Bridging technology divide to improve business environment: Insights from African nations

Abstract

Bridging the technology divide remains one of the contemporary business issues, yet limited scholarly attention has been devoted to exploring the gap between regional developing nations and their effects on can be bridged. The study examined the state of technological progress in Africa by applying an innovative two-step total factor productivity (TFP) analysis. We first estimated the TFP for 21 African countries with reference to South Africa (regional leader) and the United States (US) (international leader). We then applied the Phillips and Sul (2007) panel convergence tests. We found three convergence clubs with TFP levels relative to South Africa, where only most developed African countries have been able to catch-up. In the case of TFP levels relative to the US, we found two convergence clubs and only a couple of countries have managed to make short-lived progress of catching-up. Our analysis has implications in terms of capitalising on new technology for new businesses to flourish and accelerate the pace of change leading to the weeding-out of inefficient firms.

Key words: Technological progress; total factor productivity; Africa; Club convergence

1. Introduction

Over the past three decades or so, it has been demonstrated that technology catching-up can serve as a springboard for further industrialisation and faster economic development in developing economies (see Fuchs & Horak, 2008; World Economic Outlook, 2017). By "catching-up", we are referring to the bridging of the technological gap between lagging and leading nations (Perrez & Soete, 1988; Thutupalli & Iizuka, 2016). Indeed, emerging economies such as China, India and Brazil have successfully leapfrogged to the latest technologies in many sectors and have experienced sustainable economic development (Athreye & Cantwell, 2007; Buckley & Hashai, 2014; Lee, 2013; You & Sarantis, 2013). The catch-up process for lagging nations entails learning from leading nations to help absorb and diffuse technologies across the wider population (Malerba & Nelson, 2011; Thutupalli & Iizuka, 2016). This is more so for least developed African nations to not only bridge the gap with neighbouring nations, but also with the rest of the world. Indeed, bridging the technology divide has been regarded as one of the contemporary issues in the global economy (see World Development Report, 2016).

In spite of growing body of research on technology catch-up (e.g., Buckley & Hashai, 2014; Castellacci, 2006; Lee, 2013; Zhang & Zhou, 2016), much of the existing literature offers limited insights on the different types of the technology divide between regional nations, and compared with leading nations (see Fuchs & Horak, 2008). Such analysis could enrich our understanding of the issue of technology and digital divides, and provides basis for better public policy formulation. In this paper, we attempt to address this lacuna in the literature by examining the nature and effects of technology divide between regional nations.

We focus on Africa for two important reasons. First, although the post-colonial Africa has experienced an increased economic growth, foreign direct investment and trade with the rest of the world (Gui-Diby & Renard, 2015; Nyuur & Debrah, 2014; United Nations Conference on Trade and Development, 2010), it has increasingly become apparent the future of Africa's development and progress is partly predicated on its ability to bridge the so-called technological divide not only between its nations, but also with those of other fast industrialising countries in Asia, Latin America, North America and Europe (see Alzouma, 2005).

Second, despite solid pace of economic growth in recent decades, business failures in Africa remains regular occurrence (Amankwah-Amoah, 2014; Amankwah-Amoah and Debrah, 2014). According to the Global Entrepreneurship Monitor (2015, 2016), Africa has the highest Business Discontinuation Rate compared with other continents in 2015 and 2016. One of the important environment factors that attribute business failure is technological change (Hager et al., 1996; Tirole, 1988). Indeed, a growing body of knowledge has suggested that technology can unlock the potential of African industries and foster entrepreneurial development (Amankwah-Amoah, 2015). Therefore, bridging technology gap in African nations presents a critical challenge and an opportunity for African countries to create platforms for new businesses to flourish (see Amankwah-Amoah, 2016b).

To explore the issue, we apply an innovative two-stage approach to analyse total factor productivity (TFP) in Africa. Technology is a key non-input factor that drives the growth of TFP as using advanced technology to process input resources leads to higher efficiency of input utilisation, and hence greater value of outputs. As such, TFP is an excellent metric to analyse the state of technological catch-up and leapfrogging in Africa. We employ the superlative index number methodology (Caves, Christensen & Diewert, 1982; Diewert & Morrison, 1986). Such an index has a number of desirable properties and is widely employed by both academics and practitioners. See, for example, OECD (2001) and Griffith et al. (2004).

Thus, our estimation takes two stages. We first estimate the TFP for 21 African countries using the superlative index model. TFP are measured in relative terms to their regional leader South Africa and the global leader the US. At the second stage, we then apply panel convergence tests on the TFP to analyse the panel and club convergence pattern. Specifically we employ the Phillips and Sul (P-S) (2007) panel convergence method that is able to provide valuable information on the clustering pattern and the speed of convergence in TFP among African countries.

The study offers several contributions to technology and innovation literatures. First, in light of the global efforts towards bridging the technology divide, it is surprising that much of scholarly attention have been devoted to gaps between the world's developed and developing nations. As such, our understanding of the gaps between regional developing nations remains limited. This study contributes to the literature on technology catch-up (Landini, Lee, & Malerba, 2016; Lee & Lim, 2001) by examining the variation between regional nations as source of learning to facilitate technological leapfrogging. In addition, we also add to the growing body of research on the use panel convergence tests applying the P-S panel convergence tests on the relative TFP.

Furthermore, our analysis contribute to the literature by deepening our understanding of the important issue of technological catch-up and leapfrogging in Africa via a unique comparative regional and global perspective. Thus, we also shed light on the phenomenon of high business failure rates in Africa by looking at whether Africa's regional and global technology catch-up has been successful.

The rest of the article is presented as follows: Section 2 reviews the relevant literature on technological catch-up and leapfrogging. Section 3 describes the relevant empirical data used. Section 4 describes the analytical approach. Section 5 presents the estimation results, and Section 6 provides conclusions and policy implications.

2. Literature review

2.1. Technology catch-up and leapfrogging

Governments and international organisations such as the Organization for Economic Cooperation have long recognised the central role of technology in driving productivity and economic development (Wong & Goh, 2012). Through investments in technology, the newly industrialized economies (NIEs) in Asia including South Korea, Singapore and Taiwan were able to make the successful transition from traditional agriculture and primary commodities dependent economy to advanced and knowledge-based economy (Wong & Goh, 2015). To catch up with the forerunner, Lee and Lim (2001) suggest that, a latecomer has the choices of: a) following the path of the forerunners, b) skip stages of the path, or c) even create one of their own. The first option, path following approach, has the advantage of low costs of catch-up by adopting technologies that the forerunners no longer wish to keep because they now have low productivity. The second one, stage-skipping means that the latecomers skip the older technology to adopt the most up-to-date-ones, but this approach is costly and faces competition from the incumbent. The third option is one that the latecomers create their path of technology development by adopting the new generation of technology. Hence, the latecomers might have windows of opportunity to leapfrog the technology incumbents.

According to Perrez and Soete (1988), technology latecomers have the windows of opportunity to catch up or even leapfrog the forerunners when there is a paradigmatic change of technology due to either a disruptive shift in market demand or a major change of institutional factors, such as governmental intervention. During this window of opportunity, the incumbents might be locked into existing technologies, institutional routine and work practice, whereas the newcomers do not have those burdens and thus can skip the existing technologies to adopt the latest ones to capture the new market demands when supported by appropriate new institutional frameworks (Morrison & Rabellotti, 2016). Nevertheless, path-creating is risky, as the new technology might not be stable, and may have low productivity and high costs at the initial stage (Lee & Ki, 2016).

There have been successive catch-up cycles since the beginning of capitalism (Landini, Lee, & Malerba, 2016). A standard catch-up cycle consists of four stages: entry, gradual catching-up, forging ahead, and falling behind (Lee & Malerba, 2016). According to Landini et al. (2016), there are several variations of catch-up cycle in different industries. For example, there have been ‘persistent leadership cycles’ in the camera and memory chips industries (Kang and Song, 2016) and ‘coexistence of leadership’ and the ‘return of the old leadership’ in the wine industry (Morrison

& Rabellotti, 2016). Finally, there are many cases of 'aborted catch-up', where the latecomers were stuck at the stage of gradual catch-up or ceased to catch-up.

