ERF Working Papers Series

Conditional Convergence in Agricultural Productivity: The Case of Sudan

Ibrahim Elbadawi and Soha Ismail

Economic Research Forum
منتدى البحوث الاقتصادية

Working Paper No. 1494
October 2021

CONDITIONAL CONVERGENCE IN AGRICULTURAL PRODUCTIVITY: THE CASE OF SUDAN

Ibrahim Elbadawi and Soha Ismail

Working Paper No. 1494

October 2021

Send correspondence to:
Ibrahim Elbadawi
Economic Research Forum (ERF)
Email: iaelbadawi@erf.org.eg

First published in 2021 by
The Economic Research Forum (ERF)
21 Al-Sad Al-Aaly Street
Dokki, Giza
Egypt
www.erf.org.eg

Abstract

It is widely known that income per capita can only converge conditionally if countries adopt supportive policies and institutional frameworks that enhance their productivity. Looking closely at sectoral productivity, the literature shows that while labor productivity in the industrial sector actually converges unconditionally, agricultural productivity exhibits *unconditional divergence* but *conditional convergence*. Using a panel of 121 countries over 1991-2010, this paper asks the central question as to how might countries with low agricultural productivity converge to those at the regional or global frontier of agricultural productivity? The results show that higher growth in agricultural productivity is associated with several factors including: (1) Stable macroeconomic policy, including maintaining non-overvalued exchange rates, low inflation, and limited exchange rate variability; (2) Adequate levels of fertilizer consumption and robust infrastructure, including the areas of finance, transport, energy, and ICT; (3) Higher levels of human development and education. The paper then focuses on the specific case of Sudan, studying where it stands with respect to regional and international standards and what policy implications could be applied to improve its agricultural productivity. Agriculture is, by far, the mainstay of the Sudanese economy. Before the country can transform the sector and enhance its productivity, more public and private investments have to be channeled into agricultural supply, farmers should be more supported and empowered, and the government must end the legacy of excessive direct taxation of agriculture, as well as indirect taxation through overvalued exchange rates and hyperinflation.

Keywords: Agricultural productivity, conditional convergence, unconditional divergence, Sudan.
JEL Classifications: Q1

ملخص

من أهم النتائج المتواترة لأدبيات النمو الاقتصادي والمجمع عليها على نطاق واسع، تتلخص في أن البلدان الفقيرة تستطيع أن تحقق معدلات نمو في الناتج المحلى للفرد أسرع من تلك الأكثر ثراءً إذا تبنت سياسات داعمة للنمو وأطر مؤسسية تعزز إنتاجيتها. عليه، فإن تحقيق "التقارب" بين البلدان الفقيرة والغنية يكون مشروطاً بنجاعة المشروع التنموى والسياسات التي تنتهجها الدول النامية. في هذا السياق، النظر عن كثب إلى الإنتاجية القطاعية تظهر الأدبيات أنه في حين أن إنتاجية العمل في القطاع الصناعي تتقارب فعلياً دون قيد أو شرط، فإن الإنتاجية الزراعية تُظهر تباعداً غير مشروط ولكن تقارباً مشروطاً، تماماً كما في حالة الاقتصاد الكلى. باستخدام عينة من 121 دولة خلال الفترة 1991-2010 لتحليل نموذج محددات الانتاجية، تطرح هذه الورقة السؤال المركزي حول كيفية تقارب البلدان ذات الإنتاجية الزراعية المنخفضة مع تلك التي استطاعت تحقيق مستويات عالية من الإنتاجية الزراعية على المستويين الإقليمي والعالمي؟ تظهر النتائج أن ارتفاع النمو في الإنتاجية الزراعية يرتبط بعدة عوامل منها: (1) سياسات الاقتصاد الكلي المتزنة، بما في ذلك الحفاظ على أسعار صرف مستقرة ومتوائمة مع توازنات الاقتصاد الكلى والتضخم المنخفض؛ (2) توفير مدخلات الإنتاج الضرورية لزيادة الإنتاجية مثل الأسمدة والمبيدات والبذور المحسنة؛ (3) البنية التحتية المتينة بمعناها الواسع والتي تشمل مجالات التمويل والنقل والطاقة وتكنولوجيا المعلومات والاتصالات؛ (4) التنمية البشرية من تعليم وصحة وخدمات اجتماعية، فى الريف بصورة خاصة، وتمكين المزارعين من المشاركة الفاعلة في تشكيل السياسات الاقتصادية وتخصيص الموارد الكافية لدعم تحديث وتطوير القطاع الزراعى. تأسيساً على هذه الدلائل الكمية، تركز الورقة على حالة السودان، كدولة ذات اقتصاد زراعى واعد ولكن يعانى من ضعف مريع في الإنتاجية. تحديداً، تستعرض الورقة الإنتاجية الزراعية في السودان مقارنة بالمعدلات الإقليمية والدولية وتحلل الآثار المحتملة للسياسات التي يمكن اعتمادها لتحسين إنتاجيته الزراعية. نخلص إلى أنه لكى تتمكن هذه الدولة من إحداث تحول هيكلى مستدام في القطاع الزراعى وتعزيز إنتاجيته، عليها توجيه المزيد من الاستثمارات العامة والخاصة إلى الإنتاج الزراعي، دعم المزارعين وتمكينهم بشكل أكبر، وكذلك إنهاء إرث الضرائب المباشرة المفرطة على هذا القطاع، فضلاً عن الضرائب غير المباشرة المترتبة على المغالاة في أسعار الصرف والتضخم المفرط.

