Closing Technological Gap to Achieve the Sustainable Development Goal of Poverty Alleviation: Evidence from 17 Sub-Sahara African Countries

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Abstract

This paper examines the dynamics of technological catching-up and its effects in contributing to poverty alleviation, a crucial pillar of the Sustainable Development Goals (SDGs). Using data of 17 Sub-Sahara African (SSA) countries and employing the superlative-index number methodology, we first estimate the Total Factor Productivity (TFP) gap between these African nations with the USA (leader of advanced countries) as well as China (leader of developing countries) to provide a measure for technological catch-up that is comparable across the African countries. We then investigate the contribution of SSA technological dynamics to poverty alleviation using system Generalised Method of Moments (GMM) method. Our results show that during 1987-2014, many African nations have experienced some technological catching-up with the USA, whilst only a few of them have managed to briefly catch-up with China until early the 2000s and after which such catching-up is no longer observed due to the exceptional technological advance achieved by China in the past fifteen years. We find that closing technological gap has had significant poverty alleviation effect for African nations, although such effect is weaker in the case of TFP gap vis-à-vis China. Our paper highlights the important role played by technological progress in alleviating poverty.

Keywords: Technological progress; Technological Gap; Poverty; Africa; Sustainable Development Goals.

1 Introduction

By superseding the Millennium Development Goals (MDGs) 2000-2015, the Sustainable Development Goals (SDGs), 2016-2030 ushered in a new era with greater precision and focus on harnessing and mobilising human resources and technology for economic development and eradicating global poverty (Griggs et al., 2013; United Nations, 2015). The pivotal features of the United Nations' 2030 Agenda for Sustainable Development within the SDGs include reducing inequality within and among nations, halting poverty and improving well-being access to technology, education and jobs (Economist Intelligence Unit, 2016; Griggs et al., 2013; Sachs, 2012; United Nations, 2018). As Jeffrey Sachs observed, almost all the world's civilisations recognised the need to combine environmental sustainability, economic development and social inclusion (Sachs, 2012). The launch of the 2030 Agenda for Sustainable Development coupled with the growing recognition of the importance of inclusive growth and development have prompted many nations to devote policy attention, resources and manpower to improve living standards and foster sustainable development (United Nations, 2018). Although technology adoption is one of the most effective mechanisms for achieving these goals, technological gaps persist between advanced and developing economies. Accordingly, it has also become a matter of urgency for policy makers to seek better understanding of the core issues.

Although these developments have culminated in renewed scholarly attention to technological gap and technology catch-up (see Amankwah-Amoah, 2019; Lee and Lim, 2001; You et al., 2019), there remains some key gaps in the current literature. First, despite the importance of technology utility in this new century, limited research attention has been devoted to exploring technological gap between leading and lagging nations, and how overcoming the gap could help achieve the SDGs. Take third generation mobile broadband network, for instance, by 2016, only 61% of people in least developed countries were covered compared with 84% worldwide (United Nations, 2018). In addition, despite progress in terms of technology adoption to improve access to internet and power, around 41% of the world's population in 2016 were still cooking with polluting fuel and stoves due to limited or lack of access to energy efficient and environmentally friendly sources of power (United Nations, 2018; see also Schwerhoff & Sy, 2017). Taken together, we lack a deeper level of analysis and understanding of the technology gaps to inform national and regional policies on how best to bridge the gap.

Against this backdrop, the main purpose of this study is to examine the technological catching-up between leading and lagging nations as pathway to poverty alleviation. To accomplish this objective, we utilize data of 17 Sub-Sahara African countries and examine this pivotal issue at the cornerstone of meeting the UN's SDGs.

Following the technological diffusion literature (Nelson and Phelps, 1966; Bernard and Jones, 1996a, 1996b; Dal Bianco, 2010; Dowrick and Nguyen; 1989; Verspagen, 1991; Griffith et al., 2004; Hansson and Herkson; 1994; Harrigan, 1999; Dowrick and Rogers, 2002; Scarpetta and Tressel, 2004), we model technological change in SSA countries as a positive function of the so-called technological gap. The technological gap represents the technological distance of each follower (i.e. SSA countries) from the technological leader. Thus, its proxies follower economies' potential for technological catch-up with the leader. In particular, we identify the USA and China as the relevant technological leaders among, respectively, developed and developing economies. Our choice in terms of technological leaders is justified by the following observations. Starting with the US, this country is widely recognised as the "world technological frontier" (Feenstra et al., 2015). Moreover, previous studies have compared African countries' TFP with the one of the USA (see, for example, Van Dijk, 2003; Edwards & Golub, 2003). Thus, by doing the same, our results also become comparable with the ones of the (scant) established literature. Finally and most importantly, recent evidence shows that technology spillovers from the USA have a stronger impact on labour productivity in African countries compared with any other developed countries (Tiruneh et al., 2017). Hence, the USA is to be considered Africa's technological leader of developed countries.

Continuing with China, it is the fourth largest foreign investor in Africa and the first among developing nations (UNCTAD, 2018). Further, China has been Africa's largest trading partner since 2009 when it surpassed the United States (Comtrade, 2018). Finally, the Chinese government has recently announced that it wants to train Africa's next generation scientists, devolving conspicuous amount of money (Nature, 2018). These three features are key in the present context because both foreign direct investment, trade and human capital have been identified as fundamental determinants of technological transfer by the established literature (see, for example, Borensztein et al., 1998; Caselli and Wilson, 2004; and Benhabib and Spiegel, 2005). Further in the recent Sustainable Development Goals Report (2018), it was observed that the proportion of the world's workers living on less than $1.90 per person a day shrank from 26.9% in 2000 to 9.2% in 2017 much of it attributed to sharp increasing on economic development countries such as China and other emerging economies (United Nations, 2018). Taken together, developing African nations can acquire technological knowledge from China- technological leader of developing countries.

Operatively, we employ an innovative two-stage analysis. Adopting the superlative-index number methodology, we first estimate the Total Factor Productivity (TFP) with reference to both the USA and China to provide a measure for technological progress that is comparable across the African countries. We then calculate the technological gap with respect to both USA and China. Then in the second step we employ the system GMM estimator to assess the contribution of SSA countries technological catch-up to poverty alleviation along with a number of other influential factors. We also further examine whether structural change is an important engine of productivity growth and explore the contribution of each sector to poverty reduction in Africa.

Despite the noble objectives of the SDGs, limited research attention has been devoted to how the SDGs can be effectively operationalized to deliver meaningful outcomes for wider society. Our study extends prior research on SDGs (Fullman et al., 2017; Sachs, 2012; United Nations, 2018) and technology catch-up (Landini & Malerba, 2017; Lee, 2013; You et al., 2019) by contending that closing technological gap can be an effective mechanism for achieving one of the core objectives of the SDGs, i.e., achieving zero poverty, and by adopting an innovative two-stage analysis mentioned above for the empirical investigation.

The rest of this article is structured as follows. We begin by presenting a brief review of the literature on sustainable development, technology catch-up and poverty alleviation followed by examination of methods and data sources. In the section that follows, we present the findings of the study. The last section concludes the study by outlining some implications and opportunities for supplementary research.

2 Sustainable Development, Technology Catch-Up and Poverty Alleviation

2.1. A brief review

Recent years have witnessed increased efforts by governments, non-governmental organizations and policymakers aimed at addressing MDGs, 2000-15 and now the SDGs. As the Goal 8 emphasizes on promoting “sustained, inclusive and sustainable economic growth” whilst Goal 7 emphasizes on ensuring “access to affordable, reliable, sustainable and modern energy for all” (United Nations, 2018, p. 3-8). These among other are predicated in countries’ ability to bridge the technological gap between themselves and other nations. Taken together, the transition from MDGs to SDGs ultimately seeks to deliver sustainable economic development and poverty eradication whilst concurrently protecting the environment, delivering gender equality, and sustainable consumption.

The technological gap broadly captures the different technological capabilities between countries, i.e., stage of leading nations in adopting different technologies compared with the position of lagging nations (see Geronikolaou & Mourmouris, 2015; Jayaraman, Agrawal & Seethamraju, 1997). In many instances, it may reflect the recommended and latest technologies in a particular sector. Recent lines of research, however, suggest that capability building in tandem with organizational learning play a key role in facilitating technology catch-up (Amankwah-Amoah, 2019; Landini & Malerba, 2017; Lee & Ki, 2017). A number of studies have demonstrated that for lagging nations to catch up with the leading nations require learning at organisational and national levels to create new or follow existing path (Lee and Lim, 2001; You et al., 2019). Through specialization in short-cycle technology sectors, countries such as China has been successful in upgrading and advancing technology catch-up process (Lee, 2013).

As one of the SDGs goals, achieving zero poverty is a complex issue and existing studies have analysed the influence of a number of factors on poverty reduction. These factors include government expenditure (Anderson et al., 2018; Kazungu and Cheyo, 2014), financial development (e.g., Rewilak, 2017; Donou-Adonsoua and Sylwester, 2016), trade openness and liberalisation (e.g., Goff and Singh, 2014; Liyanaarachchi et al., 2016), inflows of foreign direction investment (e.g., Magombeyi and Odhiambo, 2018; Soumaré, 2015; Fowowe and Shuaibu, 2014,), infrastructure investment (e.g., Marinho et al., 2017; Parikh et al., 2015), economic growth (e.g., Chen et al., 2016; Moore and Donaldson, 2016; Amini and Dal Bianco, 2016) and inflation rate (e.g., Inoue, 2018; Rewilak, 2017).

The achievement of inclusive development (or pro-poor growth) depends on technological choices and technological development trajectories (Mackintosh et al., 2007). As urged by UNCTAD (2007), reducing poverty by narrowing technology gap presents an important development strategy for the least developed nations. World Bank (2018) argues that new technologies provide pathways to poverty reduction and bring prosperity in poor countries such as Latin America and Caribbean. While a number of researchers suggest that economic growth (measured through GDP) can benefit the poor through the trickle-down mechanism where wealth radiate out spatially from the rick to the poor (e.g., Bhagwati, 1985; Dollar & Kraay, 2002; Lal & Myint, 1996; Spence, 2008), poverty reduction through adaptation of technology works in a number of different pathways. One powerful channel is described as the price effect of technology in Irz et al. (2001) and Schneider and Gugerty (2011) where they argue that increased agricultural production reduces prices of food and hence raises real wages of the poor. Such price effect can also be expanded to an array of areas that are closely linked to the poor such as using technology to generate energy, fighting diseases, and provide clear drinking water more cheaply and effectively (POST, IOP and EPSRC 2010). Technology also presents a promising solution for providing better education in poor, rural and isolated communities around the world (Aftab and Ismail, 2015; The Economist, 2018). Technology has weakened market entry barriers for small businesses as it has led to exponential decline in the cost of capturing, analysing and sharing information as well as easier fundraising (Moules, 2014), both have lowered dramatically the cost of starting a business, contributing to the alleviation of extreme poverty (Agupusi, 2007; Ali et al., 2014).