Abramovitz (1986) argued that both 'technological congruence' and 'social capability' are important for technology catch up by an emerging economy. Technological congruence refers the conditions in common with technology leader economies including factors such as availability of inputs and market demand. Social capability refers to factors education infrastructure, technical competence and the wider institutional factors (Morrison & Rabellotti, 2016). As such, catching up with the technology forerunners is more than mere adoption of new technology, but also it requires creativity and innovation (Lee & Lim, 2001; Morrison & Rabellotti, 2016). Wong and Goh (2015) suggested two models of technology catch-up in Asian countries: a) the model of supporting local new start-ups, such as those adopted by South Korea and Taiwan; and b) the model of learning from foreign direct investment (FDI) such as Singapore, China and Malaysia.

Observing the change of technology leadership at sectoral level, Lee and Malerba (2016) suggested that there have been successive changes of technology leadership between forerunners and latecomers indicating substantive reduced differences in market share between firms in developed country and those in latecomer country. At national level, Ahn (2016) recently demonstrated how Korea's technology policies help the country from catch-up development to advanced economy by adopting an institutional framework of consecutive value-based technological forecasting. Szczygielski, Grabowski, Pamukcu, and Tandogan (2017) assessed the efficiency of innovation support for firms in two technology-follower countries Turkey and Poland, and found that grants for research and development activities are helpful in improving firm performance in both countries. Using 'National System of Innovation' framework, Guennif and Ramani (2012) revealed the divergence between India and Brazil in pharmaceutical technology catch-up, with India being more successful than Brazil.

2.2. Total factor productivity and club convergence

The process of a latecomer country catches up with a forerunner country described as a process of convergence, which is an implication of neo-classical growth theory and a central topic in growth literature (Diamond, 1965; Islam, 2003; Solow, 1956). It posits when poorer countries grow at a faster rate than richer ones, they will eventually reach a unique equilibrium, a common balanced growth path. There has been growing research attentions paid on cross-country convergence since 1990s, to examine whether the latecomer countries were catching up with the forerunners (Dal Bianco, 2016). Researchers have examined convergence from different approaches, for example, income-convergence versus TFP-convergence, global convergence versus local or club convergence (Islam, 2003).

TFP-convergence is a commonly used one to examine technological catch-up (e.g. Dowrick & Nguyen, 1989; Madsen, 2007; Misra, Memili, Welsh, Reddy, & Sype, 2015; Wolff, 1991), this is because TFP closely reflects the levels of technology development (Islam, 2003). As suggested by Romer (1990), the growth of TFP is driven by technology development as a result of investment by profit-maximizing agents. In a study of convergence of TFP among the OECD countries over the period 1870 to 2004, Madsen (2007) found that 93% of the increase in TFP from the catching-up countries has been solely due to technology spillover from forerunner countries to latecomer countries. Technology spillover across countries are mainly through the channels of foreign direct investment and international trade (Keller, 2004). Research has shown that the more advanced of technology content in production, the faster growth and greater convergence rate (Dal Bianco, 2016).

Earlier empirical evidence also shows the different patterns of growth and countries do not converge at a common unique equilibrium: some countries persistently grow faster over a long period of time, some grow at a moderate rate, while many countries persistently suffer the lowest growth rate (Azariadis & Drazen, 1990). Consequently, a group of countries that reach a particular equilibrium and a unique common growth path will form a convergence club, and as such there exist multiple clubs of convergence in the world’s economy (Baumol, 1986; Durlauf & Johnson, 1995; Galor, 1996). Bernard and Jones (1996) have demonstrated that the potential for productivity growth is both country and sector specific. Park, Choi, and Hong (2015) recently examined the level of digitalisation convergence across countries, using information and communication technology development index. They revealed three convergence clubs, with the group of the highest level of convergence showed the lowest speed of convergence, while the group of lowest convergence level showed the fastest convergence.

2.3. Technology development across African countries

Government plays a central role in driving technology catch-up or leapfrog (Amankwah-Amoah & Sarpong, 2016). As shown by Galang (2012), government inefficiency could inhibits technology penetration, exacerbating the technology gaps between technology forerunner countries and the latecomers. In the past 20 years, African country governments have made efforts to integrate with the world market, and progress has been made in technology development and economic growth (Menyah, Nazlioglu, & Wolde-Rufael, 2014). Recent investigation by Amankwah-Amoah and Sarpong (2016) on solar technology development in Ghana during the period of 1980-2010 indicates an increased level of government involvement in technology adoption through tax relief and subsidies and a growth of public-private partnerships in technology management. However, because of policy ineptitude, the efforts made by government have not been fully conducive to technology transfer from in the increased inflow of FDI in Africa (Osabutey & Debrah, 2012). Unlike the newly industrialized countries in East Asia, Africa countries in general still lag behind in technology and innovation, and consequently economic development (Amankwah-Amoah, 2015).

Other major barriers to African countries' technological development are identified as lack of trade openness and poor financial system (Menyah Nazlioglu, & Wolde-Rufael, 2014). Amankwah-Amoah (2015) revealed that despite the opportunities of technology leapfrogging, lack of access to financing has restricted technological adoption in African countries. Financial system in Africa is still dominated by government-controlled banks, with little competition and as such resources allocation is highly political rather than based on economic considerations (Menyah Nazlioglu, &

Wolde-Rufael, 2014; Murinde, 2012; Ndulu, 2007). Trade openness or market liberalisation encourages international business and attracts foreign direct investment (FDI) which is essential for technology transfer to the host countries (Blalock & Simon, 2009; Girma, 2005; Pack & Saggi, 1997). Yet, as revealed by Osabutey, Williams, and Debrah (2014) that there are many critical weaknesses that inhibit technology transfer between foreign and local firms in Africa: the lack of management capability, overreliance on foreign inputs, limited collaboration between foreign and host country firms, outdated government regulations and limited enforcement capacity.

2.4. Technology catch-up and business failures in Africa

As mentioned earlier, Africa has the highest Business Discontinuation Rate compared with other continents in 2015 and 2016 (Global Entrepreneurship Monitor (2015, 2016)). Many studies have pointed out possible factors that might have contributed to this phenomenon (See Fatoki (2014) for a recent review on this issue)[1]. A number of studies have highlighted that lack of technology is a critical factor causing business failures in Africa (e.g., Boeker and Wiltbank, 2005; Tushabomwe-Kazooba, 2006; Phaladi and Thwala, 2008; Scheers, 2011; Seeletse, 2012). Some business owners generally believe that technology was unaffordable or expensive luxury (Seeletse, 2012), and others may simply be constrained financially (Scheers, 2011). Furthermore, in a recent study carried out by the World Bank (i.e., Kelly and Firestone, 2016) that tracked 117 Tech Hubs across Africa, it is found that these Tech hubs, many of which have been created in the last few years, have demonstrated a high failure rate and varying degree of success. Therefore, faster and robust technology progress forms an important condition to mitigate business failures in Africa.

3. Data description

The main data-source for the present exercise is the most recent release of the Penn World Table

[1] According to Fatoki (2014), potential factors include both internal ones (i.e., lack of management experience, lack of functional skills and poor staff training and development and poor attitudes towards customers) and external ones (i.e., non-availability of a logistics chain and a high cost of distribution, competition, rising costs of doing business, lack of finance and crime.

(PWT 9.0). In the last forty years, the PWT has been a canonical source for comparable real GDP data across countries. More importantly, as explained by Feenstra et al. (2015), PWT 9.0 has three main advantages with respect to its predecessors. First, it provides measures of real GDP from both the expenditure and the production sides. Therefore, by taking the latter indicator it is possible to evaluate and compare countries' productive capacity. Second, PWT 9.0 encompasses capital stock series. This information, together with new data on real inputs (i.e. labour income in real terms), enables researchers to construct and compare TFP across countries. The third advantage of PWT9.0 is that it employs interpolated price indexes. Hence, PWT9.0 provides measures of real GDP that correct for changing prices over time and it employs International Comparison Programme benchmarks from multiple years. Thus, all series calculated in "real terms" are made less sensitive to the choice of the base year, minimising the problem on real GDP estimates in non-benchmark years noted by Johnson et al. (2013).