الكلمات المفتاحية: الإنتاجية الزراعية، التقارب المشروط، التباعد غير المشروط، السودان .

1. Introduction

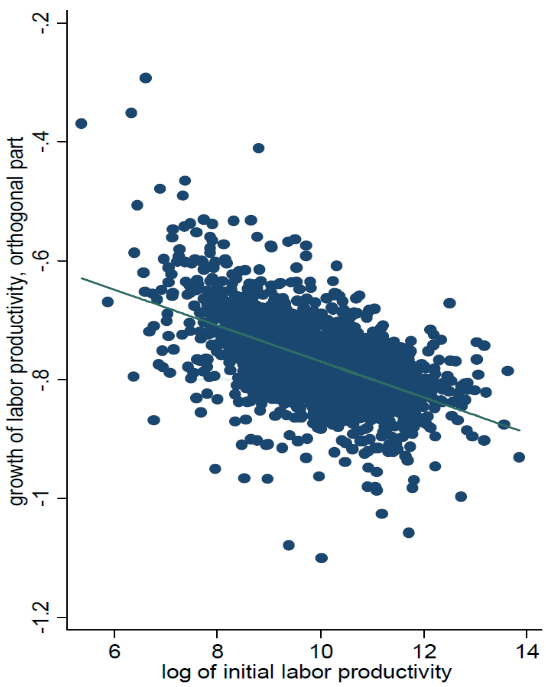
It is common knowledge among economists that per capita income levels across countries only converge conditionally. Poorer economies can only grow faster than richer economies, conditional on their endowments, policies, and institutions. Rodrik (2011), however, argues that unconditional convergence does exist in individual manufacturing industries. Once an economy starts manufacturing a given product, labor productivity in that industry should automatically follow and upward trajectory. Figure 1 below presents the results from Rodrik (2011), showing the relationship between initial industrial labor productivity and the growth rate in industrial labor productivity between 1990 and 2007. The unconditional regression (including industry and time dummies) shows a highly statistically significant and negative coefficient of -0.031, implying that countries with lowest initial productivity in a given industry can unconditionally grow and approach the frontier relatively faster. Unsurprisingly, the rate of convergence is faster once controlling for country fixed effects. The coefficient for the conditional regression is almost the double at -0.063.

Figure 1. Unconditional and Conditional Convergence in Industrial Labor Productivity

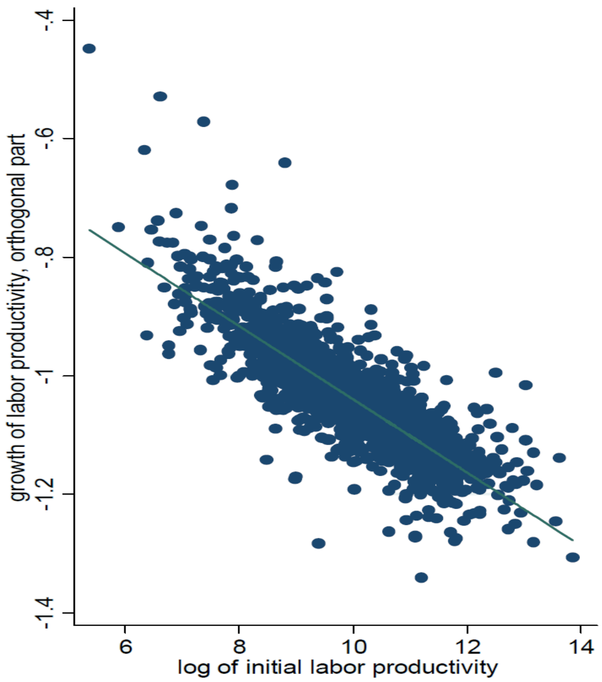
Panel A: Unconditional Convergence

Industrial Productivity

(coef. = -0.031)



