Technological Capability and Industrialisation in Africa

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Abstract

This paper focuses on the direct and indirect role of technological capability in the industrial development of Africa. First, we propose a unified analytical framework to study technological capability in Africa. The unified analytical framework measures technological capability along four dimensions: technology precondition, technology infrastructure, technology imports, and technology effort. We characterise these four dimensions, and also operationalise them using hard data. In contrast to the conventional view, we document strong heterogeneities in the levels of technological capabilities among countries in Africa. Second, we employ a spatial econometric model to examine how industrial development in an African country depends on the country's technological capability, and the technological capability and industrial development of other African countries. Our results show strong evidence of technological and industrial development interdependence among countries on the continent. Importantly, we find that the channel through which this interdependence is propagated is intra-regional trade. Our result holds important implications for the need to promote regional value chains in Africa and the active role AfCFTA must play in this regard.

Keywords: Technological capability, industrialisation, regional value chain, AfCFTA, Africa

JEL codes: O14; O19; O24; O25; O33

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1. Introduction

Over the last two centuries, successful economic development has typically been associated with industrialisation. However, for much of human history, the process of developing a complex system of factories, transportation networks and other infrastructure to support mass production and consumption was seemingly an insurmountable problem. Some historians argue that technological innovation is the *deus ex machina* that resolved the intractable problem of industrialisation.[1] Unlike Greek mythology, where the *deus ex machina* usually drops from the sky to resolve a seemingly unsolvable problem, the reality is that countries that have developed technologies or exploited existing technologies to industrialise consciously built capabilities (Fagerberg and Godinho 2004).

Starting from the work of Gershenkron (1962) and Abramovitz (1986), the long-standing literature has established that capability building is the essential prerequisite for successful industrialisation and catch-up (see Fagerberg and Srholec 2008, 2017 for an overview). The majority of the initial studies in this literature focused on how the so-called 'newly industrialising countries' in Asia developed capabilities to catch up with the West. A typical example of studies in this literature is the famous work of Kim (1997) on South Korea. More recent literature has focused on the measurement of technological capabilities (Archibugi et al. 2009; Filippetti and Peyrache 2011) and its correlation with economic development (Fagerberg and Srholec 2008) and innovation performance (Cerulli 2014). However, these studies have limited coverage of African countries. Furthermore, the technological capability index they provide is mostly cross-sectional in nature or exists for only a few periods that date back in time. To the best of our knowledge, how a country's industrialisation is determined by the technological capability the country, or technological capability of its neighbours remains empirically unexamined to date.[2]

This paper focuses on the role of technological capability in the industrialisation of African countries. The need for such an analysis cannot be overemphasised, as understanding the factors that can unlock Africa's long-awaited industrialisation remains of the utmost importance at the national and regional levels. The recent diffusion and rapid adoption of digital technologies, infrastructure development, increases in human capital, and technology imports have broadened the scope of economic activities in Africa (Choi et al. 2020). In addition, it has been demonstrated that sub-Saharan Africa (SSA) as a whole is currently going through a manufacturing (re)naissance, as evidenced by increases in the manufacturing employment share of the average African economy. This started happening around 2010 after a protracted period of deindustrialisation (Kruse et al. 2022). Is technological capability related to the recent patterns of manufacturing in Africa? In this paper, we study the spatial

[1] See Smith (2011) for a review of Allen (2009).

[2] An exception is Fagerberg and Srholec (2008), who include 22 African countries. However, their study predates the era of massive internet and digital technology diffusion in Africa.

dynamics and interdependence of technological capability and industrial development in Africa.

First, we proposed a unified analytical framework to study technological capability in Africa. The unified analytical framework measures technological capability along four dimensions: technology precondition, technology infrastructure, technology imports, and technology effort. We characterised these four dimensions, as well as operationalised them using hard data. We next assembled and harmonised data that reflect the central element of technological capability to measure the four dimensions using factor analysis. We characterised the evidence across space and over time. Our final sample comprised 50 African countries for the period 2000 to 2018. In contrast to the conventional view, we documented strong heterogeneities in the levels of technological capabilities among countries in Africa. Whilst some countries have non-existent capabilities (i.e., technological capability laggards) or low capabilities (i.e., technological capability upcomers), other countries either show potential (i.e., technological capability dynamos) or already have adequate capabilities (i.e., technological capability leaders) for industrialisation. Moreover, we show that, over time, the average technological capability has almost doubled, increasing from 25 to 41.[3] To a large extent, this reflects the increasing role of internet penetration and rapid diffusion of digital technologies across African countries.

The logical next step was to investigate how technological capability affects industrialisation. We do this using a spatial econometric model in the light of the spatial variation in capabilities and potential spillover effects. Our econometric model does not only show the direct effect of technological capabilities on industrialisation, but also captures the extent of technological interdependence across African countries and its effect on industrial development. In particular, the model incorporates a spatial interaction matrix (trade interaction) such that we can measure the direct and indirect effects of technological capabilities on industrialisation. The direct effect measures how a country's industrialisation trajectory is determined by its technological capabilities, while the indirect effect is the effect arising from the technological capabilities of its spatial partners – that is, other African countries. Our spatial model also included a spatially lagged indicator of industrialisation, further enabling us to determine whether industrialisation is spatially interdependent in Africa.

The results largely show evidence of a positive spatial industrial development interdependence in Africa, albeit statistically insignificant. Concerning technological capability, the results for both the direct and indirect effects show strong evidence of a positive association between technological capability and industrialisation, implying that improvements in the technological capability of a given African country are positively associated with industrial development in that country, as well as in the rest of African

[3] The technological capability index is normalised, ranging from 0 to 100, with higher values indicating higher levels of capability.

countries. In addition, we find that i) the magnitude of the indirect effect is higher than that of the direct effect, and ii) intra-regional trade is largely the causal pathway through which the interdependence of technological capability is propagated. Hence, our results call for regional cooperation to build and accumulate technological capability in Africa, while underscoring the need to intensify intra-regional trade and build regional value chains on the continent.

Our paper relates to four strands of literature. First, it relates to the literature that studies technological capabilities and industrialisation (Lall 1992) and manufacturing exports (Lall 2000) in developing countries. The seminal work of Lall (1992) lays out a straightforward framework for describing the expansion of national capabilities and the industrialisation of developing countries. This framework is built on the interaction of incentives, capabilities, and institutions. Our paper extends the ideas of Lall (1992) on technological capabilities and industrialisation in two important ways. First, it broadens the country-level taxonomy of Lall by including more recent measures, such as digital infrastructure, and then relates it to industrialisation in Africa. Second, and most importantly, the paper deviates from the predominant focus on a country's own technological capability to examine how the technological capabilities of a country's neighbouring communities shape its industrial trajectories. In this way, the paper introduces spatial technological dependencies and externalities into the debate on Africa's industrialisation.

More broadly, our work is related to a large body of literature that studies the role of innovation and capabilities in economic development. In particular, this includes the literature that emphasises the role of technological innovation and creative destruction (Aghion and Howitt 1992); national innovation systems, technological capabilities and economic development (Fagerberg and Srholec 2008, 2017); industrial policy in promoting technological catch-up and economic development (Rodrik 2004); and technological accumulation and industrial growth patterns between developed and developing countries (Bell and Pavitt 1993).[4] This literature argues that countries that succeed in developing capabilities catch up, while countries that fail to develop capabilities fall behind. Knitted closely to this literature is that devoted to the conceptualisation and measurement of capabilities (Archibugi and Coco 2005; Desai et al. 2002; Filippetti and Peyrache 2011; UNIDO, 2002). To date, this literature has largely focused on advanced and emerging countries, developed technological capability measures that are mostly only cross-sectional in nature or that have existed for a shorter period that dates back in time, and has made no attempt to relate the observed patterns to industrialisation. We contribute to this literature by proposing

[4] Other important studies in the field include that of Hausmann and Rodrik (2003), who discuss the idea of economic development as a process of self-discovery, in which countries identify and build upon their technological capabilities to achieve sustained growth. A closely related book, by Dosi et al. (1988), explores the dynamics of technical change and its implications for economic theory, providing insights into the process of technological catch-up in developing countries.

a unified analytical framework to study technological capability in Africa, as well as use the proposed framework to develop a time-varying technological capability index that we use to provide the first empirical evidence of the nature of the relationship between technological capability and industrialisation.

Our study also relates to the literature that studies capabilities and firm-level outcomes in Africa. For example, Avenyo et al. (2021) developed new indicators of productive capacities and relate them to export performance at the firm level. They show that a firm's direct export performance is significantly influenced by both technological and production capabilities. We contribute to this literature by providing country-level evidence for the relationship between capabilities and industrialisation in 50 African countries, providing evidence of the heterogeneities and interdependencies, and the channel through which the interdependency is propagated.

Finally, our work is closely embedded in the literature that employs spatial models to analyse different economic problems in the context of Africa. For example, Chih et al. (2021) use a spatial economic model to examine the relationship between the inflow of foreign direct investment (FDI) and economic development in Africa. On decentralisation and local development, Vincent and Kwadwo (2022) use a static and dynamic spatial model to assess the spatial diffusion of intergovernmental grants in Benin. Finally, Hu et al. (2021) studied the spatial spillover effects of Chinese FDI on Total Factor Productivity (TFP) growth in Africa. We adopt a similar spatial framework to study the direct and indirect effect of technological capabilities on industrialisation in Africa.

The remainder of this paper proceeds as follows: section 2 presents the theoretical background. Data sources, computation of variables, and estimation strategy are described in section 3. Section 4 presents the results, while section 5 concludes.

2. Theoretical Background

2.1 Conceptualisation of Technological Capability

Technological capability is multifaceted and multidimensional in nature as it encompasses different activities, ranging from the assimilation of existing knowledge and technologies to the creation of new ones. Consistent with this view, Lall (1990:17) defines technological capability as the ability to execute all technical functions entailed in operating, improving and modernising a firm's productive facilities. Kim (1997:4), on the other hand, broadly defines it as "the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies". Kim (1997) also notes that to climb the economic development ladder, technological capability should be upgraded through dynamic learning processes, further arguing that technological capability comprises three elements: production, investment, and innovation capability.

Production capability encompasses the capacity to repair and maintain physical capital, manage and optimise the operation of established production facilities, and adapt production to changing market circumstances. Investment capability encompasses the capacity to identify and acquire technology, upgrade the skills of the workforce, establish new productive facilities, and adjust project designs either to design new products or adapt to changing market circumstances. Finally, innovation capability encompasses the capacity required to create new products, processes, or services. This can result either from internal R&D, imitation, interfirm interactions or learning. Along this line, Fagerberg and Srholec (2008) conclude that technological capability includes not only organised R&D, but also other capabilities needed for the commercial exploitation of technology.