All the above improvements brought by PWT9.0 make such a dataset an extremely appealing choice for the calculation of technological efficiency in production as well as for evaluating its dynamic across countries and over time. It is hence the database used in our analysis.

In particular, the PWT9.0 series here employed are:

- $RGDP^{O}$: Output-side real GDP at chained PPPs (in millions of 2011US$), this series is based on prices that are constant across countries and over time;
- $CGDP^{O}$: Output-side real GDP at current PPPs (in millions of 2011US$), this series is based on prices that are constant across countries in a given year;
- CK: Capital stock at current PPPs (in millions of 2011US$);
- EMP: Number of persons engaged (in millions);
- HC: Human capital index, based on the average years of schooling from Barro and Lee(2012);
- LABSH: Labour income of employees and self-employed workers as a share of nominal GDP

It is worth noticing that, in order to make our TFP estimates comparable across countries and over time, we need to work with series that should be expressed at chained PPPs. This is problematic when capital stock series is considered, as PWT 9.0 reports it in current and not chained PPPs. To overcome this difficulty, we combine the information on capital stock and GDP at current PPPs with the one of GDP at chained PPPs. In particular, we calculate the capital share, as the ratio of capital stock and the output-side real GDP, both expressed at current PPPs (i.e. K_share= CK/ $CGDP^O$); then we multiplied such a ratio by the output-side real GDP at chained PPPs (i.e. RK=K_share* $RGDP^O$). Thus, having obtained capital stock data that are expressed in chained PPPs, we can calculate TFP series that are comparable across countries and over time. This is explained in detail in Section 4.1.

4. Methodology

4.1. TFP estimation

Our TFP estimates are obtained employing the superlative-index number methodology, as described in the seminal contributions of Diewert (1976) and Caves, Christensen and Diewert (1982). Such an index is superlative and transitive. The former implies that it provides a TFP measure that is as accurate as possible (i.e. it is not an approximation), and the latter ensures that the choice of the term of reference, which can be a country and/or year, is inconsequential. The transitivity property can be proved for the multilateral version of the index (see for details Mas and Stehrer, 2012) as well as for the generic base country j, as done by Feenstra et al. (2015). It allows us to isolate the productivity differences, among two (or more) countries, not explained by differences in productive inputs and, thus, it provides a measure for technological progress that is comparable across countries.

The above mentioned property of the TFP indexes allow researchers to obtain information on differences in TFP levels, rather than on growth rates. As stressed by Hall and Jones (1999), this is particularly important as cross-country differences in TFP growth rates have been shown to be as mostly transitory. By its very construction, the Törnqvist index used in our study measures the (output) distance between observed and efficient output. In the present work, we have assumed that there are two production possibility frontiers. One is regional and this is South Africa, while the other is international or global and this is the USA.

South Africa has been Africa's largest economy since 1997, only being taken over by small amount by Nigeria in period 2012-2016 (based on GDP (2010 constant US$) provided by the World Development Indicators). South Africa has relatively stable economic growth rate compared with most of other African countries, especially in the recent decade after the 2008 global financial crisis. More importantly, measured by GDP per capita (2010 constant US$) (World Development Indicators 1997-2016), South Africa is the economy with the highest living standard in the region since 1997. With regards to the level of technology, despite of recent mild slowing down in productivity growth compared with other African countries, South Africa remains the regional technological leader (Dessus et al., 2017). According to a recent report Information Technology and Innovation Foundation (Ezell, et al., 2016), South Africa was ranked number 30 out of 56 countries in terms of its domestic policies supporting global innovation, highest for African countries and higher than South Africa's BRICS partners (i.e., Brazil, Russia, India and China). Therefore, South Africa would be an appropriate regional benchmark for the purpose of investigating the process of technological catching-up within the region.

As for the international leader, the USA is widely recognised as the "world technological frontier" (Feenstra et al., 2015). Moreover, in a recent study by Tiruneh et al (2017), it is found that technology spillovers from the US have a stronger impact on labour productivity in African countries compared with any other developed countries. Some previous studies comparing African countries' TFP with the one of the USA includes Van Dijk (2003) and Edwards and Golub (2003). Therefore, by doing the same our results also become comparable with the ones of the (scant) established literature.

More formally, let assume that production output of a generic country is a function of capital stock and employment and that the production function is translog with identical second-order term; that constant returns to scale apply and that inputs are measured perfectly and in the same units for each observation. In symbols:

$$lnY = \alpha_0 + \alpha_1 lnL + \alpha_2 lnK + \alpha_3 (lnL)^2 + \alpha_4 (lnK)^2 + \alpha_5 (lnL * lnK)$$

Where constant returns to scale hypothesis requires $\alpha_1 + \alpha_2 = 1$ and $2\alpha_3 + \alpha_5 = 2\alpha_4 + \alpha_5 = 0$. Further, perfect competition is assumed in both output and input markets. It is worth noticing that all the stated assumptions are necessary to derive the TFP superlative index number. Nonetheless, some progress have been recently made in incorporating imperfect competition into the measurement of productivity, see for example Burstein and Cravino (2015).

Relying on the concept of distance function, Caves et al. (1982) derive the TFP index number of bilateral as well as multilateral comparisons. As for the TFP index for bilateral comparisons, it is assumed that there are two countries, *b* and *c*, where country *b* is the basis of comparison. The distance function $D_c(Y_b, L_b, K_b)$ represents the minimum proportional decrease in Y_b such that the resulting output is producible with the inputs and productivity levels of *c*. Or, $D_c(Y_b, L_b, K_b)$ is the smallest input bundle capable of producing Y_b using the technology in country *c* (i.e. $D_c(Y_b, X_b) = \min\{d \in R_+ : f_c(dX_b) \geq Y_b\}$, where $X_b = (K_b, L_b)$ represents country's *b* labour and capital input and Y_b is the previously described translog production function. Caves et al (1982) show that the Mälmquist index (i.e. the geometric mean) of two distance functions for any two countries, *c* and *b*, provides a superlative and transitive index number for TFP. Superlative means that is exact for the flexible aggregator function chosen (i.e. translog production function) and, thus, it is not an approximation (see for more details Diewert, (1976) and its result on the use of Törnqvist-Theil approximation to the Divisia index (Törnqvist, 1936)). It is also worth noticing that an aggregator function is flexible if it can provide a second order approximation to an arbitrary twice differentiable linearly homogeneous function. Finally, thanks to transitivity, the choice of base country and year is inconsequential. Such desirable properties have made the superlative index number a well employed methodology for TFP calculation, see for example Harrigan (1997), Griffith et al. (2004) and Dal Bianco (2016).

Drawing on these results, Feenstra et al. (2015) show that, the productivity level in country *c* relative to country *b* can be expressed as the ratio of output-side real GDP divided by the Törnqvist index of factor endowments for the country of reference. As we are interested in TFP measures that are comparable across countries and over time, we employ the output-side real GDP at chained PPPs (i.e. $RGDP^O$), instead of the output-side real GDP expressed at current PPPs (i.e. $CGDP^O$), as well as our measure for capital stock, which is expressed in at chained PPPs US$ (i.e. RK). In symbol:

$$\frac{TFP_{ct}}{TFP_{bt}} = \left(\frac{RGDP^o_{ct}}{RGDP^o_{bt}}\right) / Q_{cbt} \qquad (1)$$

where Q_{cbt} is the Törnqvist index of factor endowments for the country of reference, which can be formally written as:

$$Q_{cbt} = \frac{1}{2}(LABSH_{ct} + LABSH_{bt})\left(\frac{EMP_{ct}}{EMP_{bt}}\,\frac{HC_{ct}}{HC_{bt}}\right) + \left[1 - \frac{1}{2}(LABSH_{ct} + LABSH_{bt})\left(\frac{RK_{ct}}{RK_{bt}}\right)\right]$$

where *b* indexes the country of comparison, which in our case is either regional of the global technological leader; *c* represents the generic Sub-Saharan Africa (SSA) country in the sample and *t* indexes any year between 1980 and 2014. For the meaning of all other variables we remind to the previous section.