Panel B: Conditional Convergence
Industrial Productivity
(coef. = -0.063)



This figure presents scatter plots of average growth rate in industrial labor productivity (on the vertical axis) against the log of initial productivity (on the horizontal axis). Data is from the United Nations Industrial Development Organization (UNIDO) industrial statistics data base (INDSTAT4). Labor productivity is computed using value-added at the 4-digit level of disaggregation for the manufacturing industry. The graphs are for decadal regressions over 1990-2007. Panel A reports the unconditional relationship between the growth rate and initial value of industrial productivity. Panel B reports the conditional relationship. Unconditional convergence regressions include industry and time dummies, while conditional regressions also include country fixed effects.

An interesting question then arises: If it is the case that industrial productivity can converge unconditionally, could that also be the case for agricultural productivity? This question was originally raised by Diwan et al. (2013), who showed that there is actually unconditional divergence, not convergence, in agricultural labor productivity. When country characteristics are not controlled for, labor productivity tends to grow faster in countries with higher initial productivity, widening the gap. Once controlling for country-specific fixed effects, labor productivity does converge across countries with different initial levels. Interestingly, Diwan et al. (2013) argue that this could explain why there is neither conditional convergence nor divergence in per capita income across countries. When regressing the growth rate in gross domestic product (GDP) per worker on its initial levels, the coefficient is usually not statistically different form zero. If there is unconditional convergence in industry, but divergence in agriculture, then it would make sense for the overall productivity to show neither.

In this paper we try to answer the following questions: (1) What are the country characteristics that can determine the convergence in agricultural productivity? (2) Where does Sudan stand with respect to international standards, and what lessons could be learnt to improve its agricultural productivity? We address those questions by running cross-country panel regressions of the growth in agricultural labor productivity on the log of the initial value of productivity, while controlling for an encompassing set of fundamentals associated with agricultural growth as well as country-specific characteristics. In particular, we include three sets of important characteristics. First, policy variables, which include the rate of consumer price index (CPI) inflation, real exchange rate variability, as well as a measure of real exchange rate undervaluation. Second, infrastructure and input variables, which include different measures of infrastructure and fertilizer consumption. Third, human capital variables, which include either the human development index (HDI) or measures of educational attainment.

This study is one of the first to discuss this issue of agricultural convergence in detail, and the first to discuss the determinants of agricultural growth in Sudan in such context. Agriculture is a major sector in Sudan, which constituted around 21.8% of value-added GDP in 2019, according to the World Bank's World Development Indicators. Sudan is a country endowed by a large area of arable land, yet it remains to be one of the countries with the lowest agricultural productivity. In 2019, agricultural value added per worker in Sudan was only 43% of that in South Africa despite the fact that its arable land area is almost double that of South Africa. An important question then remains on where Sudan stands with respect to other countries and what does it need to do in order to promote its agricultural productivity.

The rest of this paper is organized as follows. Section 2 discusses the data and methodology used in the analysis. Section 3 presents the case of Sudan and how it stands with respect to peer countries. Section 4 explains the results. Finally, Section 5 concludes.

2. Data and Methodology

The study uses data for 121 countries over the period 1991-2010. This is the longest period for which all variables are available. The panel is set over four non-overlapping five-year intervals, with the exception of the last period which includes only 4 years. Accordingly, each country can have up to four periods in the panels: 1991-1996; 1996-2001; 2001-2006; 2006-2010. We use the average values of the variables over each period. Averaging data over five-year or decadal intervals is a common practice in cross-country convergence regressions to eliminate cyclical factors, focus on long-term relationships, and ensure that more data is available for a bigger set of countries. Since data for agricultural productivity is available over the period 1991-2019, unconditional regressions are run for this longer period to take advantage of the greater variation in the data.[1] Appendix Table 1 presents the summary statistics of the variables used in the analysis for all 121

[1] Similar results are obtained when restricting the analysis to the shorter period of 1991-2010.

countries, using the 1991-2010 panel. The list of countries included in the analysis is presented in Appendix Table 3. All data sources are described in Appendix Table 4.