Two streams of scholarship on technological capability have coevolved, although both are deeply rooted in the resource-based view and neo-Schumpeterian evolutionary theories of the firm.[5] The first comprises micro-level studies on firm technological capability, while the second comprises macro-level studies on national technological capability.[6] The focus of our study is on the latter. One of the predominant views shared among scholars in this latter literature is that national technological capability is an important determinant of social and economic development. Nevertheless, the level of technological capability across countries differs markedly (Archibugi and Coco 2005; Archibugi and Pietrobelli 2003; Filippetti and Peyrache 2011). Akin to the multifaceted nature of technological capability, therefore, the measurement of technological capability has held a quintessential position in this literature.

For the most part, the research objective of this literature is usually to ascertain countries' technological capability position, their changes over time, and the implications for their development. This has led to diverse measures or operationalisation of technological capability in the literature. As Archibugi and Coco (2005) hint, however, these measures often share two great similarities. First, they share a similar view that technological capability is multifaceted, as they all measure technological capability by employing diverse variables that are closely knitted to technology creation, diffusion and absorption. Second, they share the view that the various components of technological capabilities are complementary, as the methodological approach that is employed predominantly consists of summing across the diverse indicators into a single measure of technological capability. Against this backdrop, the computation of the technological capability index we employ in the empirical analysis of the present student relied heavily on these conceptual and methodological similarities that exist in the literature.

[5] See Penrose (1959) for the resource-based view theories of the firm, and Nelson (1985) for the neo-Schumpterian evolutionary theories of the firm.

[6] This also includes studies that explore within-country regional variations or cross-country regional variations (e.g., Fagerberg and Srholec 2022).

2.2 Measurement of Technological Capability

Archibugi and Coco (2005) and Archibugi et al. (2009) provide an expansive literature survey on the measurement of technological capability. Some of these studies, along with the more recent ones, need to be reviewed to rationalise the framework guiding how we operationalised technological capability in this study. A starting point is Lall's (1992) seminal paper. Although Lall does not provide a technological capability index, he developed an analytical framework that distinguishes national technological capability along three components: physical capital, human capital, and technological effort. To operationalise the various dimensions, he highlights investment in plant and equipment for physical capital; indicators of formal education, training (including on-the-job training), the experience of technological activity and inherited skills for human capital; and technical personnel, R&D expenditure, innovation and patents for technological effort.

As part of its global competitiveness index, the WEF has used a combination of surveys and hard data to produce an annual technology index across several countries since 2001. The index comprises three components: innovative capacity (based on measures such as patent count and tertiary enrolment ratio), ICT diffusion (based on measures such as internet, telephone and personal computers), and technology transfer (based on measures such as non-primary exports). Based on the number of patents produced, the sample is divided into two groups: core countries and non-core countries. Each component is then weighted differently for each country, depending on whether the country is in the core or non-core group.

Desai et al. (2002) estimated a technology achievement index (TAI) for 84 developed and developing countries based on different dimensions: the creation of technology (based on patents registered by residents at their national offices and receipts of royalty and licence fees from abroad per capita), diffusion of recent innovations (based on internet hosts and the share of medium- and high-technology exports in total goods exported), diffusion of old innovations (based on telephone mainlines and cellular, and electricity consumption per capita), and human skills (based on years of schooling in the population aged 15 and above, and the gross tertiary science enrolment ratio). The index for each dimension is calculated as the simple average of the indicator indices in that dimension, while the overall TAI is an equal-weighted simple average of these four-dimension indices.

The United Nations Industrial Development Organization ([UNIDO] 2002) measured technological capability for 87 countries across four dimensions: technological effort (based on patents at the US patent office and enterprise-financed R&D), competitive industrial performance (based on manufactured value added (MVA), medium- and high-tech share in MVA, manufactured exports, and medium- and high-tech share in exports); technology imports (based on foreign direct investment (FDI), payment of foreign royalties, and capital goods imports), and skills and infrastructures (based on tertiary technical enrolment and telephone mainlines). UNIDO (2002) created a synthetic index for each dimension but did not produce a synthetic indicator that aggregates the various dimensions into a combined index.

Archibugi and Coco (2005) estimated the technological capability of 162 developed and developing countries for two periods, 1987 to 1990 and 1997 to 2000. Three dimensions of technological capability were considered: technology creation (based on scientific publications and patents registered at the US patent office), technology infrastructure (based on the internet, telephone mainlines and mobile, and electricity consumption), and human capital (based on scientific tertiary enrolment, years of schooling, and literacy rate). The overall technological capability index of each country was then computed as an equal weighted sum of the three mentioned dimensions. In an extended analysis, they added technology imports (based on inward foreign direct investment, technology licensing payments, and imports of capital goods) as a fourth dimension.[7]

Wagner et al. (2004) developed a science and technology capacity index for 76 countries and later updated it to 150 countries (Wagner et al. 2015).[8] They used eight indicators that are aggregated and divided into three categories: enabling factors (based on gross tertiary science enrolment ratio and per capita GDP), resources (based on the number of scientific engineers, number of institutions, and R&D expenditure), and embedded knowledge (based on patents, and authorship of scientific and technical journal publications). A synthetic index that comprises the three dimensions is created through a standardised formula, with different outcomes occurring according to the weights assigned to the three index components.

Filippetti and Peyrache (2011) investigated the patterns of technological capabilities across 42 countries from 1995 to 2007. Three dimensions of technological capability were considered: business innovation (based on patent count and business R&D expenditure), knowledge and skills (based on total researchers in R&D, scientific and technical articles, and public R&D), and infrastructure (based on personal computers, fixed-line and mobile telephones, internet users, gross fixed capital formation).[9] The authors allocated a higher weight, of 0.15, to each variable in the innovation component, while a lower weight of 0.1 was allocated to each variable in the respective components of knowledge and skills, and infrastructure. Finally, the three components were transformed into a composite index.

[7] For this latter part of the analysis, the sample was reduced to 86 countries.

[8] Science and technology capacity is defined as the ability of a country to absorb and retain scientific knowledge and to use this knowledge to conduct research and development (Wagner et al. 2015:2).

[9] For the dimension of knowledge and skills, Filippetti and Peyrache (2011) also highlighted the labour force with tertiary education and enrolment in tertiary programmes as potential variables to consider. They also highlighted broadband subscribers for the case infrastructure. However, they do not consider these variables in their analysis of the claim of high correlation.

Using a sample comprising 42 countries, Yeon et al. (2021) measure national technological capability from 1996 to 2016 along two dimensions: implementation and design capability.[10] The overall national technological capability of each country is the unweighted sum of the two components, where each is calculated as an equal weighted sum of five normalised variables. For implementation capability, this includes ISO9001 certificates, total resident trademark applications, manufacturing value added per capita, the share of manufacturing employment, and gross fixed capital formation in the total manufacturing sector (% of GDP). For design capability, it includes total resident patent applications, total resident industrial design applications, per-capita high-tech exports, the share of researchers in the R&D sector, and gross domestic public and business R&D expenditure by the government (% GDP).

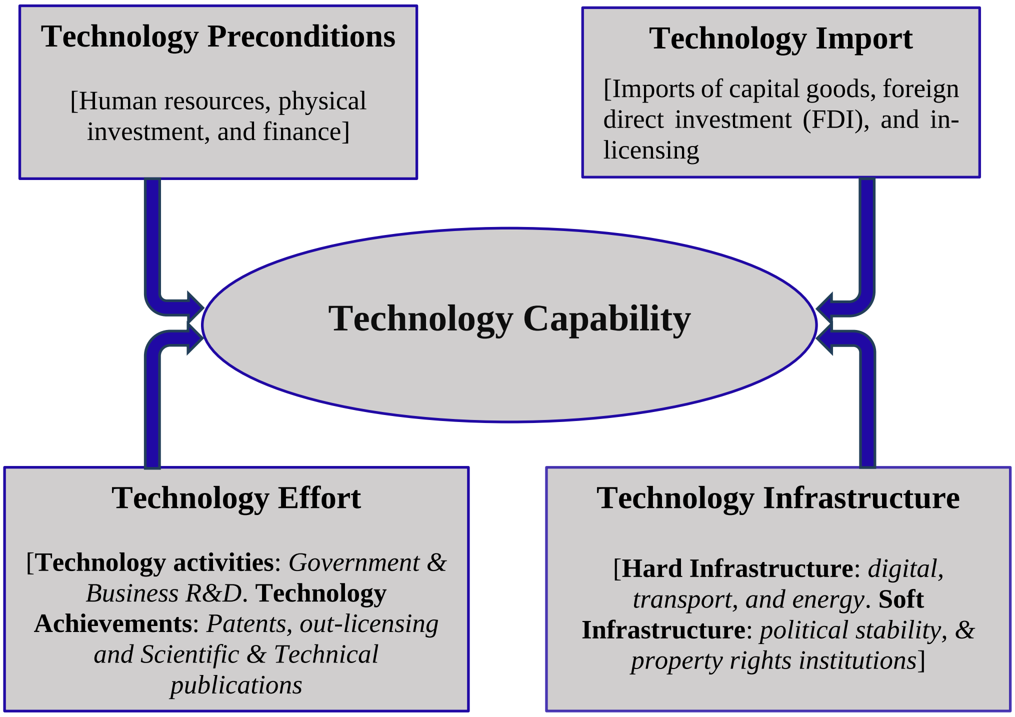
2.3 A Unified Technological Capability Framework for Africa

The previous section indicates there is an expansive literature on the measurement of technological capability. Despite this expansive literature, two limitations motivated us to create a technology capability index rather than relying on the existing ones. First, the existing technology capability measures are only for a few countries and are mostly in favour of advanced and emerging economies. Second, these measures are mostly cross-sectional in nature, or they exist for fewer periods that date back in time. Hence, they are unfit for an analysis like ours, which is primarily interested in African countries and exploring both cross-sectional and time variations. One of the major objectives and contributions of our study is to create a measure of technological capability for countries in Africa. Such an effort requires an analytical framework.

It was suggested in section 2.2 there are a plethora of analytical frameworks for such purposes that already exist in the literature. Our aim is not to add this list. While this leaves us with the option of choosing from the existing frameworks, this requires strong justification and compromise, as the inherent purpose and attributes may differ. Therefore, rather than choosing among the existing frameworks, we sought commonalities among them and created a unified analytical framework that guides how we compute technological capability. Our mapping exercise in this regard resulted in four dimensions of technological capability: technology precondition, technology infrastructure, technology imports, and technology effort. The rest of this section sheds light on the various dimensions of the unified framework (see Figure 1).

[10] As noted by the authors, implementation capability is the capacity to manage and secure the know-how knowledge when actualising a given design, while design capability is the capacity to differentiate new concept designs from existing technologies or products by applying the know-why knowledge.