Taking into consideration the most up-to-date data (NSF, 2016), we chose the US as international leader, while the regional leader is South Africa. Such a choice has been made employing the TFP superlative index number methodology for multilateral comparisons. In particular, following Griffith et al. (2004), we calculated the TFP index taking as basis for comparison the average of Sub-Saharan African countries. As South Africa exhibits the highest multilateral TFP index in almost all years relevant for our analysis, it can be considered as the regional technological leader. Multilateral TFP index calculations are not reported here but they are available upon request.

Applying Equation (1), for both the regional and the international leader, we obtained two TFP series: TFP_SA and TFP_USA (i.e. productive efficiency of each SSA country, with respect to South Africa and USA, respectively). Figures 1 to 3 report such estimates.

4.2. The Phillips and Sul Convergence Test

As discussed earlier, the P-S (2007) method is based on a time-varying factor representation and hence it is capable of accommodating long-run co-movement in aggregate behavior outside the cointegration framework and allowing for the modelling of transitional effects. Particularly, idiosyncratic factor loadings allow for individual heterogeneous and a period of transition in a path that is ultimately governed by some common long-run stochastic trend. Therefore, the P-S (2007) method can not only reveal the speed of convergence (if present) for the full panel, but also highlight the different extent and speed of the convergence in the sub-groups of members through its club formation procedure.

Relative Transition Paths

Consider a variable X_{it} where i=1,2,…,N; t=1,2,…,T. Following P-S (2007) the variable can be decomposed into g_{it}, the systematic components capturing the common components of cross-sectional dependence in a panel, and a_{it}, the transitory components, as follows:

$$X_{it} = g_{it} + a_{it}$$

P-S (2007) propose a time-varying loading factor representation:

$$X_{it} = \left(\frac{g_{it} + a_{it}}{\mu_t}\right)\mu_t = \delta_{it}\mu_t \quad \text{for all i and t,} \qquad (2)$$

where μ_t is a common component and δ_{it} is a time-varying idiosyncratic element that measures the economic distance between the common trend component μ_t and X_{it} at time t. Specifically, δ_{it} is modeled in a semi-parametric form implying non-stationary transitional behaviour in the following way:

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha}, \qquad (3)$$

where δ_i is fixed, ξ_{it} is *iid*(0, 1) across i but weakly dependent over t, and $L(t)$ is a slowly varying function (e.g., log t) for which $L(t) \to \infty$ as $t \to \infty$. Equation (3) ensures that δ_{it} converges to δ_i for all $\alpha \geq 0$, which therefore becomes a null hypothesis of interest for a cross section unit. For a panel, the corresponding null hypothesis would become $\delta_{it} \to \delta$ for some δ as $t \to \infty$ and $\alpha \geq 0$.

The main procedure of the P-S (2007) convergence test is to calculate the time-varying load loadings δ_{it} such that we can determine the club convergence if this loadings converge. To do so, P-S (2007) define the transition coefficient as h_{it} and to extract the time varying factor loadings δ_{it} as follows:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}\mu_t}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}\mu_t} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \quad (4)$$

where h_{it} is the transition parameter that measures δ_{it} in relation to the panel average at time t and therefore describes the transition path for individual i relative to the panel average. The Hodrick and Precott (H-P) (1997) filter is employed to remove the cyclical trend from the original data. The filtered transition parameter coefficients is denoted as $\hat{h}_{it}$ while the extracted time trend as $\hat{X}_{it}$.

The most important part of the club convergence test is to construct the cross sectional variance ratio $\frac{H_1}{H_t}$ where:

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(\hat{h}_{it} - 1)^2$$

P-S (2007) show that the transition distance H_t has a limiting form of:

$$H_t \sim \frac{A}{L(t)^2 t^{2\alpha}} \text{ as } t \to \infty$$

where A is a positive constant, *L(t)* is a function of t and α denotes the convergence speed. To test for the null hypothesis of convergence P-S (2007) perform the log t regressions which are explained next.

The log t Regression

A simple regression-based testing procedure is proposed by P-S (2007) where the null hypothesis of convergence is:

$H_0: \delta_i = \delta \; and \; \alpha \geq 0$

against the alternative

$H_1: \delta_i \neq \delta$ for all i or $\alpha < 0$

Correspondingly, the following OLS regression is performed:

$$Log\left(\frac{H_1}{H_t}\right) - 2log\, L(t) = \hat{a} + \hat{b}\, log\, t + \hat{u}_t \qquad (4)$$

where $L(t) = log(t+1)$, the fitted coefficient of log t is $\hat{b} = 2\hat{\alpha}$, and $\hat{\alpha}$ is the estimate of α in the null hypothesis. To account of the impact of initial conditions on the test the empirical regression run after a fraction of the sample is removed. The data for this regression starts at some point $t = [rT]$ with $r > 0$. P-S (2007) recommend $r = 0.3$. For inference purpose they employ a one-sided t test of null $\alpha \geq 0$ by using $\hat{b}$ and a standard error estimated using a heteroskedasticity and autocorrelation consistent (HAC) estimator. Given that the test statistic $t_{\hat{b}}$ is normally distributed, the decision rule for the null hypothesis of convergence is rejected if $t_{\hat{b}} < -1.65$.

Club Convergence and Clustering

P-S (2007) argue that a strict rejection of the null of full panel convergence may not necessarily rule out the existence of sub-group convergence within the panel. They correspondingly developed a club convergence algorithm detect units of such clusters. The clustering algorithm is based on repeated log t regressions and contains four main steps which are described below.

Step 1 (Ordering): Order the member (i.e. the X_{it} series) in the panel according to the last observation.

Step 2 (Core Group formation): Select the first k highest panel units are selected to form the subgroup G_k for some $N > k \geq 2$. Calculate the convergence t-statistic $t_{\hat{b}}(k)$ for each k. the core group size k^* is chosen by maximising $t_{\hat{b}}(k)$ under the condition that $\min\{t_{\hat{b}}(k)\} > -1.65$. If $k^* = N$, there is full panel convergence. If $min\{t_{\hat{b}}(k)\} < -1.65$ for$k = 2$, the first unit is dropped and same procedure for the remaining units is carried out. If $min\{t_{\hat{b}}(k)\} < -1.65$ for every subsequent pair of units, there are no convergence clusters in the panel. In all other cases, a core group can be detected.

Step 3 (Club Membership): Select units for membership in the core group (Step 2) by adding one remaining units at a time to the core group and perform the log$\mathrm{t}$ test each time. If the associated t-statistics is greater than zero (conservative choice), the new unit will be included in the current sub-group. If then the log$\mathrm{t}$ test for this sub-group shows $t_{\hat{b}} > -1.65$, the formation of this sub-group is confirmed.

Step 4 (Recursion and Stopping): Perform the log t test on the group of units not selected in step 3. If this set of units converges, then the second club is formed. Otherwise, repeat Steps 1 to 3 to reveal some sub-convergent clusters. If no sub-groups are found (Step 2), then the remaining units display divergent behaviour.

5. Empirical results

5.1. TFP estimation

Figures 1 to 3 report our estimates of TFP for each SSA country. In particular, Figure 1 shows the TFP index, with respect to South Africa; Figure 2, with respect to the US and Figure 3 compares the aforementioned series. The corresponding descriptive statistics are reported in Table 1.