The main analysis includes running a set of cross-country panel regressions of the average growth in agricultural productivity on the log of initial agricultural productivity and a set of control variables. The regression specification is as follows:

$$AgPrGr_{i\tau} = \alpha + \beta \, log(AgPr_{i\tau}) + \gamma' Policy_{i\tau} + \delta' Inf\_Inp_{i\tau} + \theta \, HumCap_{i\tau} + \rho' X_{i\tau} + \mu_\tau + \varepsilon_{i\tau} \quad (1)$$

where subscript i represents the country and τ represents the five-year time period. $AgPrGr_{i\tau}$ is the five-year average of the annual growth rate in agricultural productivity. $AgPr_{i\tau}$ is the initial value of agricultural productivity at the start of the five-year period. Agricultural productivity is measured as agricultural value added (in constant 2010 US dollars) per agricultural worker. $Policy_{i\tau}$ is a vector of policy related variables, including the CPI inflation rate, a measure of exchange rate undervaluation, and a measure of exchange rate variability. $Inf\_Inp_{i\tau}$ is a vector of infrastructure- and input-related variables, including different measures of infrastructure as well as the log of fertilizer consumption. $HumCap_{i\tau}$ is a measure of the level of human capital in the country, proxied by the log of HDI or education measures as the log of mean years of total, primary, or secondary schooling. $X_{i\tau}$ is a vector of other country controls, including the ratio of arable land to the population, the log of yearly precipitation, the ratio of rural to total population, and a dummy variable equal to one if the country is landlocked. μ_τ indicates time-specific fixed effects. α, β, γ, δ, θ, and ρ are parameters to be estimated. $\varepsilon_{i\tau}$ is the error term. All country-specific controls are included as five-year averages per period of analysis.[2]

2.1 Policy Variables

Policy variables should pose significant effects on the growth of agricultural productivity in a country. In particular, we use three policy-related variables, the annual rate of inflation, exchange rate undervaluation, and exchange rate variability. By increasing production costs of inputs and other factors of production, inflation is expected to have a negative effect on productivity growth. Moreover, a less stable exchange rate and a higher level of variability is expected to negatively affect the growth in productivity as it increases the difficulty and uncertainty of trade. Exchange rate is measured using the Darvas (2012) real effective exchange rate (REER) index, for which an increase indicates an appreciation of the home currency against the basket of trading partners' currencies. Exchange rate variability is measured as the coefficient of variation of the REER index.

[2] This is with the exception of the mean years of secondary and primary years of schooling, which are only available from Barro and Lee (2013) in five-year intervals, with 1990 being the first year relevant to our study period. Accordingly, the value in each five-year period of analysis is taken as the value in the preceding year. For example, the value of school attainment in 1990 is used for the period 1991-1996.

Exchange rate undervaluation is measured as the log of the ratio of the five-year moving average in REER to its contemporaneous value.

$$REER\_Undervaluation_{it} = log(REER\_MA_{it}/REER_{it}) \quad (2)$$

where $REER\_MA$ is the five-year moving average of the real effective exchange rate index for country i in year t.[3] Accordingly, an increase in this measure would reflect a depreciation in the REER compared to its medium-term trend. REER undervaluation should be positive if REER is below the average, indicating a relatively undervalued currency, while negative if above the average in a given year. Since a relatively undervalued exchange rate would be expected to increase international competitiveness and improve a country's global trading position, exchange rate undervaluation should positively impact the growth in agricultural productivity.

The received literature suggests that maintaining the REER close to its equilibrium level is a necessary condition for sustained growth and that countries with non-overvalued currencies are associated with sustained export-led growth and substantial export diversification (e.g. Elbadawi and Helleiner, 2004). Moreover, not only that avoiding overvaluation is necessary for growth, but also a mild undervaluation may be good for growth (e.g. Aguirre and Calderón, 2005; Rodrik, 2008; Elbadawi et al., 2012). It has been argued that a depreciation of the REER can have a positive effect on growth by increasing capacity utilization and raising the profitability of traded-good sectors, such as agriculture, which in turn can promote private investment. Moreover, a depreciated currency provides an economy-wide incentive to new potentially exportable products that might face high entry barriers under an excessively strong currency. Furthermore, REER depreciation avoids the necessity of selecting beneficiaries for export subsidies (i.e., "picking winners") as it promotes all exporting industries. Empirically, the evidence suggests that this positive effect of REER depreciation substantially dominates its potential negative effects associated with raising the cost of imported investment goods, which tends to be a large component of investment goods in developing economies.