Figure 1. A unified technological capability framework



2.3.1 Technology precondition

Technology preconditions are the *conditio sine qua non* to produce, adopt, absorb, retain and recombine technology. They therefore are the bedrock of technological capability. The first element of this component is human resources. Human resources conceive technology ideas or design technologies. They also identify technologies that are developed elsewhere, enable their imitation and adoption, as well as drive complementarity among other dimensions of technological capability. For instance, human resources are needed to efficiently use machinery, equipment and technology infrastructure, as well as to recombine existing technologies into new ones. Arguing along this line, Desai et al. (2002) note that a critical mass of skills is indispensable to technological dynamism, as both creators and users of new technology need skills. Lall and Pietrobelli (2005) note that skills in general, and technical skills in particular, are the base on which technological capabilities are built. Furthermore, they note that firms can invest little in new embodied technology when they realise that they, among others, lack the requisite skills to use it efficiently in open markets. It therefore is unsurprising that almost all the existing frameworks incorporate human resources in one way or another. Three aspects occur often: quality of education (e.g., based on the mean years of schooling), knowledge (e.g., literacy rate and tertiary enrolment), and technical skills (e.g., scientific tertiary enrolment and number of scientific engineers).

The second element, albeit seldom covered in the existing framework, is physical capital. The role of physical capital investment in technological development in developing countries cannot be overemphasised. Arguing along this line, Filippetti and Peyrache (2011) note that such investment can make a substantial contribution, especially at the beginning of catching-up processes. The importance of physical capital investment as a technological precondition is argued even more forcefully by Lall (1990:170), who notes that physical investment is in some sense a basic capacity in that plant and equipment are necessary for industry to exist. Finally, the third element that has gone largely unrecognised in the existing frameworks is finance. This is of particularly great importance in the case of developing countries, where credit constraints are binding (Konte and Ndubuisi 2021) and act as a significant barrier to technology adoption and diffusion (Zanello et al. 2016). How effectively and efficiently entrepreneurs in Africa access finance have great implications for the level, nature and patterns of national technological capability observed in the region.

2.3.2 Technology infrastructure

Technology infrastructure refers to supporting infrastructure that engenders the production of, access to, and diffusion and exchange of technology. In principle, there are two relevant types of infrastructure in this regard: soft and hard infrastructure. Soft infrastructure refers to institutions and enabling frameworks that incentivise and govern technology exchange. The establishment of physical and intellectual property rights, as well as the political stability of the country, is of utmost importance in this regard. The importance of the latter relies largely on the high cost associated with a technological investment, which in most cases is an irreversible investment. Political instability exacerbates risks and uncertainties associated with such investments, and therefore discourages potential entrepreneurs and investors. Hard infrastructure, on the other hand, includes public hardware (and to some extent private hardware such as personal computers), which is largely associated with the production of, access to and diffusion of technology. Until now, existing frameworks have focussed only on hard infrastructure. Although there is room for improvement, these frameworks have relied primarily on the following indicators to operationalise hard infrastructure: telephone penetration, internet penetration, personal computers, electricity consumption and transport systems.

2.3.3 Technology imports

Technology imports refer to knowledge and technology that are sourced from abroad. Sources of technology imports are trade, FDI, migration, bilateral or multilateral agreements, education abroad, trade fairs, and journals (Lall and Pietrobelli 2005; Zanello et al. 2016). However, Lall and Pietrobelli (2005) note that the main forms in which technologies are imported are capital goods, licensing agreements, and FDI. Anecdotal and empirical evidence lends credence to technology imports being an important source of accumulating technological capability. For instance, Blumenthal (1976) notes that, after World War II, the reconstruction and growth of the Japanese economy were based on integrating foreign technologies, while Zhao (1995) found in an empirical analysis of China that imported technology has significantly enhanced China's technological build-up. A few frameworks have also acknowledged the role of technology imports as a source of technological capability.[11] Notable among these is UNIDO (2002). Desai et al. (2002) also incorporates such imports into the extended version of their framework. While Lall (1990) did not indicate technology imports as a component of his broad categories of technological capability, he did highlight that the extent and nature of a country's reliance on foreign technology are directly relevant to national technological capability. The third component of our unified framework therefore is technology imports. Suffice to note that, given the pre-existing poor capital accumulation and technology gaps between the global north and south, technology imports provide a means for the global south to acquire world-class technologies. African countries largely fall into this grouping.

2.3.4 Technological Effort

Technological efforts are direct technology activities (e.g., R&D investments) or achievements (e.g., innovations or successful imitations). As noted by Lall (1992:170), technological effort comprises a broad spectrum of production, design and research work with firms, backed up by a technological infrastructure that provides information, standard and basic scientific knowledge, and various facilities too large to be owned by a firm. In line with this, national technological efforts lie both within and outside of the boundaries of the firms in a polity. For instance, business R&D investments and innovations by private firms constitute evidence of national technological capability that lies within the bounds of the firm. However, basic R&D, which largely happens through government institutions and scientific and technical knowledge that are produced by academic and research institutions, constitute evidence of national technological capability that lies outside the bounds of the firm. Existing frameworks implicitly share this view, as how they operationalise technological effort often encapsulates two or more variables that capture technology effort within and outside the boundaries of a firm. It can be stated unequivocally that the better a country is at ensuring interaction and collaboration among the various sources of national technological efforts, the better technological capability the country ends up with.

[11] In the much larger literature on the national system of innovation, this has been discussed extensively and incorporated into the researchers' framework (e.g., see Fagerberg and Srholec 2008; Lall and Pietrobelli 2005).

3. Technological Capability and Industrial Development

3.1 Conceptual Framework

Extant studies have focused largely only on measuring technological capability. The second objective of our study was to expand this literature by investigating the relationship between technological capability and industrialisation. We identified four channels through which capability affects industrialisation: innovation and efficiency, economies of scale, upgrading, and diversification. First, technological capability leads to the assimilation of existing knowledge and technologies to create new ones, which stimulate the invention of new machinery, processes and tools and ultimately drives industrialisation. Technological capabilities foster innovation by providing a foundation for R&D. Innovation, in turn, drives industrialisation by introducing new products, processes and business models that improve overall efficiency and create a competitive advantage. Second, technological capabilities allow the production of goods and services on a larger scale, leading to economies of scale. As industries adopt advanced technologies, they can increase production efficiency, reduce costs and lower prices. This enables mass production, which is a hallmark of industrialisation. Third, technological capabilities enable the development of innovative industries and the production of high-value goods and services, which lead to industrial upgrading, an idea that is consistent with the literature on economic complexity, export quality, and development (Hausman and Rodrik 2003). The fourth channel is the diversification channel, in which building technological capabilities enables nations to diversify their economies and move up the value chain by developing manufacturing and knowledge-intensive industries. While the foregoing is suggestive of a direct positive relationship with technological capability, the economic geography literature highlights the importance of spatial technological and knowledge spillovers in driving growth and development (Ertur and Koch 2007). Consistent with this view, we expect industrialisation in a given African country to be affected not only by the country's technological capability, but also by the technological capability of other African countries.

3.2 Empirical Strategy

To examine how industrialisation in one African country depends on industrialisation and technological capability in other African countries – that is, endogenous and exogenous interaction effects – we revert to a spatial econometric model, which has become a conventional approach to studying dependence across diverse cross-sectional units. There are different spatial econometric models with combinations of different spatial dependence structures, leading to uncertainty about the model choice (see Elhorst 2017; LeSage 2014). However, Vega and Elhorst (2013) note that there are only three spatial model specifications that need consideration: the spatial Durbin model (SDM), the spatial Durbin error model (SDEM), and the spatially lagged explanatory variable model (SLX). The SDEM captures spatial dependence in the outcome variable and the error term, while SLX captures spatial dependence in the covariates. SDM, on the other hand, captures spatial dependence in the outcome variable and covariates. As the focus of our study is on modelling spatial dependence in the outcome (i.e., industrialisation) and exogenous (i.e., technological capability) variables, we turn to SDM. Following LeSage and Pace (2009), the SDM that guides our analysis is as follows:

$$y_{it} = \rho \sum_{i \neq j} W_{ij} y_{jt} + X_{it}\beta + \sum_{i \neq j} W_{ij} X_{jt}\theta + \delta_i + \delta_t + \varepsilon_{it}, \qquad (1)$$

where $i = 1, \dots, N$ refers to the countries, and $i = 1, \dots, T$ refers to the time period. y_t is the $N \times 1$ vector of observations of the dependent variable in period t, while X_t is the $N \times K$ matrix of the observations of the independent variable in period t. W_{ij} refers to a non-negative spatial weighting matrix of dimension $N \times N$ (more on this below). The parameter ρ measures the spatial dependence of industrialisation across countries in Africa. A statistically significant ρ implies interdependence across Africa's industrialisation, with a positive (negative) coefficient indicating that industrialisation in one African country increases (decreases) with industrialisation in other African countries. β is a vector of coefficient parameters resulting from the direct effects of the estimated covariates (including technological capability), while θ is a vector of coefficients resulting from the covariates' interaction effects – that is, the indirect effect. In the case of technological capability, the direct effect is basically how a country's industrialisation trajectories are determined by its technological capabilities, while the indirect effect is the effect arising from the technological capabilities of other countries in the region. δ_i denotes the country-fixed effects, which capture time-invariant country-specific characteristics such as culture and initial institution endowment. δ_t is the time-fixed effects that account for year-based shocks or events that are common across countries, such as economic downturns. The fixed effects are included to reduce confounding factors that may bias our results. They also account for heterogeneity across the cross-sectional units and reduce spatial error dependence, which arises through the spatial autocorrelation of omitted variables (Vincent and Kwadwo 2022). ε_{it} is the error term, which is assumed to be independent and identically distributed $\left(\varepsilon_{it} \sim N(0, \sigma^2_{\varepsilon_{it}})\right)$.