These graphs document that, exceptions made for Botswana, Mauritania, Namibia and Sudan (former), the technological performance of SSA countries has been much lower than their regional leader (Figure 1) in the period considered. Expectedly, the levels are even lower when SSA countries are compared with the international leader, the US (Figure 2). Such graphical intuition is confirmed by the first two columns of Table 1, where it can be noticed that the majority of the countries exhibit a very low TFP. Further, the distribution of the indexes appears quite symmetric, as the mean and the median values are relatively close in almost all of the cases. For what concerns the four aforementioned exceptions, Botswana better than average technological performance can be explained considering its regional proximity with the regional leader, its favourable political institutions (i.e. stable and democratic) as well as its flourishing touristic sector (African Union, 2015). As for Mauritania, UNCTAD (2010) documents the historic and more present efforts to ensure technological development and capability building in order to promote sustainable growth and to avoid the resource course, possibly generated by a recent oil discovery. Passing to Namibia, this is quite exceptional among SSA countries. Its German colonial origin and its political institutions have been proved to be conducive to economic growth and development. In particular, UNESCO (2005), UNICEF (2015) and different reports by the Namibian National Commission on Research Science and Technology document the strategic importance given to research promotion and development as well as to Information and Communication Technologies (ICTs), as development booster. Finally, as for Sudan, Nour (2013) documents that after the 1999 oil discovery, public spending increased sensibly. In particular, the share of development expenditure over total expenditure passed from 9% in 1999 to an average 24% between 2004 and 2009. Moreover, the same author shows that the 2000s have been a very important decade for Sudanese technological development. In particular, Nour (2013) provides evidence of government plans for boosting technological development, such as basic research conducted by public universities and coordinated by the Ministry of Scientific Research. In sum the descriptive evidence for Botswana, Mauritania, Namibia and Sudan illustrate points towards the importance of institutional development and the role of government in boosting technological development, as illustrated by Mazzuccato (2013).

For what concerns, catching-up tendencies, the graphs show different patterns. In particular, they are more evident in some cases (e.g. Namibia) than in others (e.g. Burundi and Cameroon). Moreover, it is interesting to notice the U-shaped pattern of Nigeria. In particular, Nigerian TFP seems to have been particularly high at the beginning of the sampled period, then declined and then mildly risen again. As according to Onipede (2010), high TFP levels at the beginning of 1980s can be explained in the light of the 1981-1985 National Development Plan, aimed at diversifying the economy, modernising the agricultural sector as well as at technological development. In 1985, the military government of General Ibrahim Babangida came into power, with its austerity measures as well as the focus on the oil sector (Afolabi, 2008). Nigerian TFP index started rising again at the beginning of 2000s. Narrative evidence suggests that this might be due to the incredible growth of ICTs technologies and the diffusion of Internet. In particular, in year 2000 the government plan for the development of national ICT was launched. This led, among other things, to the ICTs training of Nigerian workers by foreign firms, Chinese ones in particular[2].

5.2. The Phillips and Sul Convergence Test Results

Once the above were completed, we then moved on to apply the $log\ t$ convergence and club convergence tests to the relative TFP levels. Following the recommendation by P-S (2007), the convergence analysis is conducted on filtered data series in which the cyclical component of each series is removed by applying the H-P filter. As mentioned in Section 4.2, h_{it}, the relative transition parameter, describes the transition path for country i *vis-à-vis* the panel average. Correspondingly, the relative transition parameters with the cross sectional means in each of the convergent club would demonstrate one club's behavior in relation to the clubs' average. Following P-S (2007), for convergent clubs, if present, we present their relative transition parameters. This procedure is very insightful as important inference can be drawn based on such visual illustration of each club's relative transition path.

We first report the full panel and club convergence tests results of the TFP levels relative to South African and the US (Table 2), then present the relative transition parameters of the corresponding convergence clubs (Figure 4 and Figure 5). The $log\ t$ convergence regression results presented in the upper panel of Table 2 suggest that, since $t_{\hat{b}} < -1.65$, the null of convergence is rejected in both the TFP levels of the 21 African countries relative to their regional leader South

[2] We further calculated the TFP gap between SSA countries and South African and the US as one minus the relative TFP presented in Figures 1 and 2. However, given they the mirror image of the relative TFP and to save space, we do not present the TFP gaps here, although they are available upon request. For readers who are interested, we also carried out extra P-S convergence tests on TFP gaps and the results confirm the convergence tests on the relative TFP.

Africa as well as relative to the global leader the US. It implies that there is no full panel convergence in both cases. We were not surprised by this finding as a full panel convergence would only be possible if the relative TFP levels of all countries have moved towards similar values via similar paths. This is clearly not the case, as shown in Figures 1 and 2.

As earlier mentioned, an important advantage of the P-S (2007) method is that it is able to highlight the different extent and speed of the convergence in the sub-groups of countries through its process of club formation. The lower panel of Table 2 presents the results of such club convergence tests.

For the TFP level of the 21 African countries relative to their regional leader South Africa, three convergent clubs are detected. Club 1 includes Botswana, Mauritania, Namibia, Nigeria and Sudan (Former). Club 2 includes Benin, Burkina Faso, CÃ´te d'Ivoire, Lesotho, Mozambique, Senegal and the U.R. of Tanzania: Mainland. Club 3 includes Burundi, Cameroon, Central African Republic, Kenya, Niger, Rwanda, Sierra Leone, Togo and Zimbabwe. The speed of convergence, measured by the value of $\hat{b}$, shows an interesting decaying order, with Club 1 has the highest speed of convergence, followed by Club 2 and Club 3. Given that Club 1 contains most countries with the highest TFP level African countries in our sample and Club 3 contains lowest, it seems that in Africa, the speed of catching up within countries with already high TFP level are much faster than that of the ones with low TFP level. In all three clubs $\hat{b} < 2$ and thus there is convergence in rates (conditional convergence) rather than convergence in levels (absolute convergence).

Examining this time the corresponding club transition paths as indicated by the relative transition parameters in Figure 4[3], countries in Club 1 have the highest level of relative TFP compared with other two clubs throughout our sample period. However, there had been a dip from 1980 to early 1990s. This could be mainly due to the substantial decline in relative TFP level in Nigeria during this period (Figure 1). Nigeria had negative GDP growth in 7 years during the period

[3] To save space, here we do not present the individual transition parameter for each country. They are available upon request.

1980-1991. Negative GDP growth occurred again in 1995 but then it grew at a fast pace for the rest of our sample period (average grow rate was 6.8% during 1996-2014 according to the World Bank). The relative level of TFP of Club 1 had started to increase after the mid-1995 until the end of our sample period, indicating countries in Club 1 are catching up fast with their regional leader South Africa. In contrast, the relative TFP level of countries in Club 3 show an opposite trajectory. There were short lived trend in growth from 1980 to end of the 1980s and then a declining trend took over for the rest of the years. It implies that compared with other African countries (especially compared with countries in Club 1), the catching-up between Club 3 countries and their reginal leader South Africa is missing. In terms of Club 2, it is interesting to observe that the trajectory has remained stable, only showing a fairly slow trend of growth during the mid-1990s until early 2000s but reversed to very slow trend of declining since mid-2000s. Overall, the relative TFP level for the three clubs had been moving towards each other during the period 1980-the early 1990s but they had drifted apart since then. By 2014, their distance had been larger than 1980.

Moving on to the case of TFP levels of the 21 African countries relative to the international leader, i.e., the US, we observed a re-configuration of convergent clubs. There are now two clubs with Club 1 including the same countries as Club 1 in the case of TFP levels relative to the regional leader South Africa and Club 2 merges countries in the previous Clubs 2 and 3. Similar though to the TFP levels relative to South Africa, we observed rate (conditional) convergence rather than level (absolute) convergence (since in all cases $\hat{b} < 2$). However, it is important to point out that the value of $\hat{b}$ for Club 1 countries in the case of TFP levels relative to the US is much higher ($\hat{b} = 1.847$) than the same countries in the case of TFP levels relative to South Africa ($\hat{b} = 1.206$). It implies that for this group of countries, their TFP level is converging faster to the international leader the US than their regional leader South Africa. This could be due to that the level of countries in Club 1 had been growing in a pace that is quite fast. For instance, the TFP level of Namibia has surpassed that of the regional leader South Africa in last three years of our sample period 2012-2014 (Figure 1), although on average the TFP level of Namibia is still lower than that of South Africa.

Consequently, a faster speed of convergence between Club 1 countries with US than with South Africa is observed. With regards to Club 2 where the rest of the 17 countries are included, we observe a speed of convergence ($\hat{b} = 0.245$) that is much lower than Club 1, most likely led by a much slower growth in TFP level compared with countries in Club 1.