2.2 Infrastructure and Input Variables

The second set of country characteristics focuses on infrastructure development and inputs, specifically fertilizer consumption. Infrastructure is measured using the comprehensive indices developed by Donaubauer et al. (2016), which capture both the quantity and quality of infrastructure in energy, information and communications technology (ICT), finance, and transport. We use those four indices separately in the regressions as well as an overall index which captures all four aspects together. All indices are scaled to range between 1 and 10, with higher values indicating a better level of infrastructure development. Both higher quantity and quality of infrastructure are expected to positively affect the growth rate in agricultural productivity. For

[3] The average of the undervaluation variable is then computed for each five-year period τ.

example, better developed road and other transport networks should reduce transportation costs for farmers and boost their productivity. Moreover, as shown by Donaubauer et al. (2016), higher infrastructure attracts more foreign direct investment (FDI) and boosts trade, both of which can contribute to higher productivity in the agricultural sector. Better access to finance should also promote investment by farmers and increase their productivity. According to Fowowe (2010), for example, farmers are the most financially excluded group in Nigeria. Improving financial inclusion in Nigeria proves to have a positive and statistically significant effect on agricultural output and productivity. In another cross-country panel study, Lio and Liu (2006) also show that the adoption of ICT has a significantly positive effect on agricultural productivity. Higher fertilizer consumption should also positively impact productivity (Rehman et al., 2019).

It should be noted that since infrastructure development requires huge amounts of public investment, which creates an opportunity cost related to lost investments in other areas of development, one might expect the impact of infrastructure on productivity to be non-linear. This is especially the case as our sample includes a large set of countries with varying levels and large disparities of infrastructure development. We expect this case to be particularly evident with finance and transport infrastructure. For example, using a country panel, Shen (2013) shows that financial development exhibits diminishing returns on the growth rate in real industrial value added. To account for such possibility, we also include the square of finance infrastructure in the regressions. Moreover, Rodrigue (2020) suggests that there might also be diminishing returns to transport investments. When the existing infrastructure is limited, investments in transport should add capacity and connectivity, hence have a greater impact on the economy. In cases where decent infrastructure already exists, benefits from new investments in transport, as opposed to investing in the maintenance of the existing stock of infrastructure, for example, should start to diminish. Where mature and long-established transportation systems exist, additional investments would then become means to maintain the system without much added value in connectivity or efficiency. To test this hypothesis, we first include a squared variable for transport infrastructure in the regression. Moreover, in a similar manner to Vandenbussche et al. (2006),[4] we define a variable of transport proximity as the log of the ratio of the transport frontier, in a given time period, to a country's own value of transport index in this period:

$$Transport\ Proximity_{it} = log(Transport\ Frontier_t / Transport\ Index_{it}) \qquad (3)$$

where, $Transport\ Frontier_t$ is measured as the median of the transport index for a given income-group. In a given year t, the frontier variable can take one of two values. It is equal to the median transport index of the low- and middle-income countries for any country in those two income groups, while it is equal to the median of the high-income countries for any high-income country.[5]

[4] Vandenbussche et al. (2006) measures the proximity to the frontier of total factor productivity as the log of the ratio of a country's total productivity level to that of the frontier (taken as the US).

[5] Income groups are defined according to the World Bank classification of FY2019.

An increase in the transport proximity would indicate that a country is further away from its frontier, hence it should be positively related to agricultural productivity.[6]