2.2. The theoretical link between technology catch-up and poverty alleviation

As previously noted in our objectives above, our testable hypothesis explicitly links poverty reduction with technological catch-up. This choice hinges upon two premises: first, recalling Dollar and Kraay (2002), economic growth is good for the poor. Second, in line with Pack and Westphal (1986), the process of assimilating existing technologies in less developed countries is not unlike that of creating entirely new technologies in the developed ones. Thus, technological diffusion is the ultimate driver of economic growth in underdeveloped economies.

Both exogenous and endogenous growth models can encompass this empirical strategy i.e., the faster the technological change, the higher the economic growth rate and thus the progressively lower the number of the poor along time.

Moreover, the empirical strategy adopted here is also compatible with the "big-push" theoretical framework that has inspired the MDGs (see Easterly and Easterly, 2006). Hence, it is particularly well-suited to analyse Sub-Saharan African countries that have experienced a negligible real growth in per capita income over the past half-century. Taking for example, Burundi, one of the countries in our sample, in 1960 its GDP per capita was 347 US$ (in 2005 purchasing power parity-adjusted US dollars as reported in the Penn World Tables). In 2010, the figure was just 396 US$.

More so, the presence of persistently poor countries could be explained by the theory of poverty traps, which refers to a situation where poor countries are locked in protracted poverty cycle due to inability to push themselves above a certain income per capita threshold (see Azariadis and Stachurski 2005). There are a number of explanations for poverty traps (for more detailed analysis and exhaustive review see Kraay and McKenzie (2014)). In the present work, we explicitly refer to two of them that are the most relevant for SSA countries. The first one is the so-called "savings trap". In such a situation, savings rate is close to zero for poor countries for subsistence reasons and then closes as income increases. The case of Burundi exemplifies such a situation. The second one is related to a non-convex production technology i.e., there is a range where investing a little has low returns and investing substantially more has a much higher returns. Referring to SSA, such "aggregate" non-convexities could stem from different returns to activities in different economic sectors. Typically, the traditional agriculture sector is characterised by constant returns, and the “modern” sector characterised by increasing returns.

More formally, consider the fundamental equation of the Solow-Swan growth model:

$$\Delta k/k = sf(k)/k \; - \; (\delta + n),$$

where k indicates the capital stock (physical, or human or both) per capita; $f(k)$ is the production function in per capita terms that is generally specified as Ak^{α} where A represents the TFP and α the capital share; s, δ and n are savings, depreciation and population growth rates, respectively. Thus, the left hand side of the equation represents capital per capita accumulation; the first and the second term on the right hand side identify the savings function and the depreciation line respectively. We refer to Barro and Sala-i-Martin (1995) for full derivation of the above equation.

If s and n are constant, and $f(.)$ is neoclassical (concave with Inada conditions), then there is a unique and stable steady state. If instead s is non-constant, as encompassed by the so-called savings trap, or the production function is non neo-classical, as per the non-convexities trap, there will be three steady states, where the Lower and Upper steady states are stable and middle one is unstable. See Figure 1 for a graphical representation.

It is apparent that the poverty trap will disappear if there is “enough” technological change or, in the terms of the present work, enough technological diffusion. In graphical terms, technological diffusion from the leader to the followers, i.e. the SSA countries, implies that SSA’s production function will move upwards. Subsequently, the saving function will not cross the depreciation line anymore in correspondence of the lower equilibrium (which will in turn disappear). The final result will be a massive reduction of poverty in the long run.

The theory of poverty traps has received mixed level of support from empirical studies. Jalan and Ravallion (2004) and Naschold (2013) find no evidence of savings or convexity traps in China (the former) and Pakistan and Ethiopia (the latter). In contrast, Kraay and Raddatz

(2007) find that when countries are very close to subsistence levels, savings and investment would be so low that growth would stagnate for long period of time. Their findings help explain the situation of Burundi. Further, Barrett et al. (2006) find supportive evidence for the existence of multiple equilibria in Kenya and Madagascar as do Adato et al. (2006) for South Africa. On a more general tone, Barrett and Carter (2013) underline that direct testing of income or asset dynamics may struggle to find poverty traps even in cases where they exist.

Proving the existence or non-existence of poverty traps goes beyond the scope of the present work. The review here demonstrates that our empirical strategy is consistent with a large spectrum of theoretical frameworks including the one of poverty traps that some scholars have proved to be extremely well-suited for analysing the situation of SSA countries.

Given its importance, a number of studies have examined the impact of technology investment and adaptation on poverty reduction (e.g., Mendola, 2007; Minten and Barrett 2008; Burney and Naylor, 2012; Ainembabazi et al., 2018). However, these studies focus mainly on the agriculture sector, and our review indicates that country-level studies investigating the impact of technology on poverty alleviation for less develop countries are very rare. Therefore, our paper intends to add to the literature by examining the impact of the technological catching-up progress on poverty alleviation for a group of 17 African countries. We conduct an innovative two-stage analysis. First, to provide a measure of the technological catching-up progress that is comparable across countries, we adopt a superlative-index number methodology to estimates of TFP of these African nations relative to the USA and China, leader of the advanced and developing economies, respectively. We then employ the system GMM method to investigate whether the closing of the technology gap between Africa and the two leaders has contributed to these African nations' poverty alleviation.

3 The Model

3.1. TFP estimation and TFP gap calculation

Following the seminal contributions of Diewert (1976) and Caves et al. (1982), we obtain our TFP estimates employing the superlative-index number methodology. Such a methodology allows one to accurately 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. This is because such a TFP index is superlative and transitive. The former property implies that it provides a TFP measure that is as precise 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 & Stehrer, 2012) as well as for the generic base country *b*, as done by Feenstra et al. (2015).

It is important to stress that, by construction, the Törnqvist index, which is here employed, measures the (output) distance between observed and efficient output. Hence, it enables researchers to obtain information on differences in TFP levels, rather than on growth rates. This is extremely relevant because, as originally noted by Hall & Jones (1999), cross-country differences in TFP growth rates have been shown to be as mostly transitory.

As the formal derivation of TFP estimates using the superlative index number methodology has been widely presented in the literature (see, for example, Feenstra et al., 2015; Dal Bianco, 2016; You et al., 2019), the interested reader is referred to Appendix A.

Here, it is important to notice that, as explained in the introduction, we consider two production possibility frontiers that are relevant for African nations: the USA, leader of advanced economies, and China, leader of developing ones. Applying the superlative index methodology, we obtain two TFP series that represent the productive efficiency of each Sub-Sahara African country with respect to the USA and China (i.e. TFP_USA and TFP_CHINA, respectively). As by its very construction the corresponding TFP index for both technological leaders is equal to 1, we calculate the technological gap by subtracting each SSA TFP indexes from 1, obtaining TFPgap_USA and TFPgap_CHINA that proxy the technological distance between any SSA country and USA and China, respectively. Intuitively, the closer the TFPgap to zero (one), the closer (further) the follower country to (from) the leader. Hence, the most (less) prominent the process of technological catch-up.

3.2.Technological gap and poverty alleviation

Having explained how we obtain the technological gap with respective to the USA and China (i.e., TFPgap_USA and TFPgap_CHINA), we next specify in detail the empirical model employed in our second stage of estimation (i.e., Section 4.3). Specifically, we assume the level of poverty (POV) depends on technological gap (TFPgap), poverty in the previous period, and a list of control variables that capture the economic conditions in SSA (Equation (1)):

$$POV_{i,t} = POV_{i,t-1} + \alpha TFPgap_{i,t} + x'_{i,t}\beta \ + \varepsilon_{i,t} \tag{1}$$

$$\varepsilon_{i,t} = \eta_i + v_{i,t} \tag{2}$$

In Equation (1), the SSA countries and time are denoted by $i = 1,2, \dots N$ and $t = 1,2, \dots T$, respectively, α is the coefficient of the technological gap, x is a column vector of control variables, and β is a row vector of correspondingly parameters. Furthermore, $\varepsilon_{i,t}$ is the disturbance term which consists of the unobserved individual specific effects (η_i) and the remainder of the disturbances $v_{i,t}$ as shown in (2).

We expect the closing of the technological gap between SSA and USA and China (i.e., TFPgap_USA and TFPgap_CHINA moving towards zero or below) and hence there is catch-up would contribute to poverty alleviation (i.e., reduce the level of poverty, POV). The list of control variables are the growth rate of GDP per capita ($GDPG$), trade openness ($OPEN$), inflation rate ($INFL$), inward FDI ($IFDI$), financial development ($FDEV$), government spending ($GSPEN$), infrastructure ($INFR$). The seminal study by Bane and Ellwood (1986) demonstrates that poverty is persistent, and hence past levels of poverty can explain the current and future poverty levels. A number of recent studies have confirmed such persistence in their analysis (e.g., Alem, 2014; Thelle at al., 2015; Marinho et al., 2017; Inoue, 2018), and thus we also introduce the lagged value of poverty in our model. The expected signs of the control variables are discussed in Section 4.1 and further summarised in Appendix B.

Since equation (1) includes as one of its regressors the lagged dependent variable, as demonstrated by Caselli et al. (1996), using conventional Ordinary Least Square (OLS) would yield biased and inconsistent estimates due to the correlation between individual specific effects (η_i) and the right hand-side variables. Furthermore, the inclusion of technological gap would also raise the endogeneity issues due to the presence of potential bi-directional causality between TFPgap and poverty. Such endogeneity may also exist between poverty and a number of the other control variables. To overcome this, we employ the system Generalised Method of Moments (GMM) (two-step) estimator developed by Arellano and Bover (1995) and Blundell and Bond (1988) for our estimations. The Arellano-Bover/Blundell-Bond estimator is also referred to as the A-B-B estimator. GMM is generally used to study the dynamics of adjustment using samples with a short-time period and relatively large cross-section. In addition, system GMM also increases the efficiency of the estimation as it takes into account country-specific effects and possible issues of endogeneity, measurement errors, and omitted variables. By using the A-B-B estimator, the endogenous regressors can be instrumented using its lagged levels. Additionally, by taking the first differences of Equation (1) it eliminates the individual specific effects. In the framework of the two-step system GMM, the Sargan-Hansen test for over-identifying restrictions is used to assess for the validity of the instruments. The null hypothesis is that the instruments as a group are exogenous. The second order serial correlation in the difference error term is also tested where the null hypothesis is that there is no serial correlation.