The transition paths of these two clubs are depicted in Figure 5. The two clubs exhibited opposite transition paths, with Club 1 far above Club 2 throughout the sample period. It is interesting to observe that until the mid-1990s, the relative transition path of Clubs 1 and 2 had been actually moving towards each other. It perhaps reflected the decline in relative TFP levels in some Club 1 countries during this period, such as Nigeria and Mauritania, and the increase in relative TFP levels in come Club 2 countries, such as Lesotho, Sierra Leone and Zimbabwe, despite relative TFP levels are higher in Club 1 than in Club 2. However, such trends have reversed since the mid-1990s. The relative transition paths of these two clubs started to diverge since the mid-1990s and only towards the end of the sample period the gap between these two clubs ceased increasing, stabilising at levels slightly higher than ones observed in 1980.

To summarise, we observed some of these systematic patterns in Figures 4 and 5. Looking specifically at a regional perspective, first, there are three convergent clubs including the most developed (Club 1), less developed (Club 2) and least developed African countries (Club 3) in our sample. Second, there had been signs of these three clubs converging towards each other during 1980 to the mid-1990s, which implies that the least developed African countries in our sample is doing rather well in terms of catching-up with their regional leader South Africa when compared with the most and less developed peers. Third, however, during the mid-1990s to 2014, we observe a divergent picture. Specifically, club includeing the most developed countries are leading the way of catching-up with their regional leader South Africa, while the less developed African countries are just maintaining their position when measured by their relative TFP to South Africa. Unfortunately, the least developed African countries (e.g., Sierra Leone, Zimbabwe) seemed to have lost the momentum and their TFP growth have been too slow such that they have become increasingly lagging behind the most developed African countries club.

We now turn to the results on the TFP level relative to the international leader the US. First, the most developed African countries again stand out forming the first club but now all the rest of the countries formed the second club. Second, similar to the relative to South Africa case, we observed the two clubs converged between 1980-the mid-1990s, and then diverged again. It echoes that many African countries in Club 2 have exhibited TFP that became lower than the US after mid-1990s (e.g., Senegal and Zimbabwe) while countries in Club 1 made some progress in catching-up with the US (e.g., Namibia and Nigeria), albeit slow or short-lived. Third, there is not a middle group whose TFP level has remained stable compared with other clubs compared with Figure 4. Therefore, although overall progress of SSA countries catching-up with the US is missing, there are nevertheless a handful of countries have made some progress, albeit short-lived.

6. Conclusion

In this paper, we examined the issue of technological catch-up in Africa using an innovative two-step approach. Specifically, we used most recent annual data from the Penn World Table (PWT 9.0) and employed the superlative-index number methodology. Based on this, we first estimated TFP for a sample of 21 African countries with reference to their regional leader, South Africa, as well as the international leader, the US. At regional level, we uncovered clear evidence of technological catching-up process for a small group of countries in our panel (e.g., Botswana, Mauritania, Namibia and Sudan (former)) with their regional leader South Africa, whilst for the rest of the countries demonstrated signs of catching-up are only observable towards the end of our sample period. When compared with the US, the majority of SSA countries have simply remained at level of relative TFP. In many cases, a decline of their TFP relative to the US is shown (e.g., Central African Republic, Senegal and Sierra Leone). Even for countries that are doing well in catching-up at regional level, i.e., Botswana, Mauritania, Namibia and Sudan (former), either their catching-up with the US is quite short-lived, or only occurred towards the end of our sample period. It shows the technological level of SSA as a whole (including regional leader South Africa) has not been growing as fast as the US and hence catching-up at international level seems to be missing. It may be that the limited progress in the catch-up process is rather attributed to factor endowment, level of education and technology/knowledge transfer and economic factors. Indeed, as suggested by Tiruneh et al. (2017), technology spillovers from the US to Africa is influenced by human capital stock and government stability in the recipient countries. It could also be a result of lacking intraregional growth spillovers within Africa (as suggested by Roberts and Deichman (2011)) and deteriorated global environment after 2008 (as suggested by Drummond and Ramirez (2009)).

We then applied the P-S panel convergence tests to our TFP estimates to reveal whole panel and club convergence information. It enabled us to understand whether TFP levels of SSA countries are moving towards the regional and international leader together as a whole, or in the form of various clubs that have different trajectories and speeds of convergence. As expected, there was no full panel convergence in both cases of SSA TFP levels relative to South Africa and the US. The following club convergence tests detected three and two convergence clubs in the former and latter case, respectively. With regards to TFP level relative to South Africa, the three clubs generally include most developed (Club 1), less developed (Club 2) and least developed African countries (Club 3), with the three corresponding relative transition parameters first converging but then became divergent again towards the end of our sample period. It implies under the overall evidence of regional catching-up process, the least developed SSA countries have initially done well up until the early 1990s but then lost their momentum, whilst a few most developed SSA countries have kept up with the catching-up and others simply maintained their positions. The results on the TFP level relative to the US were more polarised, with the relative transition parameters of Club 1 and 2 moving in opposite directions in the past twenty years. It suggests that although progress of catching-up with the US is missing for SSA countries as a whole, there are nevertheless a handful of SSA countries (in Club 1) are performing better than others, making some progress of catching-up, albeit short-lived.

From public policy standpoint, there is evidence of regional catching-up with South Africa, but less developed countries (Club 3) seem to have lost momentum of TFP growth. In this direction, it would be useful to promote help within the SSA group, i.e., more advanced SSA countries (Club 1) assist countries in Club 2 showing them experiences in catching–up. This reinforces the arguments that technology catch-up process entails learning from leading nations and providing the conditions for knowledge diffusion and best practices to spread among nations (Malerba & Nelson, 2011; Lall, 1996). Given today's uncertain global environment, knowing the nature of the gap between African countries and leading global leader would help in designing sector-specific policy measures to boost access to technology and thereby creating platform for faster technology diffusion.

Overall, the evidence of global catching-up with the US is missing. SSA group (including South Africa) as a whole needs to refer to other developing countries' (China, India) catching-up experiences (see Mathews 2002; Lall, 1996). In both cases least developed SSA countries seem to lagging further away from most developed SSA countries, regionally and internationally. This is an undesirable trend in SSA. Ultimately, new policy framework is needed to reduce such divergence among SSA countries (see Archibugi & Pietrobelli, 2003; Lall, 1996; World Development Report, 2016). It is also worth mentioning that our findings of generally missing evidence of regional and global catching-up in Africa provide an important explanation to high business failures in the region given that lack of technological progress is widely regarded as one of the key causes of high business failures in Africa (e.g., Boeker and Wiltbank, 2005; Tushabomwe-Kazooba, 2006; Phaladi and Thwala, 2008; Scheers, 2011; Seeletse, 2012).

We are aware that measurement issues concerning output and productive inputs are common to both deterministic and econometric methodologies aimed at retrieving information on productivity (Cohan & Harcourt, 2003), including our superlative index method. Also despite the advantages of the P-S panel convergence method in revealing club clustering pattern and speed of convergence, it does not have the scope to identify various factors that might have contributed to the absent of technology catch-up progress in Africa. Hence future research could explore a range of factors such as legal and economic factors to examine whether they have contributed to enlarging the gaps between some nations and global leaders. Future research could also explore whether the nature of political system plays a role in help some countries to leap forward whilst constraining others. One way of examining the impact of above mentioned factors on technological catching-up process in Africa could be dividing African countries according to their industrial, institutional, technological adoption, legal and political differences. We hope that this study ignites new streams of research on technology catch-up in emerging economies.