We estimate equation 1 with the quasi-maximum likelihood estimator developed by Belotti et al. (2017). Appropriate identification of the endogenous and exogenous interaction effects depends on choosing the right weighting matrix, as different matrices capture different channels of spillovers (LeSage and Fischer 2008). While geographical indicators such as distance and contiguity are often used to compute a weighting matrix, anecdotal and empirical evidence shows that trade has played a significant role in the spread of industrialisation (Jaworski and Keay 2020; Kaya 2010; Puga and Venables 1998). Empirical evidence also shows that trade is an important channel of knowledge and technological transfer (Coe et al. 1997; Falvey et al. 2004; Keller 1998). Moreover, falling tariffs, advances in communication technologies, and the rapid development of modern transportation have dampened the potency of geography while promoting the role of trade in cross-border knowledge and technology transfer. Given the primary research objective of our paper, trade thus provides the first-best option for a weighting matrix. Hence, our study relies on trade (W_1) to compute the matrix. Particularly, we use bilateral trade for this purpose.

$$W_1 = \begin{cases} w_{ij} = 0, & i = j \\ w_{ij} = F_{ij}, & i \neq j \end{cases}, \qquad (2)$$

where F_{ij} represents total foreign trade between country *i* and *j*. It takes on positive values in the case of positive trade flows between *i* and *j*, and zero where there is no trade flow. Although we choose trade as our preferred weighting matrix, for completeness we also show results when we use either distance (W_2) or contiguity (W_3) as a weighting matrix. The specifications for W_2 and W_3 are as given in equations 3 and 4, respectively.

$$W_2 = \begin{cases} w_{ij} = 0, \ i = j \\ w_{ij} = 1/d_{ij}^2, \ i \neq j \end{cases} \qquad (3)$$

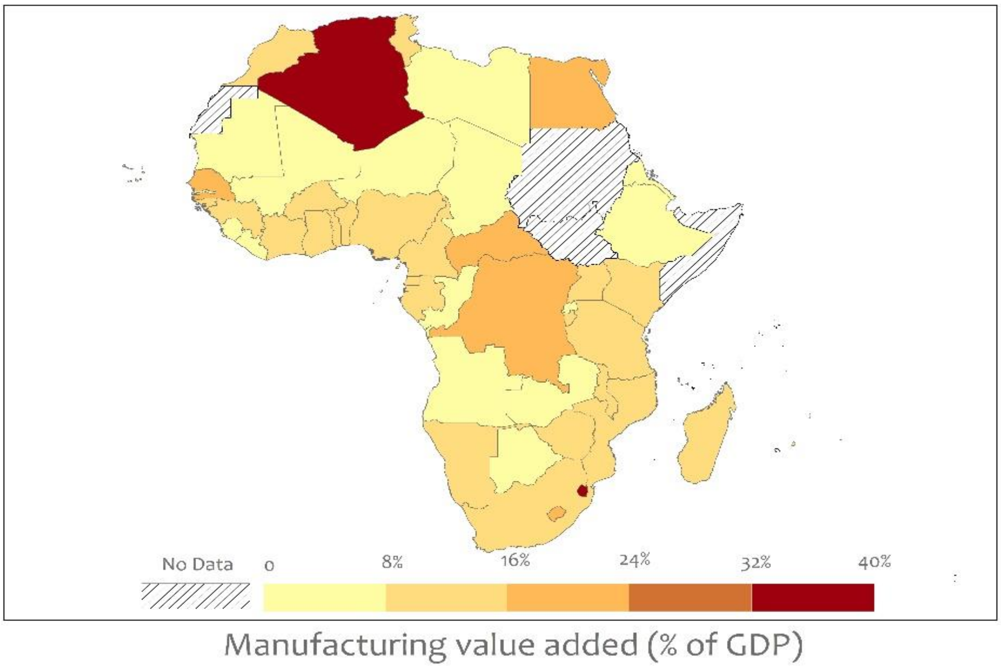
$$W_3 = \begin{cases} w_{ij} = 0, & i = j \\ w_{ij} = C_{ij}, & i \neq j \end{cases}, \qquad (4)$$

where d_{ij} is the unweighted bilateral distance between country i and j measured in kilometres, and C_{ij} is a dummy variable that takes the value of one if i and j share a common border, and zero otherwise. Furthermore, Debarsy and LeSage (2018) and Nan et al. (2022) recommend a convex combination of different spatial matrices, as a single-weight matrix may not reveal the whole picture of national transnational interaction. In the robustness check, therefore, we also show results using an unweighted convex combination of trade and distance ($W_4 = W_1 + W_2$) and trade and contiguity ($W_5 = W_1 + W_3$). Finally, note that all the weighting matrices we employ are row-normalised so that each row-normalised weight (w_{ij}) reflects a fraction of all spatial influence on the spatial unit *i* coming from spatial unit *j*.

3.3 Variables and Data Sources

Our empirical analysis depends on four sets of variables: a measure of industrialisation or manufacturing performance, technological capability, a spatial weighting matrix, and control variables. We discuss how we operationalised these variables as well as their respective data sources in the subsequent paragraphs. Our final sample comprised 50 African countries during the period from 2000 to 2018. The period and the countries covered were determined by the availability of data on the outcome variable and the variables used in computing the technological capability. To enable us to cover as many African countries as possible, we use the original data points for some variables to extrapolate and intraplate to reduce missing observations.

Figure 2: Average manufacturing value added as a share of GDP across African countries, 2000 to 2018.

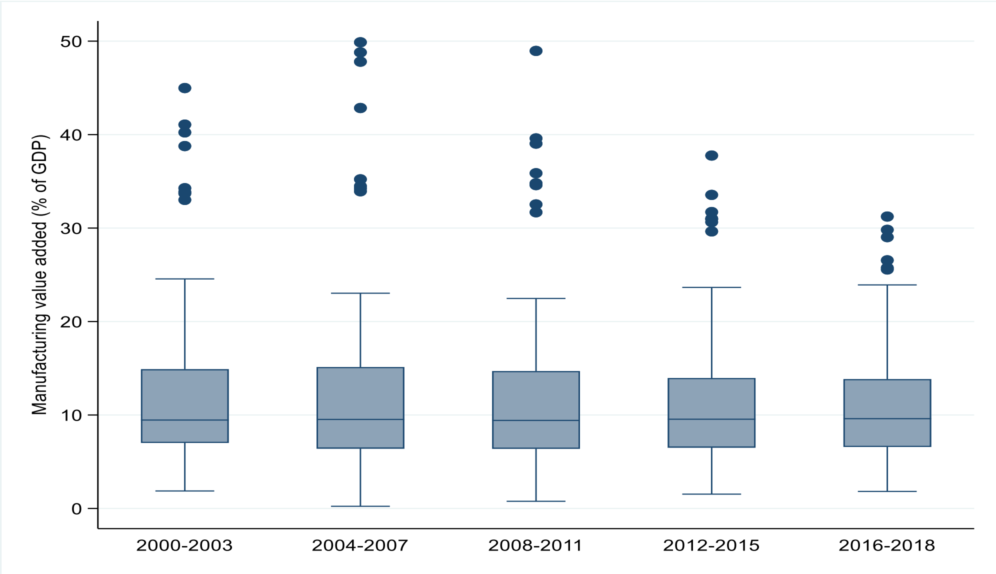


Source: Authors' illustration based on data from WDI.

3.3.1 Industrialisation

As an empirical measure of industrialisation, we used the share of manufacturing value-added in GDP, as has become conventional in the literature (Chenery 1960; Gui-Diby and Renard 2015; Rodrik 2016). Data for this variable was sourced from the World Bank Development Indicators. Since the econometrics method we employ relies on balance panel, we interpolate and extrapolate some of the few missing observations in the data. Figure 2 shows the level of manufacturing activities across African countries. Manufacturing activity is low for a typical African country, as the manufacturing share of the GDP of most countries is below 16%. The exceptions are Lesotho and Algeria, with average manufacturing shares above 30%. Figure 3 depicts manufacturing activities in Africa over time, showing that the average manufacturing share of GDP has remained unchanged at about 10% since 2000, consistent with the argument of industrial stagnation in Africa (Mensah 2020).

Figure 3: Manufacturing share of GDP in Africa over time.



Source: Authors' calculation based on data from the WDI.

In the extended analysis, we show additional results based on three variables that could be considered measures of the competitiveness of the manufacturing sector. These include manufacturing revealed comparative advantage (RCA) and a variety of manufacturing export measures. RCA measures the relative importance of a country's manufacturing in the world. Hence, it has been used extensively in the literature to measure competitiveness (Fertö and Hubbard 2003; Liu et al. 2020). Concerning export diversity, empirical evidence suggests that producing and exporting a wider variety of products increases market share, drives productivity growth, and protects against trade shocks (Feenstra and Kee 2008; Gozgor and Can 2016). In this regard, having a more diversified manufacturing export base offers a country a competitive advantage over its peers.

To this end, we began by computing Balassa's (1965) RCA using data on value added. The index is formally computed as a country's share of manufacturing value-added share in total value added relative to the world's share of manufacturing value-added share in total value added. One of the limitations of this formal approach to computing the RCA is that it is asymmetric – that is, unbounded for those sectors with an RCA, but it has a zero lower bound for those sectors with a comparative disadvantage. To address this concern, Laursen (2000) suggests a simple normalisation that results in a normalised RCA (NRCA), as formalised in equation 5:

$$NRCA_i = \frac{RCA_i - 1}{RCA_i + 1} \qquad (5)$$

where $RCA_i = m_i / M_R$, m_i is country i's manufacturing value-added share in the country's total value added, and M_R is the world's manufacturing value-added share in the world's total value added.[12] The value-added data used to compute this variable is from the UN National Accounts: Analysis of Main Aggregates database (UN AMAD). Next, for export diversity, we used the extensive export margin that results from Hummels and Klenow's (2005) decomposition of total trade.[13] Our approach to using the method to capture the variety of exports is consistent with the existing literature (see Beverello et al. 2015). Whilst Hummels and Klenow (2005) constructed the margin at the country level, we adapt their method and construct the export margin at the sector level, as formalised in equation 6.

$$ED_{i,s} = \frac{\sum_{P_{i,s}} XV_p^R}{\sum_{P_{R,s}} XV_p^R}, \qquad (6)$$

where $P_{i,s}$ is the set of products exported by country i in sector s, $P_{R,s}$ is the set of all traded products in sector s in the world, and XV_p^R is the dollar value of the world's exports of product p from sector s. Hence, the index measures the share of the product belonging to a country i's portfolio in the world. Data used to compute the index was sourced from the BACI dataset (Gaulier and Zignago 2010). The dataset contains export values across many countries in the six-digit harmonised system classification (HS). Hence, by product, we mean a six-digit HS category.

3.3.2 Technological capability

Concerning technological capability, we fitted the framework we proposed in section 1 with hard data garnered from different sources. Table 1 describes the variables and their respective data sources. Our approach consists of using principal component analysis – a widely accepted approach to transform sets of indicators into a smaller set of linear factors – to construct synthetical indexes for the respective technological capability subcomponents (viz., technology precondition, import, infrastructure, and effort), as well as composite technological capability indexes. The process entailed the construction of a data matrix, the creation of standardised variables, the calculation of a correlation matrix, the determination of eigenvectors, and then the selection of principal components. Inspired by the conventional standard in the literature (Asongu 2015; Ndubuisi et al. 2021; Rogerson 2019), we used the principal components with an eigenvalue greater than one when selecting the principal components. Before implementing the PCA, we standardised the variables to have a mean value of zero and a unit standard deviation.

