				(0.000742)
	First-stage statistics			
F-test (A)	13.08***	74.21***	72.77***	26.00***
F-test (B)		56.11***	34.90***	41.65***
F-test (C)			3.78***	
F-test (D)			2.81**	
F-test (E)			60.83***	
F-test (F)			275.87***	
F-test (G)				36.57***
F-test (H)				41.97***
Cragg-Donald F-stat	74.249	312.249	18.974	68.287
LM-stat	11.385***	24.673***	8.115***	14.444***
Controls, country & year FEs	Yes	Yes	Yes	Yes
N	801	801	801	681
R^2	0.855	0.875	0.923	0.916

Notes: Standard errors are robust to heteroscedasticity and clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Control estimates are not reported in the table. The export sophistication index is a normalized version (between 0 and 100) of the index proposed by Hausmann et al. (2007).

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

www.aercafrica.org

Learn More

www.facebook.com/aercafrica

twitter.com/aercafrica

www.instagram.com/aercafrica_official/

www.linkedin.com/school/aercafrica/

Contact Us
African Economic Research Consortium
Consortium pour la Recherche Economique en Afrique
Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org