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Table 1: Descriptive Statistics

	TFP_SA	TFP_USA
Benin		
Mean	0.2909802	0.1966304
Median	0.2906771	0.1702889
Maximum	0.4660735	0.4395684
Minimum	0.2199607	0.1387797
Number of Observations	35	35
Botswana		
Mean	0.8096915	0.6608095
Median	0.8429845	0.6737211
Maximum	0.9889211	0.8025104
Minimum	0.5678385	0.5032665
Number of Observations	35	35
Burkina Faso		
Mean	0.2756344	0.1722768
Median	0.2790177	0.1706553
Maximum	0.4155149	0.1960814
Minimum	0.1776824	0.1454464
Number of Observations	35	35
Burundi		
Mean	0.1367011	0.0873494
Median	0.1352447	0.0751355
Maximum	0.1721141	0.1265213
Minimum	0.1019527	0.0553256
Number of Observations	35	35
Cameroon		
Mean	0.3944267	0.2684829
Median	0.3772379	0.2320437
Maximum	0.5403602	0.4629935
Minimum	0.3305539	0.1783067
Number of Observations	35	35
Central African Republic		
Mean	0.2439072	0.1669105
Median	0.2402265	0.1490158
Maximum	0.292052	0.2652029
Minimum	0.152301	0.0723804
Number of Observations	35	35
Cote d'Ivoire		
Mean	0.477681	0.3251667
Median	0.4758664	0.3043459
Maximum	0.6263941	0.4709648
Minimum	0.4016889	0.2299595
Number of Observations	35	35
Kenya		
Mean	0.3760165	0.2545811
Median	0.3869716	0.2339388

Maximum	0.4548615	0.3626483
Minimum	0.2850235	0.1615371
Number of Observations	35	35
Lesotho		
Mean	0.3257718	0.2069298
Median	0.3479946	0.2089126
Maximum	0.4866043	0.2881996
Minimum	0.1857186	0.1592675
Number of Observations	35	35
Mauritania		
Mean	0.657216	0.4888618
Median	0.657271	0.4801381
Maximum	0.8806421	0.6689813
Minimum	0.5133324	0.3763455
Number of Observations	35	35
Mozambique		
Mean	0.1844163	0.1106018
Median	0.1580817	0.1096722
Maximum	0.3350926	0.1502064
Minimum	0.1129534	0.0819352
Number of Observations	35	35
Namibia		
Mean	0.8243832	0.6271617
Median	0.7918647	0.5958016
Maximum	1.228441	0.8955015
Minimum	0.7011731	0.4872546
Number of Observations	35	35
Niger		
Mean	0.2094169	0.1473945
Median	0.2085695	0.125293
Maximum	0.2958543	0.289123
Minimum	0.1611198	0.092648
Number of Observations	35	35
Nigeria		
Mean	0.576528	0.4272999
Median	0.4305341	0.3065856
Maximum	1.101284	1.136953
Minimum	0.1372096	0.0769681
Number of Observations	35	35
Rwanda		
Mean	0.1590709	0.1013032
Median	0.1635983	0.0909715
Maximum	0.2121833	0.1709019
Minimum	0.0848303	0.0502672
Number of Observations	35	35
Senegal		
Mean	0.4775298	0.3532398
Median	0.462993	0.2989357

Maximum	0.6134823	0.5355789
Minimum	0.4031922	0.2582985
Number of Observations	35	35
Sierra Leone		
Mean	0.3137777	0.2059317
Median	0.3006586	0.1901999
Maximum	0.4941975	0.3021186
Minimum	0.2023001	0.1189953
Number of Observations	35	35
South Africa		
Mean	1	0.8118886
Median	1	0.7700467
Maximum	1	1.100582
Minimum	1	0.5695519
Number of Observations	35	35
Sudan (Former)		
Mean	0.6346405	0.3980356
Median	0.592432	0.4004868
Maximum	0.9469448	0.5039065
Minimum	0.4644083	0.2881898
Number of Observations	35	35
Togo		
Mean	0.1891569	0.1256604
Median	0.1864335	0.1060688
Maximum	0.2959647	0.2660652
Minimum	0.1355309	0.0716577
Number of Observations	35	35
U.R. of Tanzania		
Mean	0.2400317	0.1602191
Median	0.2315707	0.1535171
Maximum	0.3696643	0.2700768
Minimum	0.143688	0.1104226
Number of Observations	35	35
Zimbabwe		
Mean	0.4137519	0.2794097
Median	0.4462293	0.3623066
Maximum	0.7920439	0.5380499
Minimum	0.1012043	0.0518569
Number of Observations	35	35
Total		
Mean	0.4186695	0.2989157
Median	0.3423338	0.2158904
Maximum	1.228441	1.136953
Minimum	0.0848303	0.0502672
Number of Observations	770	770

Table 2: log t convergence and club convergence tests results for the relative TFP level indicators (1980-2014)

log t convergence tests			
TFP levels relative to the regional leader South Africa		TFP levels relative to the international leader the USA	
$\hat{b}$: -0.958 t-$stat$: -35.134^{*}		$\hat{b}$: -0.878 t-$stat$: -91.054^{*}	
club convergence tests			
TFP levels relative to the regional leader South Africa		TFP levels relative to the international leader the USA	
Club 1 $\hat{b}$: 1.206 t-$stat$: 2.276	Botswana Mauritania Namibia Nigeria Sudan (Former)	Botswana Mauritania Namibia Nigeria Sudan (Former)	Club 1 $\hat{b}$: 1.847 t-$stat$: 3.792
Club 2 $\hat{b}$: 0.501 t-$stat$: 8.893	Benin Burkina Faso CÃ´te d'Ivoire Lesotho Mozambique Senegal U.R. of Tanzania: Mainland	Benin Burkina Faso Burundi Cameroon Central African CÃ´te d'Ivoire Kenya Lesotho Mozambique Niger Rwanda Senegal Sierra Leone Togo U.R. of Tanzania: Mainland Zimbabwe	Club 2 $\hat{b}$: 0.245 t-$stat$: 5.621
Club 3 $\hat{b}$: 0.182 t-$stat$: 1.805	Burundi Cameroon Central African Republic Kenya Niger Rwanda Sierra Leone Togo Zimbabwe		

Note: * indicates rejection of the null hypothesis of convergence at the 5% significance level.