[12] To compute the indicator for the world, we used the sum of all the countries in the UN AMAD.
[13] It decomposes total exports into two: the extensive margin and the intensive margin. The former measures the variety of exported products, while the latter measures the intensity of the exported products.

Table 1: Operationalisation of technological capability

Subcomponents (1)	Subcomponents (2)	Variables	Data sources
Technology precondition		Domestic credit to private sector by banks (% GDP)	World Development Indicators
		Human capital	UNCTAD Statistical Database
		Gross fixed capital formation (%GDP)	UNCTAD Statistical Database
Technology infrastructure	**Hard infrastructure**	Transport infrastructure	UNCTAD Statistical Database
		Energy infrastructure	UNCTAD Statistical Database
		ICT infrastructure	UNCTAD Statistical Database
	Soft infrastructure	Institution	UNCTAD Statistical Database
		Rule of law	World Governance Indicator
Technology imports		Imports of capital goods	BACI-CEPII
		Foreign direct investment inflow (% GDP)	UNCTAD Statistical Database
Technology effort		Scientific and technical journal articles	World Development Indicators
		Resident patents, count	World Development Indicators, WIPO Intellectual Property Database

Note: As defined in the UNCTAD Statistical database, i) human capital captures the education, skills and health conditions possessed by the population, and the overall research and development integration in the texture of society through the number of researchers and expenditure on research activities; ii) transport measures the capability of a system to take people or goods from one place to another. It is defined as the capillarity of roads and railways network, and air connectivity; iii) energy measures the availability, sustainability and efficiency of power sources; iv) information and communications technology (ICT) measures the accessibility and integration of communication systems within the population. It includes fixed-line and mobile phone users, internet accessibility and server security. Institution measures political stability and efficiency through regulatory quality, effectiveness, success in fighting criminality, corruption and terrorism, and safeguarding citizens' freedom of expression and association. For imports of capital goods, we used the UN Broad Economic Categories to map each country's imports in terms of the six-digit HSC. We considered six-digit HSC products with an associated BEC code of 41 and 521 as capital goods. In the PCA, we used predicted values of patent application from a reduced form equation that controls for country-specific and time-varying characteristics.

For the technological capability precondition, we used three variables: gross fixed capital formation (% GDP) to capture physical capital, domestic credit to the private sector (% GDP) to capture access to finance and financial development, and human capital index to capture human resources. For technology imports, following Archibugi and Coco (2005), Desai et al. (2002) and UNIDO (2002), we used FDI inflows (% GDP) and imports of capital goods.[14] As noted in section 2.3, technology infrastructure consists of two parts: hard technology infrastructure and soft technology infrastructure. Inspired by Archibugi and Coco (2005) and Filippetti and Peyrache (2011), we captured hard infrastructure with three variables, notably energy consumption, transport and information and communications technology (ICT). For the soft infrastructure, which is our expansion, we used two variables, namely a measure of

[14] We used the UN Broad Economic Categories to map each country's imports in terms of the six-digit HSC. We considered six-digit HSC products with an associated BEC code of 41 and 521 as capital goods. Furthermore, a third component of technology imports is licences. However, we were unable to find data that could be used to operationalise this variable.

political stability and an index that captures the rule of law and the effectiveness of private regulation. Ideally, one would also wish to capture institutions such as intellectual property laws and regulations (viz., patent and trademark laws and enforcement) that are directly responsible for the production, governance and exchange of knowledge and technology. However, data that help us capture this dimension of the soft infrastructure are not readily available. Hence, they are currently omitted.[15]

Finally, for the technological effort we used the number of scientific publications and resident patent applications. The choice of these variables was inspired by the extant framework (see section 2.2) and data availability. For instance, the lack of readily available and trusted data for business and government R&D for the countries in the region limits us to capturing this dimension in our framework. Original data for both variables were sourced from the WDI. Patent applications and grants are highly heterogeneous across countries.[16] For instance, a country may have higher numbers of patent applications and grants not because of the introduction of novel inventions, but due to strategic patenting activities of firms in a bid to block competitors. It may also stem from differences in what the law considers a patentable invention. To account for this, past studies focus only on a single market, say the US or Europe. A limitation of such an approach is that firms only patent in foreign markets where they have business interests. In this case, the approach underestimates the patents for those countries that have firms with less business interest, say in the US and Europe. To this end, we resorted to using domestic patent applications and then used the predicted values of patents from a reduced-form equation that controls for country-specific and time-varying characteristics.

3.3.3 Weighting matrix and control variables

As noted in section 3.1, trade is our preferred option for the causal pathway by which technological capability in a given country spills over to other countries. To compute the weighting matrix, we used bilateral trade data from the CEPII database. We also sourced data for contiguity and bilateral distance from the same database. We used the data for contiguity and bilateral distance to construct the alternative weighting matrices, as discussed in section 3.1. The variable on contiguity takes a value of one if countries share a common border, and zero otherwise. Bilateral distance, on the other hand, measures the kilometre distance between the capitals of countries i and j. Finally, for the control variables included in the econometric analysis, we sourced data for GDP per capita from the UNCTAD statistical database, while data for population, urbanisation and natural resources were sourced from the WDI.

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[15] We treat all missing data points in the patent data as zero.

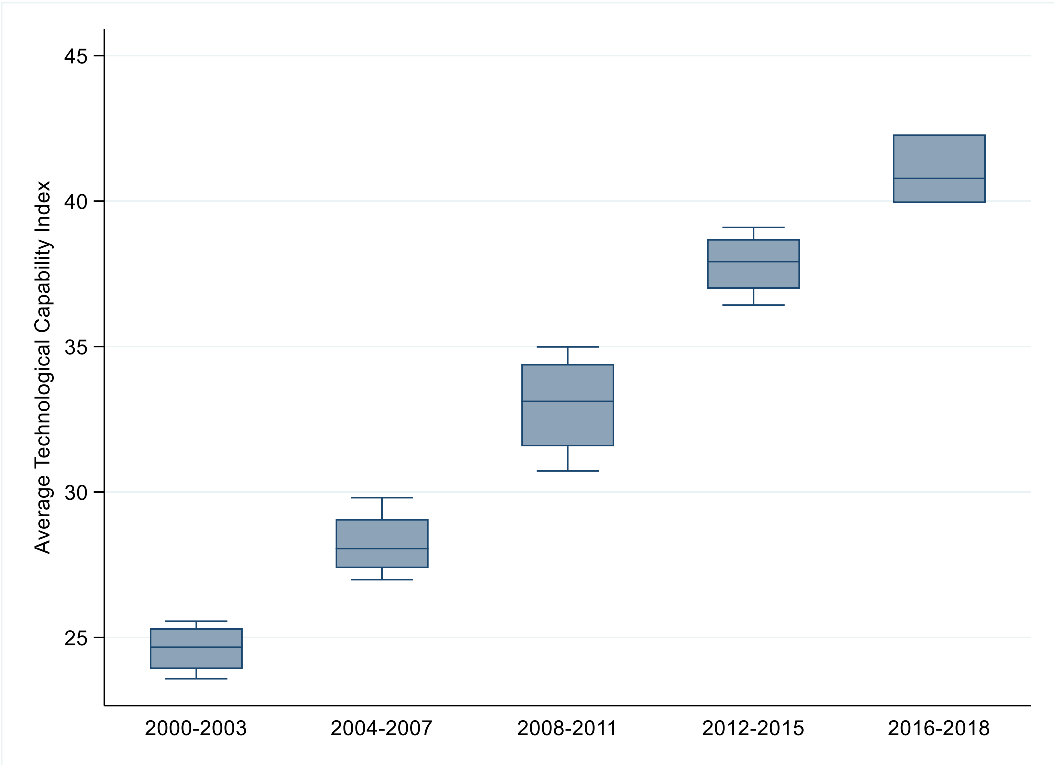
[16] We use patent applications rather than grants, since we are largely interested in effort rather than creation. Also, note that data for the patents are obtained by combining data from the World Bank Development indicators and World Intellectual Property Organization. For those countries with missing observations, we replace them with zeroes.

4. Empirical Results

4.1 A First Look at Technological Capability

Figure 4 show the average technological capability in Africa over time. The figure shows that the average technological capability has almost doubled, increasing from 25 to 41. To a large extent, this reflects the increasing role of internet penetration and rapid diffusion of digital technologies across African countries.

Figure 4: Average technological capability in Africa over time

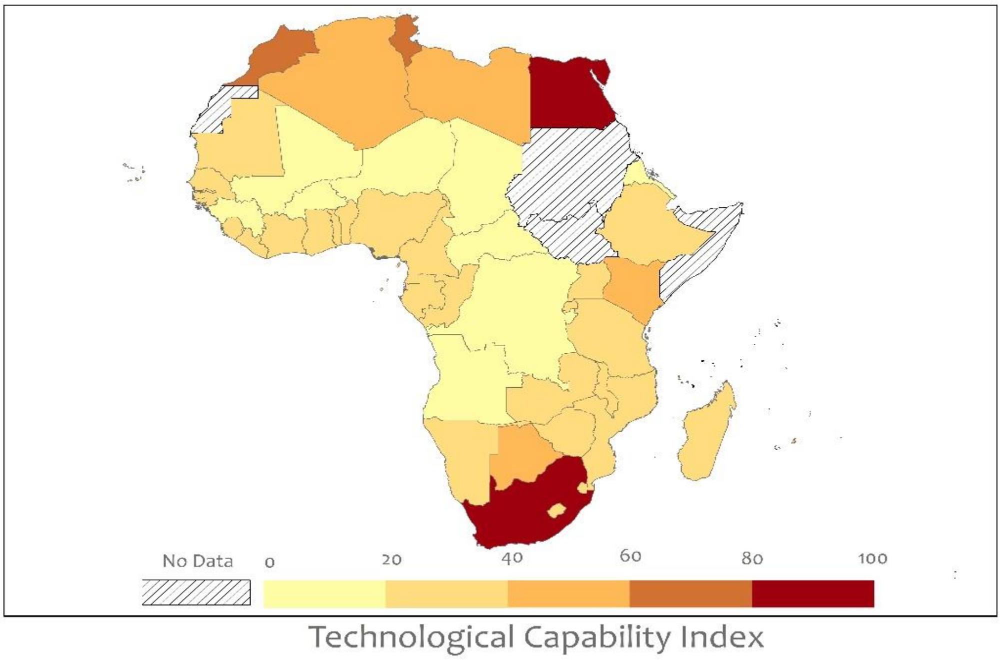


Source: Authors' illustration based on PCA analysis. The technological capability index is normalised, ranging from 0 to 100, with higher values indicating higher levels of capability.