2.3 Human Capital Variables

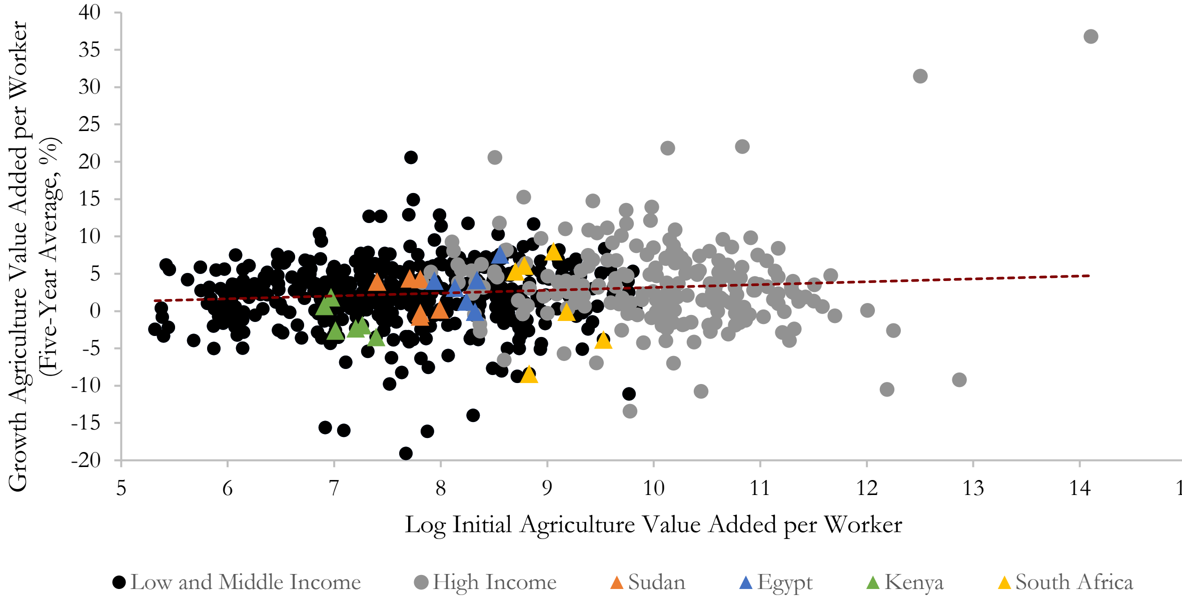
A basic augmented Solow-Swan model predicts that human capital is a major determinant of productivity growth and its conditional convergence. In a similar manner, higher levels of human capital are expected to positively impact productivity in the agricultural sector. We measure human capital using either the HDI of the United Nations development program (UNDP), or measures of educational attainment. The HDI is a composite index, which gauges the level of human development with respect to the average achievement in three dimensions: life expectancy, education, and per capita income. The used measures of educational attainment include the mean years of schooling, obtained from the UNDP, as well as the mean years of primary and secondary schooling, obtained from Barro and Lee (2013).

3. Results and Discussion

Figure 2 shows the unconditional relationship between the growth in agricultural productivity and the log of initial agricultural productivity.

[6] The average of the variable is then computed for each five-year period τ.

Figure 2. Unconditional Divergence in Agricultural Labor Productivity



coef. = 0.381, se (robust) = 0.178, p = 0.032 **

This figure presents a scatter plot of the unconditional relationship between the five-year average growth rate in agriculture labor productivity (on the vertical axis) and the log of initial productivity (on the horizontal axis). Results of a similar regression are shown in Table 1, column (1). Agriculture productivity is measured as the agriculture value added per agriculture labor (in constant 2010 USD). Initial agriculture value added is the first-year value of each five-year interval. The analysis uses a panel data of 121 countries over 1991-2019, in five-year intervals. Hence, a country can have between one to six points on the plot in Panel A. Highlighted are Egypt, Sudan, Kenya, South Africa, in addition to the median of low-income and middle-income countries as defined by the World Bank.

The results of the unconditional regression are reported in the first column of Table 1. Unconditionally, there is divergence in agricultural productivity. The coefficient is positive at 0.38 and highly statistically significant. Although the conclusion is in line with the results from Diwan et al. (2013), our coefficient is quite smaller (they report an unconditional coefficient of 1.47). Nevertheless, while our regressions use five-year panel data, theirs used decadal data. This result of unconditional divergence is robust to using different sets of countries and time spans.