Figure 1: TFP superlative index number, country of reference South Africa

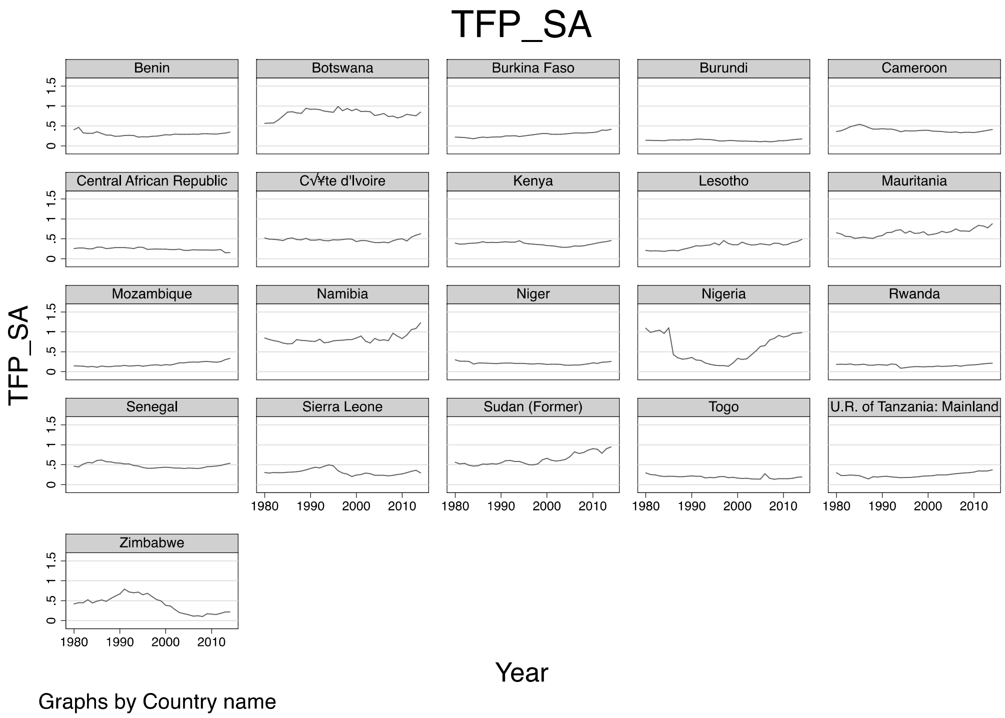

Figure 2: TFP superlative index number, country of reference USA

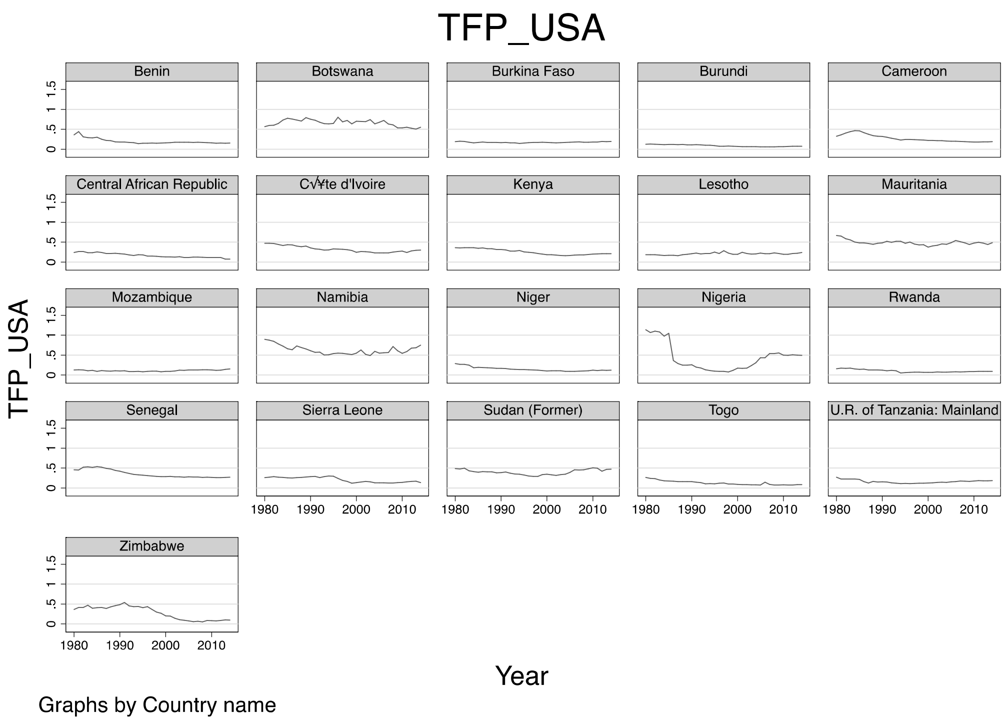

Figure 3: TFP_SA and TFP_USA

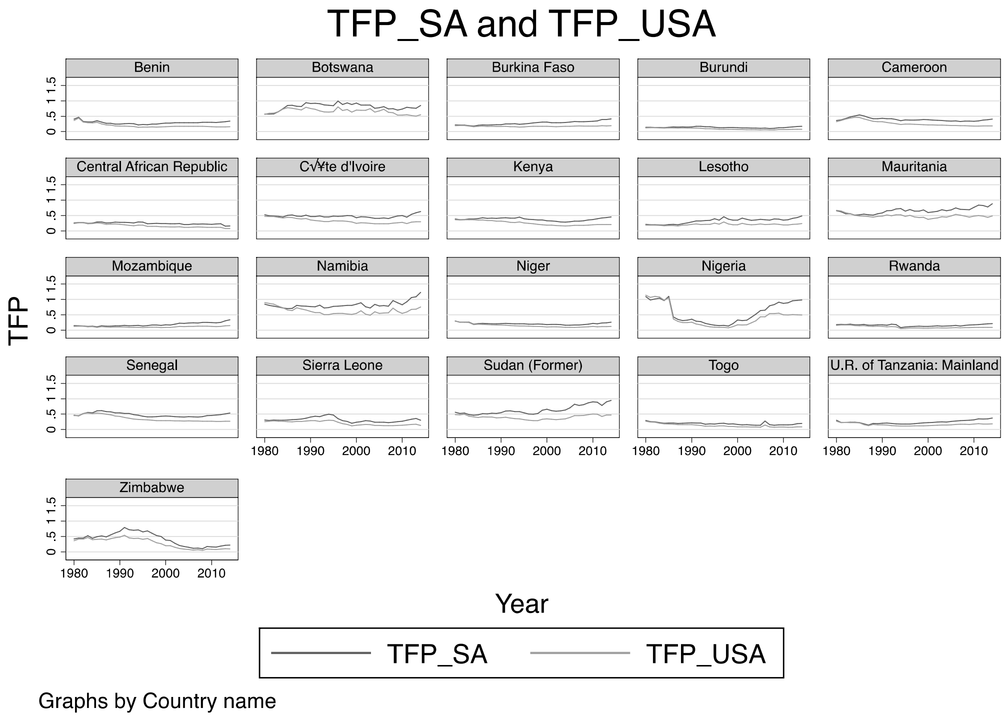
TFP_SA and TFP_USA
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Central African Republic
C√¥te d'Ivoire
Kenya
Lesotho
Mauritania
Mozambique
Namibia
Niger
Nigeria
Rwanda
Senegal
Sierra Leone
Sudan (Former)
Togo
U.R. of Tanzania: Mainland
Zimbabwe
TFP
0 .5 1 1.5
1980 1990 2000 2010
Year
TFP_SA
TFP_USA
Graphs by Country name

Figure 4: Relative transition paths across clubs based on the TFP level relative to the regional leader South Africa (1990-2014)

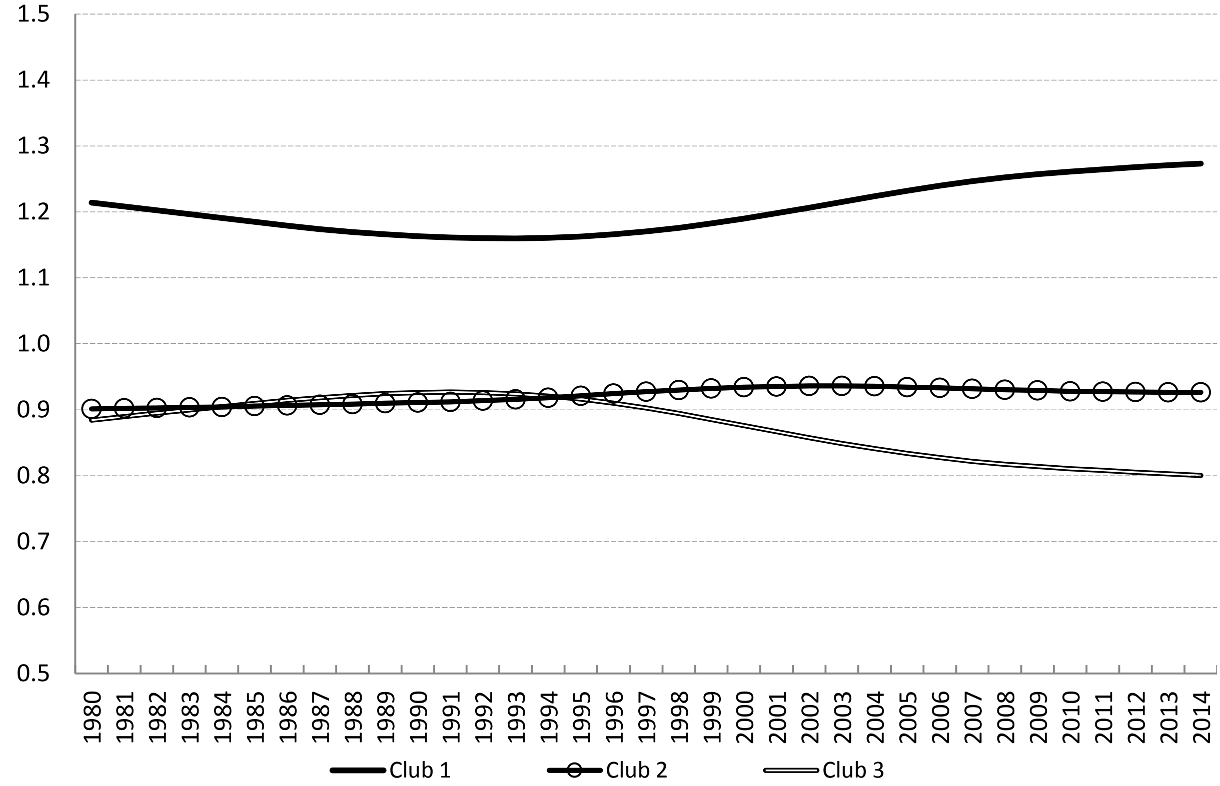

Figure 5: Relative transition paths across clubs based on the TFP level relative to the international leader the USA (1990-2014)