Despite its advantages, the system GMM is not free from some caveats. In system GMM, the number of instruments tends to increase rapidly with the endogenous variables, leading to a weakened Hansen test for over-identification restrictions and increased finite-sample bias. To tackle this issue, we adopt the recommendation by Roodman (2006), limiting the number of lags employed and collapse the instrument matrix. Specifically, the "collapse" option (available in Stata) was employed so that one instrument is created for each variable and lag distance, instead of for each time period.

4 Empirical Results

4.1 Variable measurement and data source

Our study covers 17 Sub-Sahara African countries, i.e., Benin, Botswana, Burkina Faso, Burundi, Cameroon, Côte d'Ivoire, Kenya, Mauritius, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, and Togo. Although it would be ideal to include all SSA nations, our sample choice is restricted by the overall data availability and hence we have settled for the above mentioned 17 countries in our analysis.

The dataset here employed for estimating our TFP indexes is the Penn World Table. In the last forty years, the PWT has been a canonical source for comparable real GDP data across countries. Unfortunately, we couldn't use the long-awaited PWT 9.1, as its release, due in Summer 2018, has been postponed to Spring 2019 (GGDC, 2019). Hence, we rely on PWT 9.0, that, as explained by Feenstra et al. (2015), PWT 9.0 still possesses 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 features 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.

At this point, it must be noted 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 combined the information on capital stock and GDP at current PPPs with the one of GDP at chained PPPs. In particular, we calculated 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/ $CGDP^O$, see Appendix B for variables description); 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 were able to calculate TFP series that are comparable across countries and over time. Details on TFP calculation are reported in Appendix A.

Turning now to the data of used in the second stage, i.e., the system GMM analysis. Our dependant variable, poverty, is measured using the widely employed headcount ratio of the World Bank to measure poverty (e.g., Ainembabazi et al., 2018; Inoue, 2018; Donou-Adonsoua and Sylwester, 2016). Specifically, the percentage of headcount living below the poverty line of $1.9 a day in 2011 PPP is employed as the indicator of poverty. The data is available at a 3-year time interval. Our key variable of interest, technological gap, is estimated as outlined in Section 3.1 and the estimates are further discussed in Section 4.2. We expect the technology catching-up (i.e., closing the technology gap between African nations and the USA and China) would reduce the ratio of headcount under the poverty line.

Based on relevant studies reviewed in Section 2, we introduce a number of control variables in our analysis in Section 4.3. These variables include government expenditure, trade openness, inward FDI, financial development, inflation, growth of real GDP per capita and infrastructure. Government spending on transfers and subsidies can reduce poverty directly by raising the real disposable income of poor households. By leading to better nutrition, health, and education among poor, government spending can leads to higher market income of the poor (Anderson et al., 2018). There can be welfare gains from trade openness at the country level through specialization, investment in innovation, productivity improvement, or a better resource allocation, which may have a positive impact on poverty reduction (Goff and Singh, 2014). Increased FDI has been touted as an important stimulant for improving economic conditions and reducing high poverty rates (Fowowe and Shuaibu, 2014). Rewilak (2017) finds that fragile financial sectors may impair the financial sectors' ability to extend credit to individuals or innovative small enterprises which may block a poverty reducing channel. The poor population are likely to have a larger share of cash in small portfolios and relatively limited instruments for hedging against inflation, and hence high and unpredictable price changes are considered to have a strong negative impact on the poor (Easterly and Fischer, 2001; Holden and Prokopenko, 2001). Infrastructure improves the poor's access to local markets, other regions, information and health service, and thus increases the productivity and wellbeing among poor people (Marinho et al., 2017). Economic growth can generally assume to improve the living condition of the poor through the mechanism of trickling down from the rich to the poor (Spence, 2008). In other words, when the economic output expands, members in all income bands will generally benefit. As such, we expect that higher levels in government spending, trade openness, inward FDI, financial development, economic growth and infrastructure would reduce poverty, while the opposite is true for inflation.

Taking into account the overall availability of data, our sample period covers 1987-2014. To be consistent with measurement of poverty provided by the World Bank, which is available every three years (e.g., in year 1987, 1990, 1993, etc.)[1], we apply the same 3-year time interval to our data used in Section 4.3 (i.e., we use data in year 1987, 1990, 1993,…, until year 2014). Detailed variable measurement and data source are illustrated in Appendix B.

4.2. TFP

Figures 2 to 4 report our estimates of TFPgap for each SSA country. In particular, Figure 2 shows the TFPgap with respect to the USA (i.e., TFPgap_USA), Figure 3 TFPgap with respect to China (i.e., TFPgap_CHINA), and Figure 4 compares the aforementioned two series. The corresponding descriptive statistics are reported in Table 1. Figure 5 reports the technological gap between China and the USA.

A number of facts emerge from their observation. To begin with, observing the descriptive statistics from Table 1, it could be appreciated that the technological dynamics of the majority of the countries with respect to the USA has been quite stagnant in most of the period considered. From Figure 2, it can be seen that only Nigeria exhibits clear signs of catching-up. In addition, there are some signs of catching-up towards the end of sample period for Burkina Faso, Côte d'Ivoire, Kenya, Mozambique, Niger, Rwanda, and Tanzania. The other interesting exceptions are represented by Botswana, Mauritius and South Africa. These countries seem to have lost ground with respect to the USA and a process of technological

[1] For year 2014, the World Bank provide the headcount ratio for 2013 and 2015 instead of 2014, and hence we take the average value of year 2013 and 2015 as the ratio for 2014.

divergence seems to be at work. The enlargement of the technological gap is even more apparent between African countries and China. Table 1 reports the huge differences between the minimum and the maximum level of TFPgap_CHINA and it also shows the symmetry of this variable's distribution (i.e. mean value very similar to the median). This observation applies to all countries but to Sierra Leone. This is probably due to the civil war that lasted from 1991 to 2002. Figure 3 also shows that, at the beginning of the period of observation, the vast majority of SSA economies were technologically ahead China (i.e. 14 countries having a TFPgap_CHINA around zero or below). Then, from the early 1990s, SSA countries have started diverging from China but another short bust of catching-up is observed from the mid-1990s till the beginning of the 2000s. After 2000, the upward trend of TFPgap_CHINA became a common feature across all of the SSA countries sampled. This means that also the historically most dynamic economies of Nigeria, Botswana, Mauritius and South Africa are close to become technological laggards with respect to China.

Figure 4 compares SSA catching-up with respect to both the advanced and developing countries' leaders (i.e., the USA and China respectively). Not surprisingly, most African countries are far behind the USA than China, although, the impressive fact is that their technological gap with respect to China is getting bigger and bigger.

Figure 5 shows that the process of technological divergence with respect to China has been mainly driven by the exceptional performance of China. Since the 2000s, China is closing its technological gap with the USA at an astonishing pace, despite a very short-lived slowdown in 2009 when the Great financial crisis hit emerging economies the most (Didier et al., 2011).

In conclusion, the descriptive evidence shows that African countries are lagging behind both the advanced and developing countries' leaders. Moreover, a process of divergence seems to be in place for many African nations, especially with respect to China. Correspondingly, from the figures here presented, we expect that the effect of technological catch-up on poverty reduction might be milder in the case of China, than to the USA. This is because, on the one hand, there is more scope for catching-up with respect to the USA (i.e. China is itself lagging behind the US) and, on the other, because the technological gap between SSA economies and China is, in fact, increasing and not decreasing.

Structural change is one of the earliest and most central insights of the literature on economic development (see Lewis (1954) for seminal contribution). It describes the rise of overall productivity and incomes generated by labour and other resources moving from less (e.g., agriculture) to more productive modern economic activities (McMillan and Rodrik, 2011). In the following section, we examine whether structural change is an important engine of productivity growth in Africa. Following McMillan et al. (2014) and Diao et al. (2019), we decompose productivity growth into two terms: 1) the productivity growth originated from pure technological progress within sectors; 2) the structural change term that captures productivity growth introduced by inter-sectoral labour reallocation. More details of this method can be found in Appendix C.

Due to that sectoral level data from PWT9.0 is limited, in this part of analysis we employ annual (1990-2014) sectoral value added (in 2011 PPP $) and employment data from the World Bank for 1) agriculture, forestry, and fishing (agriculture for short hereafter), 2) Industry, and 3) Services sectors (as in Sampath (2014)). We compute sectoral productivity by dividing each sector's value added by its corresponding employment as proposed by McMillan et al. (2014). To be consistent we construct economy wide productivity in the same way[2]. In line with Diao et al. (2019), we then calculate the average annual growth rates for the within sector and structural change terms for the 1990-2014 period. The results are present in Table

[2] We have also used data from PWT9.0 to calculate economic wide productivity using the method of McMillan et al. (2014). The results are very similar to ones obtained using the World Bank data. To be consistent with the sectoral level results we adopt the World Bank data in this part of analysis.

3, where the contribution of within sector productivity growth and structural change to the economic wide productivity growth are illustrated in the second and last column, respectively.

Data in Table 3 shows that structure change has brought positive productivity growth in a handful of African countries (i.e., Burkina Faso, Cameroon, Rwanda and Tanzania). However, for the majority of the countries, the prime contributor of the economic wide productivity growth has been within-sector (e.g., Benin, Botswana, Cote d'Ivoire, Kenya, Mauritius, Mozambique, Nigeria, Senegal, Sierra Leone, South Africa, Togo). Amongst these countries, Botswana, Cote d'Ivoire, Kenya and Sierra Leone experienced structural change that was growing reducing rather than inducing. The level of productivity in Industry and Services is much higher than that in the agriculture sector in these four countries, yet labour share in industry sector has been shrinking by an average annual rate of 1.6%, 1.1%, 2.4% and 0.9%, respectively, and labour share in the agriculture sector has either been growing (e.g., by an average annual rate of 1.7% Botswana in and 1.0% in Kenya) or stayed largely unchanged (e.g., in Cote d'Ivoire and Sierra Leone).