Figure 5 shows the average of the composite technological capability index, while Figure 6 shows the averages of the subcomponents across space (also see Table A1 in the appendix). Both figures show strong variation in levels of technological capabilities among countries in Africa. For instance, South Africa has the highest composite technological capability score of 90. This is followed by Egypt with a composite technological capability score of 81, and Tunisia with a score of 76. However, Niger has the lowest average technology capability score, of 8. This is followed by the Central African Republic and Chad, each with an average technological capability score of 11.

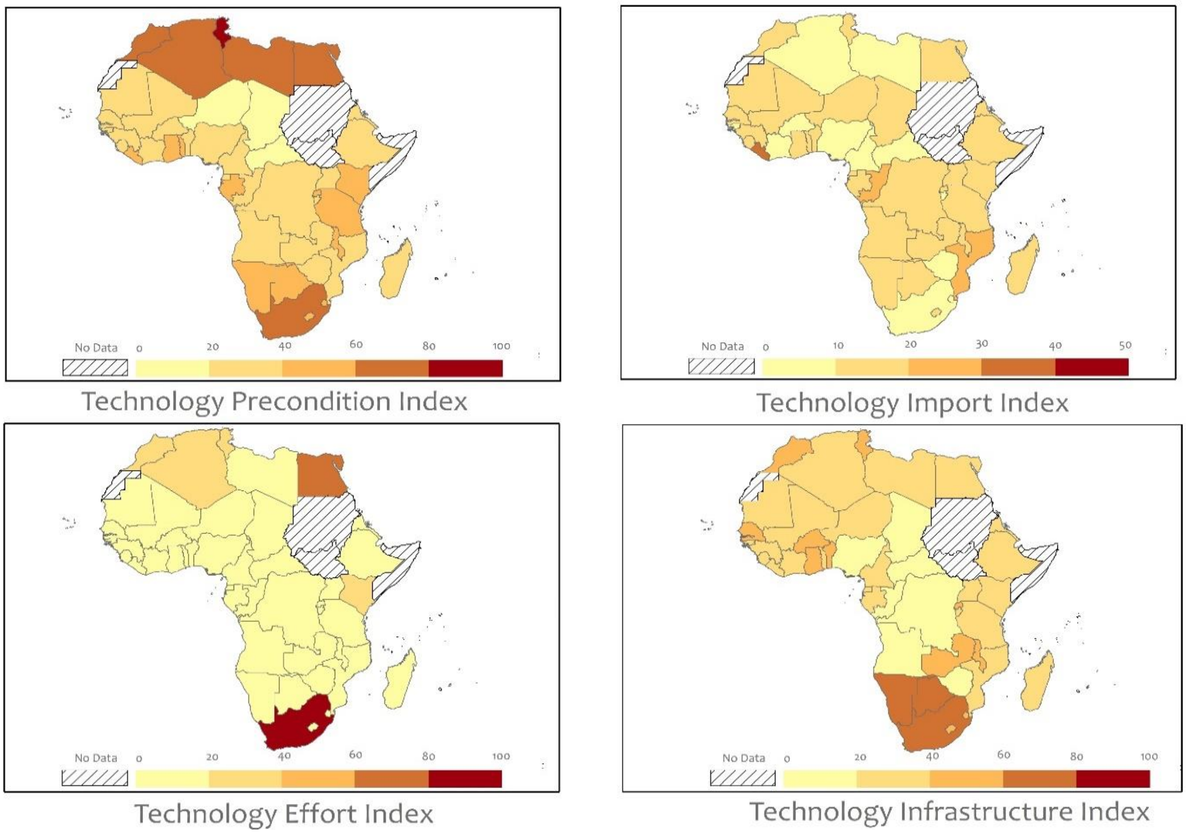
South Africa's high composite technological capability is largely explained by its high technological effort score of 95, followed by its high score of 71 for both technological precondition and infrastructure (see Table A1 in the appendix). Egypt's high composite technological capability is also largely explained by its technological effort, but its technological precondition differs from its technological infrastructure, with the country having an average score of 66 for the former and 35 for the latter. However, Tunisia's high composite technological capability, unlike that of South Africa and Egypt, is largely explained by the country's technology precondition, although the country performs relatively well on technology infrastructure and effort (see Table A1 in the appendix). Nevertheless, these least-performing countries performed poorly, as none of the three scored 30 across the subcomponents.

Figure 5: Technological capability across space



Source: Authors' illustration based on data from the PCA analysis. The technological capability index is normalised, ranging from 0 to 100, with higher values indicating higher levels of capability.

Figure 6: Sub-components of technological capability



Source: Authors' illustration based on data from the PCA analysis. The sub-indices are normalised, ranging from 0 to 100, with higher values indicating higher levels of capability.

To provide a further perspective on technological capability heterogeneity within the region, we mapped the countries into four quartiles based on their technological capability. We categorise the first quartile as regional technological capability laggards; the second quartile as regional technological capability upcomers; the third quartile as regional technological capability dynamos; and the fourth quartile as regional technological capability leaders. We report the result for the composite technology capability mapping in Table 3, while Table A2 in the appendix reports the results for the subcomponents. Our mapping results to 13 countries ending up as regional laggards, 12 countries as regional upcomers, 13 as dynamos, and 12 as regional leaders. Sao Tomé and Príncipe, Namibia, Algeria, Tunisia, Cape Verde, Libya, South Africa, Morocco, Egypt, Botswana, Kenya and Mauritius are the regional technological capability leaders, while the rest of the countries are either technological capability dynamos, upcomers or laggards. For the most part, we observe that the regional technological capability leaders are consistently in the fourth quarter of two or three subcomponents of the technological capability, as reported in Table A2 in the appendix. At the same time, we observe a few surprises (marked in red), with a country like Nigeria ending up as an upcomer, while Liberia, Sierra Leone and Djibouti are dynamos. We highlight this as areas that warrant further investigation.

Table 2: Regional group: Technological capability index

Regional group: Technological capability index			
Regional laggards (1st Quartile)	**Upcomers (2nd Quartile)**	**Dynamos (3rd Quartile)**	**Regional leaders (4th Quartile)**
Burkina Faso	Senegal	Lesotho	Sao Tomé and Príncipe
D.R. Congo	Congo	Liberia	Namibia
Chad	Mauritania	Comoros	Algeria
Eritrea	Madagascar	Ghana	Tunisia
Mozambique	Benin	Togo	Cape Verde
Burundi	Cameroon	Gabon	Libya
Angola	Zimbabwe	Sierra Leone	South Africa
Ethiopia	Guinea-Bissau	Swaziland	Morocco
Mali	Nigeria	Tanzania	Egypt
Guinea	Zambia	Djibouti	Botswana
Niger	Equatorial Guinea	Uganda	Kenya
Central African Republic	Gambia	Rwanda	Mauritius
Côte d'Ivoire		Malawi	

Source: Authors' illustration, based on data from the PCA analysis

4.2 Econometrics Results

4.2.1 Main results

Table 3 displays our main econometrics results on the spatial interdependence of technological capability and industrial development in Africa using our main outcome variable, manufacturing value-added share in GDP. To conserve space, we only report the results for the direct and indirect effects. The results for total effect are reported in Table A3 in the appendix. Estimation across the columns is achieved using our preferred spatial weighting matrix, intra-Africa trade. Beginning with the estimated value of the spatially lagged term, Rho (ρ), it is positive in all the columns in the table, albeit statistically insignificant at the conventional significance levels. As noted in section 3.2, ρ captures spatial dependence in the outcome variable, which in our case is the spatial dependence of industrialisation across countries in Africa. Hence, the result for the parameter ρ is indicative of limited evidence of spatial dependence of industrialisation across countries. One possible explanation for this result could be the low manufacturing base in the region.

Table 3: Technological capability and Industrialisation

Technological capability and Industrialisation					
Panel A: Direct effect					
Log GDP per capita	-1.1067***	-0.9844***	-0.9695***	-1.2131***	-1.1105***
	(0.3423)	(0.3406)	(0.3334)	(0.3542)	(0.3425)
Log GDP per capita squared	0.0536**	0.0479**	0.0359	0.0536**	0.0536**
	(0.0236)	(0.0236)	(0.0230)	(0.0236)	(0.0236)
Log population	2.0624***	2.0967***	2.2305***	3.0539***	2.0975***
	(0.7381)	(0.7423)	(0.7333)	(0.8913)	(0.7373)
Log population squared	-0.0385*	-0.0366*	-0.0437**	-0.0385*	-0.0385*
	(0.0214)	(0.0216)	(0.0213)	(0.0214)	(0.0214)
Log natural resources	-0.0783***	-0.0818***	-0.0620***	-0.0783***	-0.0783***

	(0.0211)	(0.0211)	(0.0214)	(0.0211)	(0.0211)
Urban growth	0.0356***	0.0355***	0.0411***	0.0356***	0.0356***
	(0.0123)	(0.0124)	(0.0124)	(0.0123)	(0.0123)
Technology precondition	0.0905*				
	(0.0494)				
Technology imports		0.0239**			
		(0.0100)			
Technology infrastructure			0.2066***		
			(0.0407)		
Technology effort				1.3720*	
				(0.7491)	
Technological capability					0.1360*
					(0.0742)
Panel B: Indirect effect					
Log GDP per capita	-5.7515***	-4.2196***	-3.7954***	-6.1631***	-5.7661***
	(1.2784)	(1.1340)	(1.0807)	(1.3459)	(1.2805)
Log GDP per capita squared	0.3124***	0.2189***	0.1910***	0.3124***	0.3124***
	(0.0826)	(0.0750)	(0.0709)	(0.0826)	(0.0826)
Log population	7.9357***	7.8623***	8.3530***	11.7742***	8.0718***
	(1.9678)	(1.9755)	(1.9843)	(2.3077)	(1.9629)
Log population squared	-0.2103***	-0.2014***	-0.2290***	-0.2103***	-0.2103***
	(0.0605)	(0.0613)	(0.0607)	(0.0605)	(0.0605)
Log natural resources	-0.0139	-0.0311	-0.0610	-0.0139	-0.0139
	(0.0584)	(0.0588)	(0.0578)	(0.0584)	(0.0584)
Urban growth	-0.0420	-0.0457	-0.0258	-0.0420	-0.0420
	(0.0393)	(0.0393)	(0.0394)	(0.0393)	(0.0393)
Technology precondition	0.3504***				
	(0.1314)				
Technology imports		0.0358			
		(0.0328)			
Technology infrastructure			0.1198		
			(0.1115)		
Technology effort				5.3109***	
				(1.9908)	
Technological capability					0.5263***
					(0.1973)
rho	0.0803	0.0803	0.0803	0.0803	0.0803
lambda	0.0533***	0.0536***	0.0525***	0.0533***	0.0533***
No. of observations	950	950	950	950	950
R-squared	0.018	0.009	0.013	0.020	0.020

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: Estimation is achieved using trade as the weighting matrix.