Table 1. Unconditional and Conditional Convergence in Agriculture Productivity

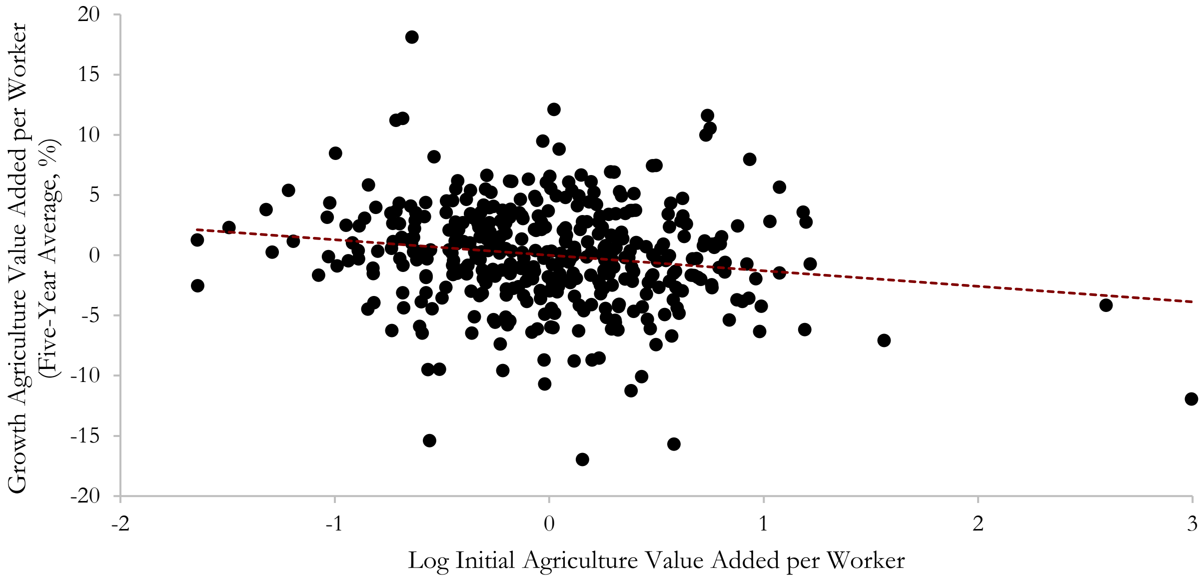
This table reports cross-country panel regressions, in five-year intervals, for 121 countries over 1991-2019 for column (1) and 1991-2010 for columns (2)-(10). Column (1) reports the unconditional regression of the five-year average of annual growth rate in agriculture value added per agriculture labor (in constant 2010 USD) on the log of initial value added. Columns (2)-(10) report conditional regressions, controlling for a set of policy, infrastructure and input, in addition to human capital variables Real exchange rate (REER) undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Transport proximity is the log of the ratio of the transport frontier to own transport index, where the frontier is defined as the specific country-group median of the transport index, separately for low- and middle-income countries (LMIC) and for high-income countries (HIC). LMIC (HIC) are dummies equal to one if the country is of a low- or middle-income (high-income). Human capital is proxied by the log of the human development index. Conditional regressions also include country-specific controls (not reported for brevity) of the ratio of arable land to population, the log of yearly precipitation, the ratio of rural to total population, and a dummy variable equal to one if the country is landlocked. Initial value added is the first-year value of each five-year interval, while other control variables are computed as the five-year averages. Columns (2)-(10) include time dummies. Robust standard errors are in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

	Dependent Variable: Growth in Agriculture Productivity (%)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agricultural Productivity	0.381**	-1.290***	-1.341***	-1.499***	-1.186***	-1.031***	-0.944***	-0.952***	-1.252***	-1.246***
(In logs, Real Initial Value)	(0.18)	(0.38)	(0.40)	(0.38)	(0.34)	(0.33)	(0.33)	(0.33)	(0.35)	(0.35)
Policy Variables										
REER-Undervalue		9.470***	9.264**	9.074***	13.074***	12.027***	9.176**	9.330**	8.816**	8.871**
(Index)		(3.63)	(3.89)	(3.45)	(3.44)	(3.26)	(3.62)	(3.68)	(3.55)	(3.57)
REER-Variability		-8.198**	-7.725*	-7.876**	-11.683***	-10.749***	-8.251**	-8.342**	-7.567*	-7.579*
(Index)		(4.02)	(4.26)	(3.87)	(3.55)	(3.30)	(3.97)	(4.04)	(3.91)	(3.95)
Inflation Rate		-0.005***	-0.005***	-0.005***	0.000	-0.001	-0.005***	-0.005***	-0.005***	-0.005***
(%)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Infrastructure and Input Variables										
Overall Index		0.429**								
		(0.21)								
Energy Index			0.458							
			(0.31)							
ICT Index				0.793***						
				(0.26)						
Finance Index					0.251	3.004***				
					(0.21)	(0.83)				
(Finance Index)^2						-0.280***				
						(0.08)				
Transport Index							0.098	1.177	0.642**	0.685**
							(0.17)	(0.73)	(0.27)	(0.28)
(Transport Index)2								-0.115		
								(0.08)		
Transport Proximity									3.163***	
									(1.12)	
Transport Proximity*LMIC										2.964***
										(1.13)
Transport Proximity*HIC										3.821**
										(1.75)
Fertilizer Consumption		0.214*	0.254**	0.253**	0.211*	0.181	0.228**	0.227**	0.279**	0.274**
(In logs of tonnes used)		(0.11)	(0.12)	(0.11)	(0.12)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)
Human Capital Variables										
Human Development Index		3.690**	5.153***	3.420**	5.362***	4.628***	3.739***	2.910**	4.329***	4.173***
(In logs)		(1.53)	(1.93)	(1.38)	(1.55)	(1.49)	(1.40)	(1.36)	(1.40)	(1.38)
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	678	412	378	421	392	392	422	422	422	422
R-squared	0.014	0.167	0.175	0.183	0.117	0.139	0.164	0.167	0.181	0.182

Columns (2) to (10) report results for the conditional regression, controlling for country-specific characteristics as explained in Model (1) above. Column (2) reports the results after accounting for the three sets of country-specific variables. Infrastructure is measured using the overall composite index, which accounts for the quantity and quality of energy, ICT, finance, and transport infrastructure. Human capital is measured using the HDI, accounting for life expectancy, educational attainment, and standard of living. Appendix Tables 2a-2c report the same set of regressions, while using different measures of human capital as the mean years of total, primary, and secondary schooling.