Our finding indicates that not enough labour has been moving to sectors with relatively higher productivity in Africa. Though discouraging, it is consistent with McMillan et al. (2014) and Diao et al. (2019)[3]. McCullough (2017) points out that, despite cross-sector productivity gaps, households in Africa are not able to move across sectors because of limited human capita, experience, or financial capital. Africa is also influenced by globalisation in a way that does not promote cross-sector labour movement. Lack of technological capabilities to start with, trade opportunities for African nations is dictated by export opportunities that currently exist in some sectors, in particular natural resource based and agricultural (Sampath, 2014). Such situation may lead to some primary sectors (e.g., minerals) to operate at high productivity level,

[3] Note that we have included a much larger number of African nations and longer data span in our sample compared with Mamillan et al. (2014) and Diao et al. (2019).

but these sectors have very limited capacity to generate substantial employment, and hence do not bring about strong structural change (McMillan et al., 2014).

4.3. Technology gap and poverty alleviation

In this section we examine the direction and magnitude of influence technology catching-up has on poverty alleviation. We estimate Equation (1) using the system GMM method in present the results in Table 2. Models (1) and (3) are for the case of Africa's technological catching-up with the US and Models (2) and (4) are that with China. In Models (5-(8) we exclude South Africa from our sample. Sargen-Hansen tests and serial correlation tests are reported at the bottom of the table. In all cases, both Sargan and Hansen tests suggest reject the overidentifying of restrictions, thus supporting the validity of the chosen instruments. The serial correlation tests show there are first order serial correlations, which is often expected, but no evidence of second-order serial correlation in the differenced error terms, implying that the GMM estimators are consistent in all models.

In Model (1) of Table 2, African nations' relative level of TFP vis- à -vis the leader of developed countries, the USA (TFPgap_US) has a positive sign and is statistically significant, implying that closing of such technological gap has a strong poverty reduction effect for SSA. The size of the coefficient is 0.2176, suggesting that a one percentage increase (decline) in the relative of TFP gap would raise (reduce) poverty headcount by 0.22 percent. It supports the view noted by Fofack (2008) that the widening income and welfare gap between SSA and the rest of world is largely accounted for by the technology trap responsible for the poverty trap. It also echoes Dutz et al. (2018) who find evidence for the positive impact new technology adoption on inclusive growth - growth that improves the job prospects of lower-skilled workers in the context of Latin America and the Caribbean

The lag of poverty is positive and highly significant. It confirms previous studies that at least in the short-term poverty rates are highly persistent (e.g., Alem, 2014; Thelle at al., 2015; Marinho et al., 2017; Inoue, 2018). Other variables that are significant include GDP growth (GDPG), inflation (INFL), inward FDI (IFDI), and infrastructure (INFR). The negative signs of GDPG, IFDI and INFR suggest these factors contribute to poverty alleviation in SSA, while the positive coefficient of INFL reflects the adverse impact of inflation on poverty.

On the other hand, openness (OPEN), government spending (GSPEN) and financial development (FDEV) turn out to be in significant. While engagement in international trade may raise the real wages of labour and thus help alleviate poverty, competition in export market may drive productions away from labour intensive to capital intensive sectors, lowering demand for unskilled labour. Consequently, the real wage of the unskilled labour would drop (Davis and Prachi, 2007; Kelbore, 2015), limiting the poverty reduction effect of trade openness. In terms of GSPEN, Anderson et al., (2018) find no evidence that higher government spending has played a significant role in reducing income poverty in low- and middle-income countries, and they attribute such finding to that fiscal policy plays a much more limited redistributive role in developing countries, in comparison with OECD economies. Focusing on Tanzania, Kazungu and Cheyo (2014) suggest government expenditures to finance poverty reduction strategies may take time to realise its intended effect. Furthermore, Asghar et al. (2012) discover that government spending on budget deficit and economic and community services appeared to be responsible for poverty in Pakistan as that government spending has had unintended inflationary consequence and that poor areas either did not have access to these services or were neglected all together. Wilhelm and Fiestas (2005) find that government spending in sectors that are generally seen as pro-poor tended to benefit the richer quintiles of the population, and thus such government spending has minimal poor reduction effect and could actually enlarge inequality between the rich and poor. With regards to financial development, although it may widen the financial services access to the poor and thus raise their income and reduce poverty (Jalilian and Kirkpatrick, 2002), it may also lead to unintended negative consequence of financial instability (Akhter and Daly, 2009). A further study by Jeanneney and Kpodar (2011) confirms that despite the benefits of financial development, financial instability arising from financial development hurts the poor, and this seems to be the case for our sample of African countries since the positive effect of financial development on poverty reduction is insignificant.

Overall, the results based on African nations' relative level of TFP vis- à -vis the USA suggests that closing technological gap between SSA and the world leader the USA presents a powerful channel to alleviate poverty. Other contributing factors include the overall economic growth per capita, low inflation, inward FDI and infrastructure expansion. There is also strong evidence of poverty persistency in Africa.

We then examine the case of relative level of TFP vis- à -vis the leader of developing countries, China (i.e., Model (2)). Again, we found the TFP gap between African nations and China (i.e., TFPgap_CHINA) has the expected positive sign and statistically significant, confirming poverty reduction impact of technological catching-up. Specifically, every percentage increase (reduction) in the relative of TFP gap would reduce (raise) poverty headcount by 0.04 percent. The log of poverty (POV(t-1)), GDP growth (GDPG), inflation (INFL), and infrastructure (INFR) remain significant, while openness (OPEN) also becomes significant. In contrast, government spending (GSPEN) and financial development (FDEV) stay insignificant (as in Model (1)). It is interesting to notice that the inward foreign direct investment (IFDI) is no longer significant. Due to lack of mobility in the labour market in Africa, inward FDI may favour those that already have high income and high skills but bypass the low-skilled low-income workers (Feenstra and Hanson, 1997), restricting the positive influence IFDI could have on poverty reduction.

Comparison between the above two sets of results highlights one important difference that the poverty alleviation effect seems to be stronger in the case of Africa's technological catching up with the USA than that with China. As shown in Figure 4, the SSA nations' relative TFP vis- à -vis the USA (TFPgap_US) is higher than vis- à -vis China (TFPgap_CHINA), suggesting wider technological gap between the SSA-USA pair than between the SSA-China pair. Therefore, technological catching-up between SSA and the USA represents an earlier stage of catching-up than that between SSA and China. In analogy with capital accumulation, our findings suggest that the concept of diminishing returns can also be applied to the effect of technological catching-up on poverty alleviation, as the early steps of technological catching-up are relatively more effective in reducing poverty and are less costly to achieve. Using data on 89 developing economies for the period 1990–2013, Asadullah and Savoia (2018) find that poverty headcount tends to decrease faster in countries with initially more severe income poverty (see similar argument in Noorbakhsh, 2007), and initial severe poverty is often linked to low starting level of technology. Although poverty is much more acute and level of technology is much lower in most SSA nations than both the USA and China, the gaps are much more profound between SSA and the USA, and hence any technological catching-up with the USA would have more poverty reduction effect for SSA nations. Another explanation is the exceptional growth in technology China has experienced in the past decade (Figure 5), making the technological catch-up of African nations towards China much less profound that that toward the US.

Although we have employed the sum of landline and mobile phone per 100 persons as our indicator of infrastructure development (as in Andrés et al. (2013)) in SSA, a recent study by Arimah (2017) finds that the spectacular growth in the mobile phone users in Africa over the last one and half decades has contributed greatly to the poverty reduction and prosperity of African cities. Mobile technology is found to be the infrastructure with the highest impact on poverty reduction, followed by electricity, roads and irrigation for developing countries (Runsinarith, 2009). Therefore, in Models (3) and (4) we employ an alternative measurement of infrastructure, i.e., mobile phone per 100 person (as in Arimah, 2017) (MOBILE). We obtained very similar results as in Models (1) and (2), respectively, for all coefficients (in terms of size, sign and level of significance)[4]. It is worth mentioning that technological gap variable remains correctly signed and significant in both Models (3) and (4)[5].

As one of the largest economies in Africa (only second to Nigeria), South Africa has the highest living standard in the region since 1997 (based on GDP per capita (2010 constant US$) provided by the World Development Indicators 1997-2016). Over the recent three decades, South Africa also experienced relatively stable economic growth rate compared with most of other African countries, especially in the recent decade after the 2008 global financial crisis. In spite of the recent mild slowing down in productivity growth compared with other African countries, South Africa remains the regional technological leader (Dessus et al., 2017; You et al., 2019). Our estimates also confirm South Africa's leader position in Africa having the smallest technological gaps vis- à -vis the US and China (Figure 4). Given its unique position in the region, we exclude South Africa from our sample and re-estimate Models (1)-(4). The results are presented as Models (5)-(8) in Table 2.

We obtained similar findings in Models (5)-(8) as in Models (1)-(4). The lag of poverty, TFPgap_USA, TFPgap_China, GDPG, INFL, INFR, and MOBILE continue to have the

[4] We have also employed fixed landline per 100 person (as in Magombeyi and Odhiambo, 2018) as an alternative measurement of infrastructure. However, it was insignificant in all Models (1)-(4). It may reflect that the number of landlines in Africa have stagnated especially in the past ten years. The technological gap variable again remains correctly signed and significant. Results are not presented here to save space but are available upon request.

[5] A number of studies have examined whether good governance reduces poverty (see a recent review by Jindra and Vaz (2019)). We employ the widely used World Bank's Worldwide Governance Indicators (WGI) that represent six components of governance since 1996: voice and accountability; political stability and absence of violence/terrorism; government effectiveness; regulatory quality; rule of law; and control of corruption. We construct an average of these six indicators and included this overall governance index as an additional variable in Models (1)-(4). However, the index was not significant in any of the model. The relationship between quality of governance and poverty may be development stage-dependent (e.g., Grindle, 2004; Khan, 2007, 2009; Sachs et al., 2004). In the case of Africa nations, good governance may have limited impact as the general resources may be too low to effectively translate government capabilities into positive outcomes on poverty level.

correct signs and remain significant, although openness is no longer significant in the case of TFPgap_China (i.e., models (6) and (8)) whilst inward FDI is in the case of TFPgap_USA (i.e., models (5) and (7)). However, one interesting difference emerged. The coefficients of technological gap (i.e., TFPgap_USA and TFPgap_China) have increased in models (5)-(8) compared with (1)-(4), respectively. It shows that technological catching-up is more effective in alleviating poverty in countries where initially poverty is more severe (since South Africa is a large economy with the highest living standard in Africa).