Panel A reports on the direct effect of technological capability on industrial development. Although our focus is on the composite technological capability, we begin by reporting the results for the subcomponents of technological capability in columns 1 to 4, while column 5 reports the results for composite technological capability. The estimated coefficients of the technological capability subcomponents are all positive and statistically significant at the conventional significance levels. Unsurprisingly, the coefficient of the composite technological capability index, as reported in column 5, turns out to be significantly positive.

This provides evidence of a positive association between technological capability in a given African country and the manufacturing value-added share in that country. The significantly positive coefficient observed for the four technological capability subcomponents suggests that the industrial development gains from building domestic technological capability accrue both jointly and independently from improvements and increase across the four subcomponents of technological capability vis-à-vis technology precondition, imports, infrastructure and efforts.

Panel B shows the results of the indirect effect of technological capability – that is, the results for the spatial interactions in the covariates. The estimated coefficients of the technological capability subcomponents remain positive across the columns, albeit that only those of technological precondition and effort turn out statistically significant at the conventional significance levels. The composite technological capability index, however, is positive and statistically significant at the 1% significance level. This provides evidence of spatial dependence and spillovers of technological capability across African countries for manufacturing value added. In particular, the result indicates that improvements in the technological capability of a given African country are positively associated with an increase in the share of manufacturing value added in the rest of African countries. Except for technology infrastructure, in which case the size of the estimated coefficient for the indirect effect is twice less than its direct effect, the respective sizes of the estimated coefficients for the indirect effect of other technology capability subcomponents and the composite technology capability are larger than their corresponding direct effects. While this may seem counterintuitive, it is expected, as the direct effect only considers the local country, while the indirect effect considers the cumulative spillover effects over many cross-sectional units (LeSage and Dominguez 2012). In Table A3 in the appendix, we report the total effect of technological capability on industrial development. The estimated coefficients for both the technological capability subcomponent and composite indexes are unsurprisingly all positive and statistically significant, given that their respective direct and indirect effects are all positive.

Concerning the control variables, we observe that the sizes of their corresponding coefficients are higher for the indirect effect compared to the direct effect, thereby corroborating our earlier conjecture regarding the pattern we observed for the technological capability index. Furthermore, we find a U-shaped relationship between per capita GDP and manufacturing value added in both the direct and indirect relationship. We also observe a similar relationship for the population. These results are different from those of Mensah (2020) and Naudé and Tregenna (2023), who documented an inverted-U relationship. The differences may be explained by differences in the methods, as unlike in these studies, we considered cross-sectional dependence across the covariates and outcome variable. As per urbanisation, it is positive and statistically significant for the direct effect, while the indirect and total effects are statistically insignificant at the conventional statistical significance level. Furthermore, natural resource abundance has a direct significant negative effect on manufacturing value-added share. Although the coefficient remains negative for the indirect effect, and ultimately for the total effect, it turns out insignificant at the conventional statistical significance level. The significantly negative coefficient of the direct effect of natural resources is consistent with the resource curse literature (Gylfason 2001; Sachs and Warner 2001).

4.2.2 Alternative weighting matrix

Our baseline results are based on using intra-Africa trade as the weighting matrix, as trade provides an important causal pathway through which industrialisation and technological capacity in a given country diffuses to another region (see Coe et al. 1997; Falvey et al. 2004; Jaworski and Keay 2020; Kaya 2010; Keller 1998). Yet, as noted in section 3.2, geographical indicators such as distance and contiguity are often used to compute a weighting matrix in the spatial analysis literature. To this end, we re-estimated equation 1 while employing geographical indicators as the weighting matrix.

The results of this exercise are reported in Table 4. Column 1 shows the result using relative distance as the weighting matrix. The spatially lagged term, Rho (ρ), turns significantly positive, indicating spatial dependence of industrialisation across countries in Africa. However, the coefficients of the direct and indirect effects of technological capability turn out to be statistically insignificant at all conventional significance levels. Column 2 shows the results when we employ contiguity as the weighting matrix. The coefficients of the direct and indirect effects of technological capability remain statistically insignificant, as in column 1, although the parameter ρ reverts to being statistically insignificant.

Compared to the baseline results, therefore, the results reported in columns 1 and 2 undermine the efficacy of the employed geographical indicators while extolling intra-Africa trade as a causal pathway to technological capability interdependence in Africa. This conclusion is supported by the additional results presented in columns 3 and 4 of Table 2. On the one hand, column 3 shows the results when we re-estimate equation 1 using an unweighted convex combination of intra-Africa trade and distance as the weighting matrix. Column 4, on the other hand, shows the results when we employ the unweighted convex combination of intra-Africa trade and contiguity as the weighting matrix. In both cases, the results are identical to those of the baseline results.

Table 4: Technology capability and industrialisation: Alternative weighting matrix

Technology capability and industrialisation: Alternative weighting matrix

Panel A: Direct effect	[1]	[2]	[3]	[4]
Technological capability	0.0731	0.0101	**0.1360***	**0.1360***
	(0.0747)	(0.0789)	(0.0742)	(0.0742)
Log GDP per capita	-1.3475***	-1.2601***	-1.1105***	-1.1105***
	(0.3489)	(0.3513)	(0.3425)	(0.3425)
Log GDP per capita squared	0.0701***	0.0633***	0.0536**	0.0536**
	(0.0241)	(0.0242)	(0.0236)	(0.0236)

Log population	2.9521***	3.4818***	2.0975***	2.0975***
	(0.7138)	(0.7082)	(0.7373)	(0.7373)
Log population squared	-0.0726***	-0.0861***	-0.0385*	-0.0385*
	(0.0217)	(0.0210)	(0.0214)	(0.0214)
Log natural resources	-0.0929***	-0.0925***	-0.0783***	-0.0783***
	(0.0219)	(0.0213)	(0.0211)	(0.0211)
Urban growth	0.0291**	0.0334***	0.0356***	0.0356***
	(0.0125)	(0.0129)	(0.0123)	(0.0123)
Panel B: Indirect effect				
Technological capability	-0.0349	-0.2052	**0.5263*** **	**0.5263*** **
	(0.1150)	(0.1483)	(0.1973)	(0.1973)
Log GDP per capita	-1.3415**	-1.0045	-5.7659***	-5.7661***
	(0.6524)	(0.9797)	(1.2805)	(1.2805)
Log GDP per capita squared	0.0848*	0.0920	0.3123***	0.3124***
	(0.0433)	(0.0682)	(0.0826)	(0.0826)
Log population	6.5352***	0.2809	8.0710***	8.0718***
	(1.6062)	(1.5875)	(1.9630)	(1.9629)
Log population squared	-0.1778***	0.0322	-0.2103***	-0.2103***
	(0.0502)	(0.0503)	(0.0605)	(0.0605)
Log natural resources	-0.0408	-0.0921*	-0.0139	-0.0139
	(0.0412)	(0.0534)	(0.0584)	(0.0584)
Urban growth	-0.0323*	-0.0774***	-0.0420	-0.0420
	(0.0183)	(0.0258)	(0.0393)	(0.0393)
Panel C: Total effect				
Technological capability	0.0383	-0.1951	**0.6622*** **	**0.6623*** **
	(0.1266)	(0.1396)	(0.1993)	(0.1993)
Log GDP per capita	-2.6890***	-2.2646**	-6.8764***	-6.8766***
	(0.8097)	(1.0883)	(1.3604)	(1.3604)
Log GDP per capita squared	0.1549***	0.1552**	0.3660***	0.3660***
	(0.0543)	(0.0756)	(0.0885)	(0.0885)
Log population	9.4873***	3.7627**	10.1685***	10.1693***
	(1.7045)	(1.6291)	(2.0954)	(2.0953)
Log population squared	-0.2504***	-0.0540	-0.2488***	-0.2489***
	(0.0529)	(0.0524)	(0.0652)	(0.0652)
Log natural resources	-0.1338***	-0.1846***	-0.0922	-0.0922
	(0.0465)	(0.0577)	(0.0633)	(0.0633)
Urban growth	-0.0032	-0.0440	-0.0064	-0.0064
	(0.0241)	(0.0306)	(0.0428)	(0.0428)
rho	0.1082**	-0.0348	0.0802	0.0802
lamda	0.0550***	0.0559***	0.0533***	0.0533***
No. of observations	950	950	950	950
R-squared	0.003	0.003	0.020	0.020

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Column 1 reports the results when distance is employed as a weighting matrix. Column 2 uses contiguity as the weighting matrix, while columns 3 and 4 show the results when a convex combination of regional trade and geography are employed jointly.

4.2.3 Alternative indicators of manufacturing

Thus far, our analysis has focused on manufacturing value added (% GDP). We extend our analysis by considering other indicators of manufacturing performance, as discussed in the literature on the data. The results of this exercise are reported in Table 5. Estimation across the columns is achieved using our preferred spatial weighting matrix, intra-Africa trade. Column 1 shows the results using manufacturing export diversity. The coefficient of technological capability turns significantly positive for the direct and indirect effects. Column 2 shows the results from the adapted index of RCA. The results are largely consistent with the previous results. Finally, column 3 shows the results for manufacturing efficiency. Two results stand out; first, we observe that technological capability in a given country significantly drives only its manufacturing efficiency, not that of other African countries. Second, improvements in manufacturing efficiency in a given African country drag other African countries' industrial development. In other words, there is manufacturing efficiency divergence rather than convergence in the region.