We are further interested in evaluating the contribution of technological catching-up at sectoral level to poverty alleviation in Africa. We divide sectoral level productivity (constructed in Section 4.2) of an African nation by the corresponding value of the US (China) to obtain the relative sectoral productivity. We then multiply each ratio by the respective sectoral labour share, and the sum of these three sectors present the relative productivity of this African nation to the US (China).

To make this relative productivity comparable to the relative TFP index estimated using the superlative – index number methodology (Section 4.2), we divide the latter by the former to provide a scaling factor. By adjusting the relative sectoral productivity by this scaling factor and then subtracting the scaled outcome by 1, we obtain proxies of technological gap between an African country and USA (China) in agriculture (TFPgap_USA_A, TFPgap_China_A), industry (TFPgap_USA_I, TFPgap_China_I) and services sector (TFPgap_USA_S, TFPgap_China_S). Then the economic wide technological gap (i.e., TFPgap_USA, TFPgap_China) in Models (1) – (4) was replaced by three sectoral gaps and the results are summarised in Models (9) – (12) in Table 4. In Models (13) – (16) of Table 4, we account for the distribution of labour across sectors by multiplying sectoral gaps by their corresponding labour shares, generating the weighted sectoral technological gaps for agriculture (TFPgap_USA_AW, TFPgap_China_AW), industry (TFPgap_USA_IW, TFPgap_China_IW) and services sector (TFPgap_USA_SW, TFPgap_China_SW). Note the three-year interval applied to data in Table 2 is also applied to the sectoral gaps.

For all models in Table 4, both Sargan and Hansen tests supports the choice of the instruments and, thus, it implies that our estimates are reliable. The serial correlation tests show the expected first order serial correlations and reject second-order serial correlation in the differenced error terms, indicating that the GMM estimators are consistent.

In models (9)-(12), among the three sectoral technological gaps, only that in the agriculture sector has significant poverty reduction effect. It reflect an interesting fact that despite having the lowest level of productivity, agriculture sector in the 17 African countries has actually experienced the fastest sectoral productivity growth during 1990-2014 (i.e., 2.2% average annual growth rate compared with 1.4% in industry and 1.3% services sectors based on World Bank data). The lag of poverty, GDPG, OPEN (in the case of TFP gaps vis- à -vis the USA), INFL (in the case of TFP gaps vis- à -vis China), INFR and MOBILE remain significant and correctly signed, whilst IFDI, FDEV and GSPEN continue to have no impact.

In models (13)-(16), two important findings emerge. First, the weighted agricultural technological gap in these four models has higher coefficients compared with Models (9)-(12). Whilst Models (9)-(12) highlight the poverty reduction power of agricultural technological catching-up, Models (13)-(16) further shows that labour allocation in agriculture sector has reinforced such poverty reduction power. Indeed, in contrast to countries like China where labour has been moving out of agriculture to industry and service sectors in the past three decades (You and Sarantis, 2013), such structural change has not become a strong occurrence in Africa (as discussed in Section 4.2). Second, the weighted technological gap in the services sector becomes significant in the case of TFP gaps vis- à -vis the USA. It probably captures the combined growth effect in services sector’s productivity as well as its labour share (i.e., annual average rate of 1.3% and 1.5%, respective) in Africa. This variable is not significant in the case for TFP gaps vis- à -vis the China, as China's Service sector productivity is growing at a much higher annual average rate of 8.0%.

The sectoral level investigation highlights the agriculture sector (and to some extend the services sector) as the prime contributor to poverty reduction in Africa, and that the lack of sizeable structural change in Africa as a whole seems to have strengthened such contribution.

5. Conclusions and Implications

The main purpose of the present study was to assess the impact of technological diffusion, i.e. closing the technological gap, on poverty reduction for a selected group of Sub-Saharan African (SSA) countries. We adopted a two-stage analysis framework. First, we estimated the Total Factor Productivity gap between the African nations and the USA (leader of advanced countries) and China (leader of developing countries). We employed the superlative-index number methodology which provides a measure for technological progress that is comparable across the African countries. Our estimates show that whilst some African countries (e.g., Nigeria, Burkina Faso, Côte d'Ivoire, Kenya, Mozambique, Niger, Rwanda, and Tanzania) have illustrated catching-up process with the US, especially towards the end of the sample period, such process is missing between African nations and China except some cased of brief catching-up around year 2000 (e.g., Benin, Burkina Faso, Botswana, Cameroon, Côte d'Ivoire, Mauritius, Nigeria and Zimbabwe). Such contrast is explained by the exceptional pace that China has experienced in closing its technological gap with the USA since year 2000. Using sectoral level data, we also found evidence that the main engine of productivity growth in Africa comes from within sector rather than structural change.

In the second stage, we examined whether technological catching-up has had poverty alleviation effect. Such effect was expected through a number of pathways including reducing prices/raising real wages, providing more accessible education, and lowering cost of starting a business for the poor. Based on GMM estimates, we found that closing technological gap between African nations and both the USA and China has had strong poverty reduction effect. There is also strong evidence of poverty persistence. Other poverty alleviation factors include GDP growth and infrastructure whilst inflation deteriorates the poverty headcount ratio. Government spending and financial development appears to have no or little influence on poverty in Africa. This is the case for both technological gap vis- à -vis the USA and China. In addition, inward FDI and trade openness was found to alleviate poverty headcount ratio in the former and latter case, respectively. The results are robust regardless, if South Africa is included in the sample. Our sectoral level analysis shows that the agriculture sector instead of the modern sectors (e.g., Industry and Services sectors) as the prime contributor to poverty reduction in Africa.

5.1. Implications for theory and practice

Our results suggest that closing of technological gap is a crucial ingredient for poverty alleviation in the context of the African countries during 1987-2014. However, our estimates also shown that such technological catching-up was largely missing in Africa, regardless if we measure the gap against leading developed country, i.e., the US, or against leading developing country, i.e., China. A recent study by the World Bank (i.e., Cirera and Maloney (2017)) establishes that countries farther from the production frontier are more likely to lack critical innovation complementary factors across many markets and, in particular, firm capabilities. Government policy and support can create conditions for citizens to adopt new technologies and firms to embrace technology as means to improve their competitiveness. Some prior research has demonstrated that governments can also create incentives via subsidies for firms to upgrade the production facilities and materials, and implement industry-wide training programme aimed at fostering adoption of new processes, technologies and energy efficiency (Debrah & Ofori, 2005, 2006). By establishing and raising production, safety and technical standards via government regulations, firms can be forced to adopt new technologies. Without such pressure, firms might be reluctant to adopt new technology. In addition, bureaucratic bottlenecks can also stifle the development of new businesses and their ability to adopt technology (Amankwah-Amoah, 2016). By eliminating such red tapes, firms would be better placed to innovate via improvement in process (Amankwah-Amoah et al., 2019; Zhang et al., 2018).

Technological transfer from China to Africa presents a great opportunity for enhanced productivity and competitiveness in Africa (United Nations and African Union, 2014). However, our results highlight that such transfer is generally missing and instead a process of technological divergence seems to be in place for most African countries with respect to China. Despite technology transfer between China and Africa has existed and developed since the issue of the Eight Principles for Economic Aid and Technical Assistance to Other Countries in 1964, there is a large room for the improvement for Chinese companies both in scale and depth to strengthen China-Africa Cooperation. (Li, 2016). In 'The Forum on China–Africa Cooperation Johannesburg Action Plan (2016–2018)' that was recently issued in China–Africa Summit, 'technology transfer' is greatly emphasised. To tackle poverty in Africa, further intensified technological collaboration between China and Africa is needed. As suggested by the African Union during the 2018 FOCAC-Africa-China Poverty Reduction and Development Conference, technological collaboration aimed to reduced poverty in Africa include not only Chinese experts' visits and assistance in crop planting, pest disease prevention and control, product processing, livestock breeding, and fish farming, but also more comprehensive ways of collaboration such as learning from China in natural resources management, in agriculture transformation, in policy research, in evidence-based planning and in supporting Competitive Value Chains and Agri-Business Development.

Furthermore, structural change has played limited role in raising productivity in Africa.

Thus, structural change presents an important growth potential for African region, yet it is not an automatic process. Therefore, policy guidance with appropriate direction promoting growth-inducing structural change is urgently needed for African nations, especially for ones that have a strong comparative advantage in natural resources (McMillan and Rodrik, 2011)

Finally, in addition to emphasising the critical role played by technology catching-up in poverty reduction, our study also highlights a number of other important contributing factors including economic growth, trade openness, infrastructure and financial development. However, it also pointed out the that government spending and inward FDI may not necessary alleviate poverty, suggesting that policy makers need to make sure at least part of their spending and capital inflow are specifically targeted at the poor population.

5.2. Limitations and directions for future research

Our paper identifies that a process of technology divergence seems to be in place for most African nations with respect to the USA and China, especially the latter. Investigating the reasons of the lack of technological transfer from China to SSA countries is beyond the scope of this paper but provides an important area for future research. A related area of research extension is to link technological catching-up (or the lack of it) to technology absorption capability. To exploit the full potential of closing technological gap, technological laggards have to possess the necessary absorptive capacity, which is the ability to identify, assimilate and exploit outside knowledge (Cohen and Levinthal, 1989). Hence, it would be very informative to re-model the process of technological diffusion, and thus of technological catch-up, making it conditional to followers' absorptive capacities, such as human capital, domestic R&D as well as patents. Operatively, this line of research could be implemented for instance following Bond et al. (2001) that is including the absorptive capabilities variables as extra-instruments when employing the System-GMM estimator. Finally, based on our finding, government spending and inward FDI seem to have an undesired adverse effect on poverty reduction in Africa. Although this finding coincide with a number of previous studies (e.g., Anderson et al., 2018; Huang et al., 2010) where several theoretical explanations have been presented, a future research direction would be full-fledged models and empirical examinations to provide better understanding of the fundamental causes of such unexpected relationship.

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Table 1. TFP_gap: Descriptive statistics (1987-2014)

Country	TFPgap_USA	TFPgap_CHINA
Burundi (BDI)		
Mean	0.92	0.53
Median	0.93	0.54
Maximum	0.94	0.74
Minimum	0.88	0.21
Number of observations	28	28
Benin (BEN)		
Mean	0.83	0.24
Median	0.84	0.25
Maximum	0.86	0.49
Minimum	0.78	-0.06
Number of observations	28	28
Burkina Faso (BFA)		
Mean	0.83	0.14
Median	0.83	0.11
Maximum	0.85	0.39
Minimum	0.81	-0.04
Number of observations	28	28
Botswana (BWA)		
Mean	0.34	-0.52
Median	0.33	-0.57
Maximum	0.50	-0.03
Minimum	0.20	-1.05
Number of observations	28	28
Côte d'Ivoire (CIV)		
Mean	0.71	-0.19
Median	0.71	-0.17
Maximum	0.77	0.22
Minimum	0.60	-0.61
Number of observations	28	28
Cameroon (CMR)		
Mean	0.77	-0.05
Median	0.78	-0.04
Maximum	0.82	0.40
Minimum	0.62	-0.66
Number of observations	28	28
Kenya (KEN)		
Mean	0.77	0.02
Median	0.79	-0.02
Maximum	0.84	0.33
Minimum	0.66	-0.41
Number of observations	28	28
Mozambique (MOZ)		
Mean	0.89	0.37

Median	0.90	0.36
Maximum	0.92	0.56
Minimum	0.85	0.21
Number of observations	28	28
Mauritius (MUS)		
Mean	0.23	-0.80
Median	0.24	-0.79
Maximum	0.36	-0.37
Minimum	0.09	-1.42
Number of observations	28	28
Niger (NER)		
Mean	0.87	0.51
Median	0.88	0.49
Maximum	0.91	0.62
Minimum	0.82	0.39
Number of observations	28	28
Nigeria (NGA)		
Mean	0.71	-0.21
Median	0.75	-0.25
Maximum	0.92	0.47
Minimum	0.44	-0.67
Number of observations	28	28
Rwanda (RWA)		
Mean	0.91	0.44
Median	0.92	0.53
Maximum	0.95	0.68
Minimum	0.87	-0.06
Number of observations	28	28
Senegal (SEN)		
Mean	0.68	0.00
Median	0.71	0.07
Maximum	0.74	0.24
Minimum	0.51	-0.54
Number of observations	28	28
Sierra Leone (SLE)		
Mean	0.81	-0.05
Median	0.84	0.26
Maximum	0.88	0.56
Minimum	0.70	-1.20
Number of observations	28	28
Togo (TGO)		
Mean	0.90	0.40
Median	0.91	0.37
Maximum	0.93	0.72
Minimum	0.84	0.00
Number of observations	28	28

Tanzania (TZA)		
Mean	0.85	0.39
Median	0.86	0.39
Maximum	0.89	0.65
Minimum	0.81	0.27
Number of observations	28	28
South Africa (ZAF)		
Mean	0.24	-0.81
Median	0.24	-0.76
Maximum	0.43	-0.39
Minimum	0.05	-1.16
Number of observations	28	28
Total		
Mean	0.72	0.02
Median	0.82	0.16
Maximum	0.95	0.74
Minimum	0.05	-1.42
Number of observations	476	476

Table 2: Technological Gap and Poverty: System GMM results

Dependent Variable: Poverty Headcount Ratio (1987 – 2014 with 3-year interval)								
Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
POV(-1)	0. 6929***	0.7140***	0.6674***	0.7265***	0.5067*	0.7400***	0.5304**	0.7346***
	(3.51)	(5.02)	(2.93)	(5.36)	(1.87)	(5.39)	(2.04)	(5.03)
TFPgap_USA	0. 2176**		0.2264**		0. 3345**		0.3251**	
	(1.97)		(2.09)		(2.22)		(2.26)	
TFPgap_CHINA		0.0440**		0.0422**		0.0651**		0.0649**
		(2.12)		(2.07)		(2.45)		(2.38)
GDPG	-0.0066***	-0.0125***	-0.0066**	-0.0126***	-0.0070**	-0.0075***	-0.0069**	-0.0080***
	(-2.71)	(-3.06)	(-2.57)	(-3.14)	(-2.42)	(-3.60)	(-2.37)	(-4.15)
OPEN	-0.0002	-0.0009*	-0.0003	-0.0009*	-0.0001	-0.0004	-0.0001	-0.0004
	(-0.28)	(-1.70)	(-0.40)	(-1.76)	(-0.09)	(-0.71)	(-0.07)	(-0.74)
INFL	0.0009***	0.0007*	0.0009***	0.0007*	0.0011***	0.0009**	0.0010***	0.0009***
	(2.64)	(1.96)	(2.89)	(1.83)	(2.77)	(2.49)	(2.83)	(2.66)
IFDI	-0.0037*	0.0020	-0.0031	0.0022	-0.0053***	-0.0046	-0.0049**	-0.0040
	(-1.77)	(0.39)	(-1.05)	(0.44)	(-2.81)	(-1.01)	(-2.50)	(-0.97)
FDEV	-0.0001	-0.0005	-0.0002	-0.0005	-0.0018	-0.0003	-0.0017	-0.0006
	(-0.33)	(-0.94)	(-0.42)	(-0.98)	(-1.22)	(-0.49)	(-1.30)	(-1.06)
GSPEN	0.0070	0.0015	0.0075	0.0011	0.0098	-0.0020	0.0096	-0.0000
	(1.03)	(0.77)	(1.04)	(0.75)	(1.23)	(-0.15)	(1.24)	(-0.02)
INFR	-0.0004***	-0.0004**			-0.0004***	-0.0005*		
	(-3.00)	(-2.10)			(-2.87)	(-1.86)		
MOBILE			-0.0008***	-0.0004**			-0.0004***	-0.0004*
			(-2.66)	(-2.14)			(-2.86)	(-1.89)
CONST	-0.0650	0.2317**	-0.0566	0.2250***	-0.0707	0.1942*	-0.0775	0.1999*
	(-0.46)	(2.03)	(-0.42)	(2.04)	(-0.50)	(1.90)	(-0.52)	(1.83)
N	153	153	153	153	144	144	144	144
No of groups	17	17	17	17	16	16	16	16
ar1(p-value)	0.015	0.024	0.022	0.022	0.006	0.034	0.007	0.034
ar2(p-value)	0.184	0.738	0.201	0.720	0.332	0.257	0.325	0.313
Sargan(p-value)	0.915	0.729	0.817	0.725	0.857	0.736	0.854	0.756
Difference in Hansen tests (p-value)	0.921	0.964	0.886	0.983	0.933	0.893	0.949	0.895

Note: t-stats are in brackets. ***, ** and * indicates the statistical significance at the 1%, 5% and 1% level respectively. ar1 and ar2 are tests for 1st order serial 2nd order serial correlation respectively. Models (1) – (4) include all 17 African nations in our sample. Models (5) – (8) exclude South Africa.

Table 3. Productivity growth within sector and due to structural change (average of annual growth rates during 1990-2014)

	Productivity growth of the whole economy (%)	Within sector (%)	Structural change (%)
Benin	1.04	1.02	0.02
Botswana	2.25	2.92	-0.67
Burkina Faso	3.66	0.47	3.19
Burundi	-0.57	-0.57	0.00
Cameroon	0.24	-1.17	1.41
Cote d'Ivoire	-0.13	0.05	-0.18
Kenya	0.95	1.52	-0.57
Mauritius	3.93	3.60	0.33
Mozambique	4.66	2.64	2.02
Niger	-0.22	-0.21	0.00
Nigeria	2.37	2.12	0.25
Rwanda	3.84	1.21	2.62
Senegal	1.57	0.98	0.59
Sierra Leone	2.37	2.53	-0.16
South Africa	0.81	0.73	0.09
Tanzania	2.27	0.48	1.79
Togo	0.63	0.58	0.05
China	9.95	8.25	1.70
United States	1.42	1.39	0.03

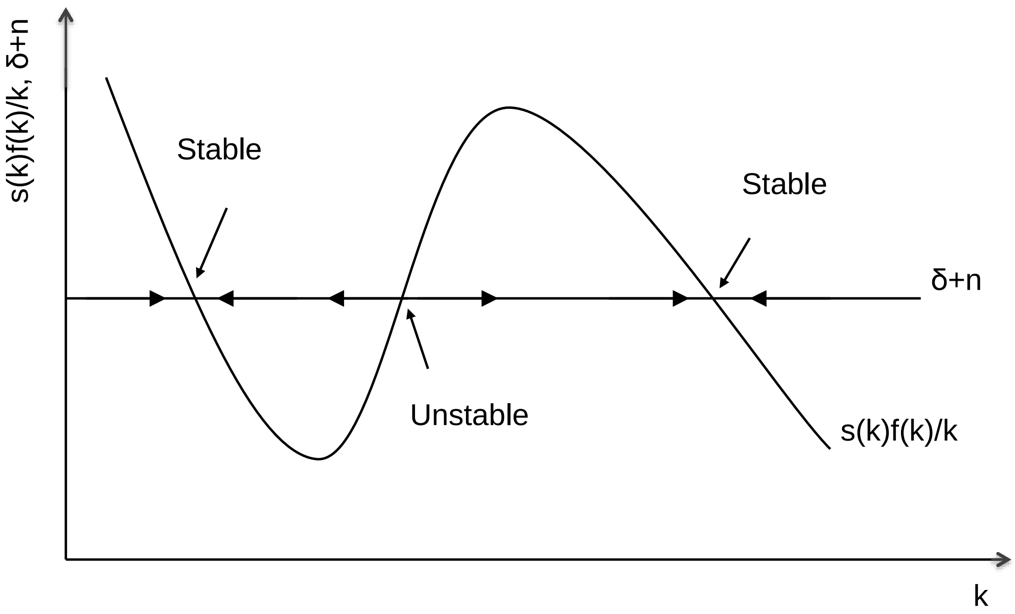
Note: Following McMillan et al. (2014) and Diao et al. (2019), the within sector item captures the productivity growth originated from pure technological progress within the sectors, and the structural change term captures productivity growth introduced by inter-sectoral labour reallocation. See Appendix C for more details of this method.