Table 5: Technological capability and industrialisation: Alternative indicators

Technological capability and industrialisation: Alternative indicators

Panel A: Direct effect	[1]	[2]	[3]
Technological capability	**0.1908*** **	**0.0401** **	**0.0175***
	(0.0374)	**(0.0201)**	**(0.0101)**
Log GDP per capita	0.1207	0.0612	-0.5273***
	(0.1737)	(0.0923)	(0.0451)
Log GDP per capita squared	-0.0064	-0.0042	0.0406***
	(0.0120)	(0.0064)	(0.0031)
Log population	2.7642***	2.2691***	0.5679***
	(0.3705)	(0.1988)	(0.0981)
Log population squared	-0.0687***	-0.0567***	-0.0090***
	(0.0108)	(0.0058)	(0.0028)
Log natural resources	-0.0160	-0.0229***	-0.0146***
	(0.0106)	(0.0057)	(0.0028)
Urban growth	0.0121*	-0.0010	-0.0006
	(0.0062)	(0.0033)	(0.0016)
Panel B: Indirect effect			
Technological capability	**0.4275*** **	**0.0956** **	-0.0183
	(0.1089)	**(0.0478)**	(0.0172)
Log GDP per capita	-3.4349***	-0.7749***	-0.6120***
	(0.6836)	(0.2832)	(0.0993)
Log GDP per capita squared	0.2106***	0.0496***	0.0313***
	(0.0451)	(0.0187)	(0.0066)
Log population	-5.0034***	1.3537***	0.5798***
	(1.0894)	(0.4728)	(0.1680)
Log population squared	0.1577***	-0.0494***	-0.0175***
	(0.0334)	(0.0145)	(0.0051)
Log natural resources	0.1145***	0.0264*	0.0000
	(0.0309)	(0.0137)	(0.0049)
Urban growth	0.0027	-0.0198**	0.0027
	(0.0207)	(0.0093)	(0.0033)
Panel C: Total effect			
Technological capability	0.6183***	0.1357***	-0.0007
	(0.1102)	(0.0473)	(0.0152)
Log GDP per capita	-3.3142***	-0.7136**	-1.1394***
	(0.7279)	(0.2997)	(0.0990)
Log GDP per capita squared	0.2042***	0.0454**	0.0719***
	(0.0484)	(0.0200)	(0.0066)
Log population	-2.2392*	3.6229***	1.1478***

	(1.1567)	(0.5005)	(0.1614)
Log population squared	0.0890**	-0.1061***	-0.0265***
	(0.0358)	(0.0156)	(0.0050)
Log natural resources	0.0985***	0.0034	-0.0145***
	(0.0335)	(0.0147)	(0.0048)
Urban growth	0.0148	-0.0207**	0.0021
	(0.0225)	(0.0100)	(0.0033)
rho	0.1162	-0.0525	-0.2712***
lamda	0.0136***	0.0039***	0.0009***
No. of observations	950	950	950
R-squared	0.371	0.047	0.008

Standard errors in parentheses
* p < 0.10, ** p < 0.05, *** p < 0.01
Note: Estimation is achieved using trade as the weighting matrix.

5. Conclusion

To date, how to unlock Africa's long-awaited industrialisation remains the priority agenda on the national and regional levels. This paper contributes to this discussion by bringing to the fore the role of technological capability, paying particular attention to the direct and indirect effects of technological capability on industrialisation. To this end, we employed a spatial econometrics model. The direct effect thus measures how a country's industrialisation trajectory is determined by its technological capabilities, while the indirect effect is the effect arising from the technological capabilities of its spatial partners – that is, other African countries. Akin to these, our econometrics model also enables us to determine whether the industrialisation trajectory in an African country drives industrialisation in other African countries.

To address our research objective, we first proposed a unified analytical framework to build a technological capability index for countries in Africa. Fitting the framework with hard data, we documented strong heterogeneities on the levels of technological capabilities among countries in Africa. In particular, we found that, while some countries already show strong technological capability, others are either still lagging significantly, or are upcomers. Furthermore, our econometrics results largely show evidence of positive spatial industrial development interdependence in Africa. However, the results are mostly statistically insignificant, which may be reflective of the region's existing low manufacturing base. The results for technological capability, however, show significant evidence of a positive association between technological capability and industrialisation for both the direct and indirect effects. In addition, we find that the indirect effect is higher than the direct effect, and that technological capability interdependence is propagated through regional trade.

Put together, our findings have important policy implications. First, the evidence for the heterogeneity of technological capability within Africa is suggestive of a unique window of opportunity for learning, given the advantages of relational proximity among African countries. Second, our results for technological interdependence call for regional cooperation in building technological capability in Africa, while underscoring the need to intensify intra-regional trade and build regional value chains on the continent. Cooperation in the building of digital and physical infrastructure is one area that deserves policy attention. More generally, removing trade barriers to encourage intra-African trade can be an important conduit for building capabilities and industrial development. The African Continental Free Trade Area (AfCFTA) can be an important policy lever for achieving these outcomes.

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Appendix

Table A1: Average technological capability index

Average technological capability index					
Country	Technological precondition	Technology imports	Technological effort	Technological infrastructure	Technological capability
Algeria	75	10	21	26	60
Angola	26	12	4	17	18
Benin	38	11	4	47	27
Botswana	58	12	4	79	41
Burkina Faso	22	10	4	41	15
Burundi	29	9	4	22	20
Cameroon	36	10	4	24	25
Cape Verde	67	19	4	82	47
Central African Republic	15	10	4	10	11
Chad	16	17	4	12	11
Comoros	47	9	4	41	33
Congo	37	24	4	20	26
Côte d'Ivoire	31	10	4	24	22
D.R. Congo	22	15	4	17	15
Djibouti	44	18	4	43	31
Egypt	66	12	80	35	81
Equatorial Guinea	34	19	4	23	24
Eritrea	23	12	4	24	16
Ethiopia	31	12	5	23	23
Gabon	51	13	4	39	36
Gambia	34	12	4	44	24
Ghana	43	13	4	57	31
Guinea	27	14	4	22	19
Guinea-Bissau	33	10	4	27	23
Kenya	46	11	22	35	41
Lesotho	44	13	4	57	31
Liberia	44	38	4	24	31
Libya	74	10	4	24	52
Madagascar	38	14	5	35	28
Malawi	41	11	4	44	29
Mali	23	12	4	32	16
Mauritania	37	19	4	26	26
Mauritius	79	12	4	96	56
Morocco	72	12	37	46	65
Mozambique	30	27	6	38	22
Namibia	56	16	5	67	40
Niger	11	14	4	27	8
Nigeria	29	10	11	19	24
Rwanda	46	11	5	46	33
Sao Tomé & Príncipe	55	24	4	57	39
Senegal	40	11	4	47	28
Sierra Leone	40	17	4	30	29
South Africa	71	10	95	71	90
Swaziland	45	10	4	42	32
Tanzania	49	13	4	35	35
Togo	42	12	4	30	30

Tunisia	92	13	27	56	76
Uganda	40	12	5	37	29
Zambia	39	15	6	46	28
Zimbabwe	40	10	4	16	28

Table A2: Technological capability subcomponents

Technological capability subcomponents

1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
	Technology precondition		
Niger	Ethiopia	Uganda	Gabon
Central African Republic	Guinea-Bissau	Sierra Leone	Sao Tomé and Príncipe
Chad	Equatorial Guinea	Malawi	Namibia
Democratic Republic of the Congo	Gambia	Togo	Botswana
Burkina Faso	Cameroon	Ghana	Egypt
Eritrea	Mauritania	Djibouti	Cape Verde
Mali	Congo	Lesotho	South Africa
Angola	Benin	Liberia	Morocco
Guinea	Madagascar	Swaziland	Libya
Burundi	Zambia	Rwanda	Algeria
Nigeria	Senegal	Kenya	Mauritius
Mozambique	Zimbabwe	Comoros	Tunisia
Côte d'Ivoire		Tanzania	
	Technology imports		
Central African Republic	Eritrea	Niger	Chad
Burkina Faso	Mali	Democratic Republic of the Congo	Mozambique
Burundi	Angola	Guinea	Equatorial Guinea
Nigeria	Benin	Ethiopia	Mauritania
Côte d'Ivoire	Senegal	Gambia	Congo
Guinea-Bissau	Malawi	Madagascar	Zambia
Cameroon	Togo	Uganda	Sierra Leone
Zimbabwe	Rwanda	Ghana	Djibouti
Swaziland	Kenya	Lesotho	Liberia
Comoros	Botswana	Tanzania	Sao Tomé and Príncipe
South Africa	Morocco	Gabon	Namibia
Libya	Mauritius	Egypt	Cape Verde
Algeria		Tunisia	
	Technology effort		
Niger	Niger	Niger	Niger
Central African Republic	Central African Republic	Central African Republic	Central African Republic
Chad	Chad	Chad	Chad
Eritrea	Eritrea	Eritrea	Eritrea
Mali	Mali	Mali	Mali
Guinea	Guinea	Guinea	Guinea
Guinea-Bissau	Guinea-Bissau	Guinea-Bissau	Guinea-Bissau
Equatorial Guinea	Equatorial Guinea	Equatorial Guinea	Equatorial Guinea
Gambia	Gambia	Gambia	Gambia
Cameroon	Cameroon	Cameroon	Cameroon
Mauritania	Mauritania	Mauritania	Mauritania
Congo		Cape Verde	Tunisia
Benin		Mauritius	
Senegal			

Sierra Leone			
Togo			
Liberia			
Swaziland			
Comoros			
Gabon			
Sao Tomé and Príncipe			
Libya			
Technology infrastructure			
Central African Republic	Niger	Burkina Faso	Benin
Chad	Mali	Mozambique	Senegal
Democratic Republic of the Congo	Côte d'Ivoire	Gambia	Ghana
Eritrea	Guinea-Bissau	Zambia	Lesotho
Angola	Cameroon	Uganda	Rwanda
Guinea	Mauritania	Malawi	Sao Tomé and Príncipe
Burundi	Madagascar	Djibouti	Namibia
Nigeria	Sierra Leone	Swaziland	Botswana
Ethiopia	Togo	Comoros	Cape Verde
Equatorial Guinea	Liberia	Tanzania	South Africa
Congo	Kenya	Gabon	Mauritius
Zimbabwe	Algeria	Egypt	Tunisia
Libya		Morocco	

Table A3: Total effect of technological capability on industrialisation

	Total effect of technological capability on industrialisation				
Log GDP per capita	-6.8582***	-5.2039***	-4.7650***	-7.3761***	-6.8766***
	(1.3577)	(1.1913)	(1.1261)	(1.4419)	(1.3604)
Log GDP per capita squared	0.3660***	0.2668***	0.2269***	0.3660***	0.3660***
	(0.0885)	(0.0800)	(0.0749)	(0.0885)	(0.0885)
Log population	9.9981***	9.9590***	10.5835***	14.8281***	10.1693***
	(2.1007)	(2.1233)	(2.1180)	(2.4123)	(2.0953)
Log population squared	-0.2489***	-0.2380***	-0.2727***	-0.2489***	-0.2489***
	(0.0652)	(0.0664)	(0.0653)	(0.0652)	(0.0652)
Log natural resources	-0.0922	-0.1128*	-0.1230**	-0.0922	-0.0922
	(0.0633)	(0.0634)	(0.0620)	(0.0633)	(0.0633)
Urban growth	-0.0064	-0.0102	0.0154	-0.0064	-0.0064
	(0.0428)	(0.0427)	(0.0434)	(0.0428)	(0.0428)
Technology precondition	0.4410***				
	(0.1327)				
Technology imports		0.0597*			
		(0.0353)			
Technology infrastructure			0.3264***		
			(0.1207)		
Technology effort				6.6828***	
				(2.0114)	
Technological capability					0.6623***
					(0.1993)
No. of observations	950	950	950	950	950

Standard errors in parentheses
* p < 0.10, ** p < 0.05, *** p < 0.01
Note: Estimation is achieved using trade as the weighting matrix.

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