Table 4: Sectoral Level Technological Gap and Poverty: System GMM results

Dependent Variable: Poverty Headcount Ratio (1990 – 2014 with 3-year interval)									
Independent Variables	(9)	(10)	(11)	(12)	Independent Variables	(13)	(14)	(15)	(16)
POV(-1)	0. 7437***	0.8153***	0.7406***	0.8271***	*POV(-1)*	0.6530***	0.7160***	0.6415***	0.7320***
	(9.36)	(7.94)	(9,36)	(8.55)		(5.18)	(3.70)	(4.76)	(4.15)
TFPgap_USA_A	0. 1057*		0.1048*		*TFPgap_USA_AW*	0. 2915***		0.3018***	
	(1.88)		(1.81)			(2.93)		(2.91)	
TFPgap_USA_I	0.0238		0.0231		*TFPgap_USA_IW*	0.0093		-0.0003	
	(1.48)		(1.47)			(0.14)		(-0.00)	
TFPgap_USA_S	-0.0001		0.0040		*TFPgap_USA_SW*	0.1659**		0.1778**	
	(-0.00)		(0.09)			(2.37)		(2.49)	
TFPgap_CHINA_A		0.0286***		0.0275***	*TFPgap_CHINA_AW*		0.1031**		0.0978***
		(3.13)		(2.96)			(2.59)		(2.68)
TFPgap_CHINA_I		0.0036		0.0032	*TFPgap_CHINA_IW*		0.0045		0.0021
		(0.52)		(0.11)			(0.11)		(0.05)
TFPgap_CHINA_S		-0.0086		-0.0076	*TFPgap_CHINA_SW*		0.0537		0.0510
		(-0.65)		(-0.55)			(1.11)		(1.29)
GDPG	-0.0073***	-0.0073***	-0.0075***	-0.0074***	*GDPG*	-0.0076***	-0.0069***	-0.0069**	-0.0073***
	(-2.78)	(-3.71)	(-2.67)	(-3.78)		(-2.96)	(-3.23)	(-2.78)	(-3.43)
OPEN	-0.0006**	-0.0002	-0.0007**	-0.0002	*OPEN*	0.0001	-0.0004	-0.0001	-0.0005
	(-2.25)	(-0.44)	(-2.40)	(-0.51)		(0.03)	(-0.57)	(-0.13)	(-0.64)
INFL	0.0008	0.0007***	0.0009	0.0007***	*INFL*	0.0007	0.0009**	0.0010	0.0009***
	(1.58)	(4.07)	(1.61)	(3.71)		(1.35)	(2.32)	(1.38)	(2.79)
IFDI	0.0001	-0.0020	0.0002	-0.0017	*IFDI*	-0.0005	-0.0058	0.0007	-0.0050
	(0.06)	(-0.83)	(0.14)	(-0.78)		(-0.32)	(-0.84)	(0.26)	(-1.36)
FDEV	-0.0002	0.0003	-0.0003	0.0002	*FDEV*	0.0004	-0.0001	-0.0004	-0.0002
	(-0.90)	(0.77)	(-1.03)	(0.67)		(1.34)	(-0.84)	(-1.19)	(0.27)
GSPEN	0.0007	-0.0008	0.0007	-0.0008	*GSPEN*	0.0003	-0.0013	0.0003	-0.0012
	(0.52)	(-0.69)	(0.57)	(-0.70)		(0.18)	(-0.84)	(0.19)	(-0.78)
INFR	-0.0004**	-0.0005***			*INFR*	-0.0004**	-0.0005**		
	(-2.11)	(-2.70)				(-2.38)	(-2.57)		
MOBILE			-0.0004**	-0.0004***	*MOBILE*			-0.0005**	-0.0005***
			(-2.08)	(-2.70)				(-2.41)	(-2.66)
CONST	0.0862	0.1502*	0.0894	0.1437*	*CONST*	0.0137	0.2189	0.0177	0.2121
	(1.57)	(1.71)	(1.54)	(1.73)		(0.20)	(1.45)	(0.24)	(1.48)
N	153	153	153	153	N	153	153	153	153
No of groups	17	17	17	17	No of groups	17	17	17	17
ar1(p-value)	0.052	0.047	0.051	0.048	ar1(p-value)	0.040	0.029	0.038	0.033
ar2(p-value)	0.568	0.326	0.545	0.348	ar2(p-value)	0.473	0.218	0.513	0.248
Sargan(p-value)	0.778	0.712	0.797	0.713	Sargan(p-value)	0.762	0.541	0.800	0.606
Difference in Hansen tests (p-value)	0.969	0.851	0.946	0.844	Difference in Hansen tests (p-value)	0.994	0.780	0.994	0.826

Note: t-stats are in brackets. ***, ** and * indicates the statistical significance at the 1%, 5% and 1% level respectively. ar1 and ar2 are tests for 1st order serial 2nd order serial correlation respectively. Although Table 4 uses data for period 1990-2014 and Table 2 uses data for period 1987-2014, both tables have the same number of observation (i.e., 153) when all 17 countries are included in the estimation. This was due to that data for year 1987 did not enter the estimation due to the inclusion of the poverty lag in Table 2. Hence both tables' estimation starts on 1990 and hence the same number of observations.

Figure 1: Savings and Non-convexities traps



Source: Authors' elaboration

Figure 2. TFP gap of SSA nations with respect to the USA (TFPgap_USA)

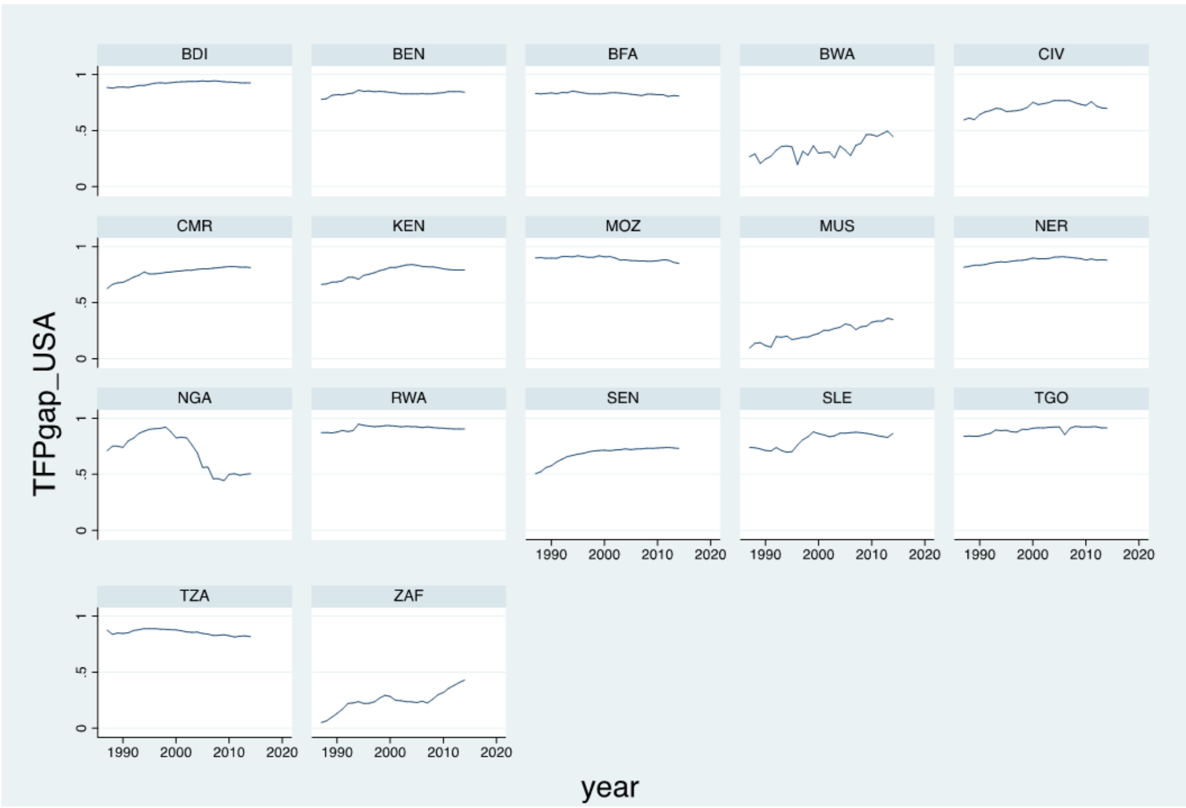


Figure 3. TFP gap of SSA nations with respect to China (TFPgap_CHINA)

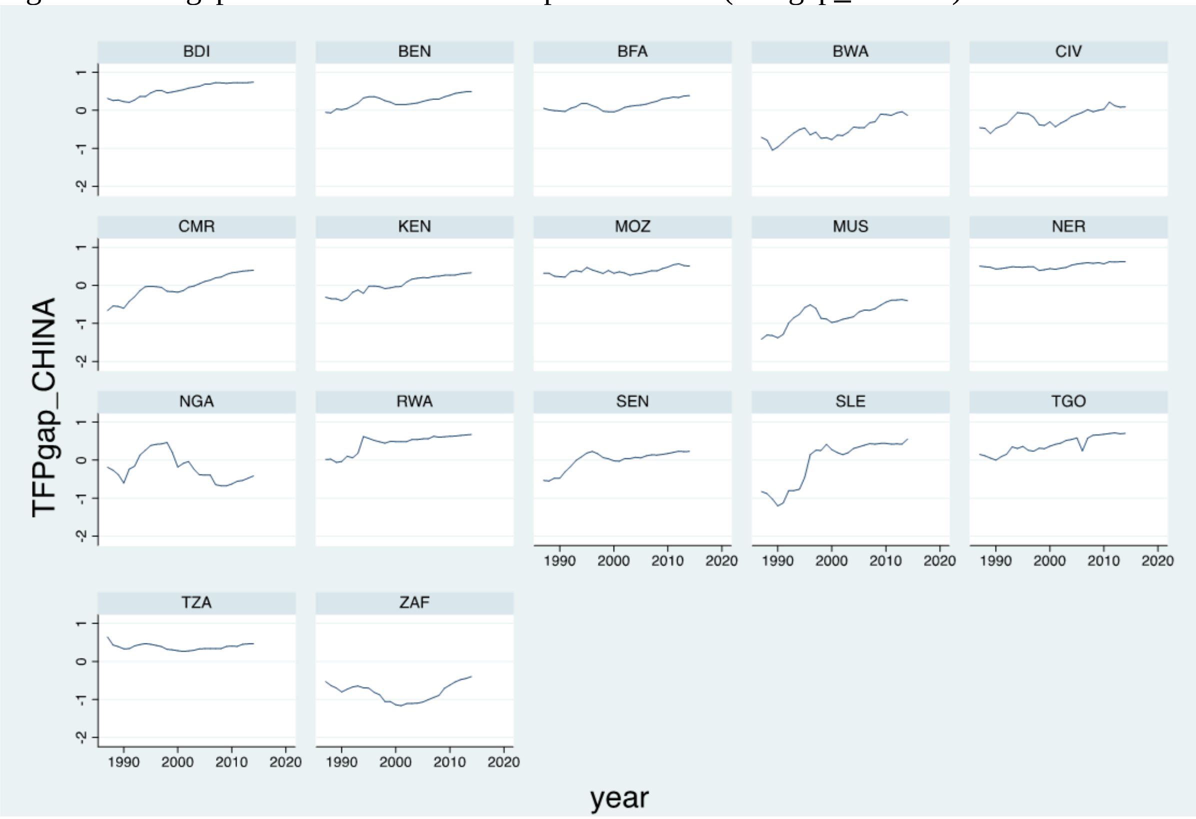


Figure 4. TFP gap of SSA nations with respect to the USA and China: A comparison

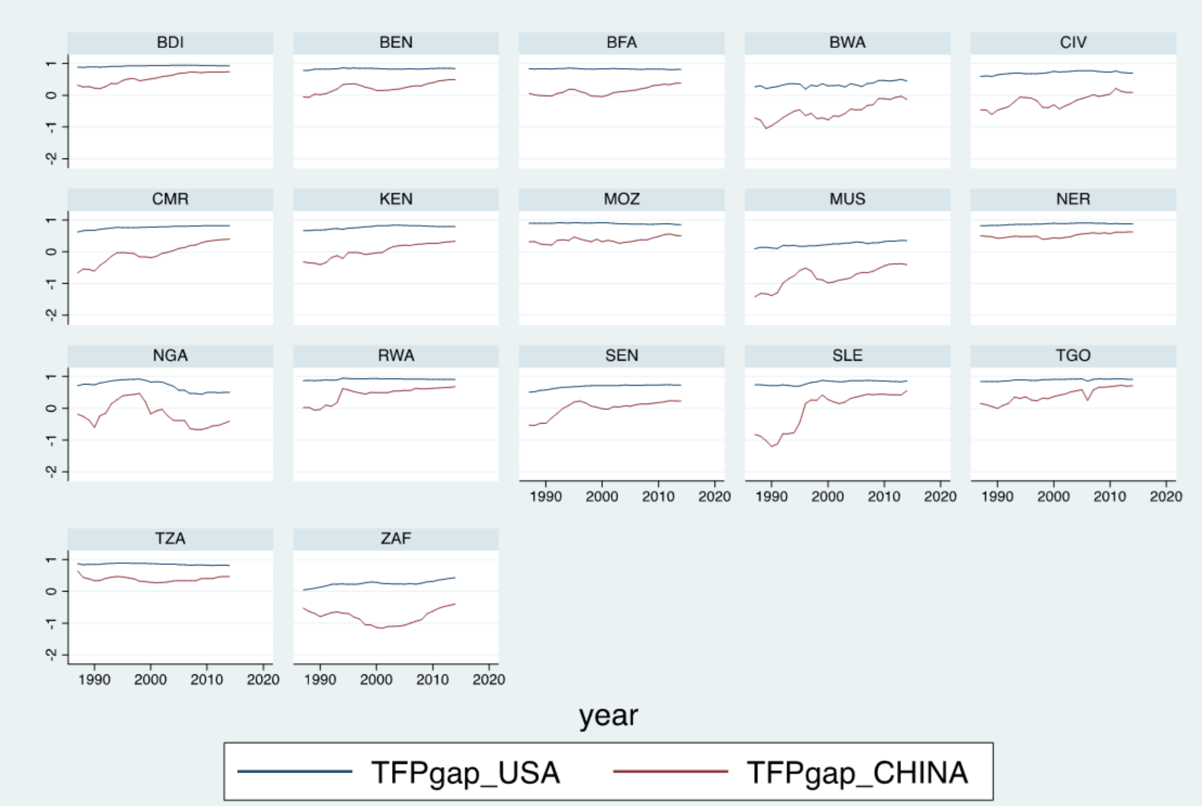
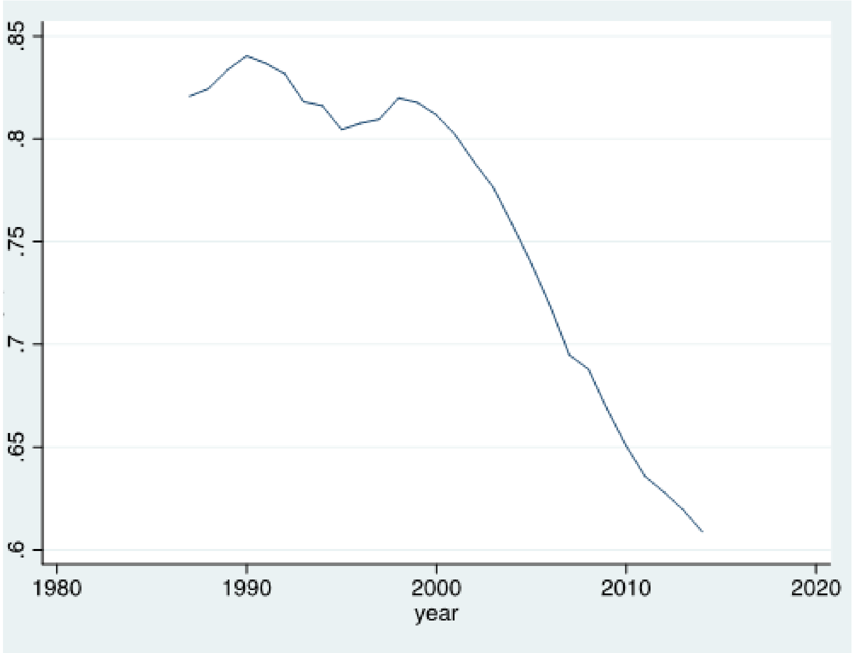


Figure 5. TFP gap between China and the USA



Appendix A: The superlative index number methodology and TFP estimation

This appendix explains how the superlative index number methodology has been employed to retrieve TFP indexes that are comparable across countries and along time.

It is assumed 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 & Cravino (2015).

Relying on the concept of distance function, Caves et al. (1982) derive the TFP index number for 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 *b*'s 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 it is exact for the flexible aggregator function chosen (i.e. translog production function) and, thus, it is not an approximation (see for more details in 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. $RGDP^O$) rather than the output-side real GDP expressed at current PPPs (i.e. $CGDP^O$). The same applies to our measure for capital stock, which is expressed in at chained PPPs US$ (i.e. RK). In symbols:

$$\frac{TFP_{ct}}{TFP_{bt}} = \left(\frac{RGDP^o_{ct}}{RGDP^o_{bt}}\right)/Q_{cbt} \qquad \text{(A1)}$$

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 the leader of advanced economies (i.e. USA) or the leader of developing economies (i.e China); *c* represents the generic African country in the sample and *t* indexes any year between 1987 and 2014.

Appendix B. Variable measurement and data source

TFP gap			
Variable name	**Measurement**	**Data Source**	**Prices**
$RGDP^{O}$	Output-side real GDP at chained PPPs (in millions of 2011US$)	PWT 9.0	Constant across countries and over time
$CGDP^{O}$	Output-side real GDP at current PPPs (in millions of 2011US$)	PWT 9.0	Constant across countries in a given year
CK	Capital stock at current PPPs (in millions of 2011US$);	PWT 9.0	Constant across countries in a given year
EMP	Number of persons engaged (in millions)	PWT 9.0	Not applicable
HC	Human capital index, based on the average years of schooling	Barro and Lee (2012)	Not applicable
LABSH	Labour income of employees and self-employed workers as a share of nominal GDP	PWT 9.0	Not applicable

System GMM Analysis (dependent variable Poverty)			
Variable name	**Measurement**	**Data Source**	**A-Priori Sign**
Poverty	*POV*: Percentage of headcount living below the poverty line of $1.9 a day in 2011 PPP	PovcalNet of the World Bank	
Lag of Poverty	$POV_{(t-1)}$: Percentage of headcount living below the poverty line of $1.9 a day in 2011 PPP	PovcalNet of the World Bank	+
TFPgap	*TFPgap_USA* (*TFPgap_CHINA*) measures the technological gap between the SSA nations and the USA (China)	Estimated in the first stage	+
Trade openness	*OPEN*: The sum of exports and imports divided by GDP	World Development Indicators (WDIs)	-
Inward FDI	*IFDI*: Inward FDI to GDP ratio	WDIs	-
Financial development	*FDEV*: domestic credit to GDP ratio	WDIs	-
Inflation	*INFL*: percentage change of the Consumer Price Index	WDIs	+
Economic growth	*GDPG*: Growth rate of real GDP (constant LCU)	WDIs	-
Infrastructure	It is measured using two alternative indicators, i.e., mobile phone and landline per 100 person (*INFR*) and mobile phone per 100 person (*MOBILE*)	WDIs	-
Government Spending	*GSPEN*: Government spending to GDP ratio	WDIs	-

Appendix C. The decomposition of productivity growth

McMillan et al. (2014) and Diao et al. (2019) propose to decompose productivity growth of an economy into two terms as follows:

$$g_y^t = \sum_i \theta_i^{t-1}\pi_i^{t-1}g_{y_i}^t + \sum_i \Delta\theta_i^t\,\pi_i^{t-1}\left(1 + g_{y_i}^t\right)$$

where $g_y^t = \frac{\Delta y^t}{y^{t-1}}$ and $g_{y_i}^t = \frac{\Delta y_i^t}{\Delta y_i^{t-1}}$ with y^t refers to economy wide productivity level at time t and y_i^t denotes the productivity level of sector i; $\pi_i^t = \frac{y_i^t}{y^t}$ refers to the relative labour productivity for sector i; θ_i^t denotes the share of employment in sector i at time t; and the Δ operator refers to the change in productivity or employment shares between $t-1$ and t. The first term is the weighted sum of productivity growth within individual sectors, where the weights are determined by the employment share and relative productivity for each sector at the beginning of the period. The second term is the inner product of the relative productivity for sector at t to the economy wide productivity at $t-1$, with the change in employment shares across sectors. Therefore, the first term captures the productivity growth originated from pure technological progress within sectors; the latter is the structural change term that captures productivity growth introduced by inter-sectoral labour reallocation (i.e., structural change).

McMillan et al. (2014) suggest that the economic wide productivity is computed by dividing the economy’s value added by the total employment, while the sectoral productivity is computed by dividing each sector’s value added by the corresponding level of sectoral employment. Please refer to McMillan et al. (2014) and Diao et al. (2019) for more detailed explanation of construction of the within sector and structural change terms for African countries.