The results in Table 1 show a negative and highly significant coefficient for the log of initial agricultural productivity, implying conditional convergence. All other variables are highly significant and exhibit the expected signs. Growth in agricultural productivity tends to increase with a more stable and trade-oriented macro-economic policy that exhibits a relatively undervalued exchange rate as well as lower exchange rate and price volatility. As expected, a more developed infrastructure level also promotes productivity growth. An increase in the overall infrastructure index by one standard deviation (1.71) is associated with an increase of 0.73 percentage point in the average growth rate of agricultural productivity. Moreover, on average, doubling the amount of the fertilizer consumed can raise labor productivity growth by around 0.21 percentage points. The level of human development is also a significant determinant of agricultural productivity growth. On average, an improvement in HDI by 10 percent is associated with around 0.37 percentage points in productivity growth. Figure 3 plots the conditional relationship between the growth in agricultural productivity and the log of initial agricultural productivity from this regression. The relationship becomes obviously negative.

Figure 3. Conditional Convergence in Agricultural Labor Productivity



coef. = -1.290, se (robust) = 0.379, p = 0.001 ***

This figure presents a scatter plot of the conditional relationship between the five-year average growth rate in agriculture labor productivity (on the vertical axis) and the log of initial productivity (on the horizontal axis). This is an adjusted partial residual plot, which shows the relationship between the log initial productivity and the growth of productivity, after including the explanatory variables in the regression reported in Table 1, column (2). Agriculture productivity is measured as the agriculture value added per agriculture labor (in constant 2010 USD). Initial agriculture value added is the first-year value of each five-year interval.

Columns (3), (4), (5), and (7) of Table 1 report similar results, using the separate infrastructure indices for energy, ICT, finance, and transport, respectively. ICT index seems to be the strongest and most highly significant. An increase in the ICT infrastructure index by a single standard deviation (1.43) is associated with an increase of 1.13 percentage points in the growth rate of agricultural productivity. At a first glance, coefficients for other infrastructure variables seem to be insignificant in the main regressions. The energy and finance coefficients are more significant when using the measures of educational attainment rather than the HDI to account for human capital. For example, in Appendix Table 2b, when controlling for the mean years of primary schooling, the coefficient for energy infrastructure is 0.68 and highly significant. Moreover, the coefficient for finance infrastructure is 0.42 and becomes significant at the 10% level. The absolute transport index is not significant in any of the specifications.

To test the arguments of diminishing marginal returns to finance and transport infrastructure, columns (6) and (8) add the squared values for each of the infrastructure variables. The results in Table 1 show a very evident case of diminishing returns in finance infrastructure. The results indicate a concave relationship between finance infrastructure and agricultural productivity growth, with a maximum value reached at an infrastructure index of 5.36. Interestingly, this value is very close to the mean (5.60) and median (5.67) finance index values of high-income countries, which can be thought of as the frontier of financial development. The squared value for the transport index is not significant when using HDI as the measure of human capital in Table 1. Nevertheless, when using years of school attainment instead in Appendix Tables 2a-2c, transport infrastructure also exhibits a concave relationship. For instance, in Appendix Table 2a the maximum of transport infrastructure can be reached at 5.15, which again is remarkably close to the mean of high-income countries of 5.16.

If it is the case that transport infrastructure exhibits diminishing returns, then one would expect the positive benefits of additional infrastructure developments to be higher for countries with the lowest levels to start with. To investigate this further, we include in the regression the transport proximity variable explained in Model (2). This variable is the log ratio of the transport frontier to the own country's transport index in a given period, and hence would be higher for countries farther away from the frontier. Column (9) adds this transport proximity variable to the regressions, while column (10) adds the variable interacted with dummy variables for high-income and low- and middle-income countries. Interestingly, not only that the coefficient for transport proximity is positive and highly significant in all specifications, but the coefficient for the absolute transport index also becomes significant. In Table 1, the transport index has a coefficient of around 0.64, indicating that an increase in the index by a single standard deviation (1.6) is associated with an increase in agricultural productivity growth by around 1 percentage point. The coefficient for transport proximity is a positive 3.16, indicating that countries with the lowest transport infrastructure index compared to their frontier will benefit the most from any marginal improvements.

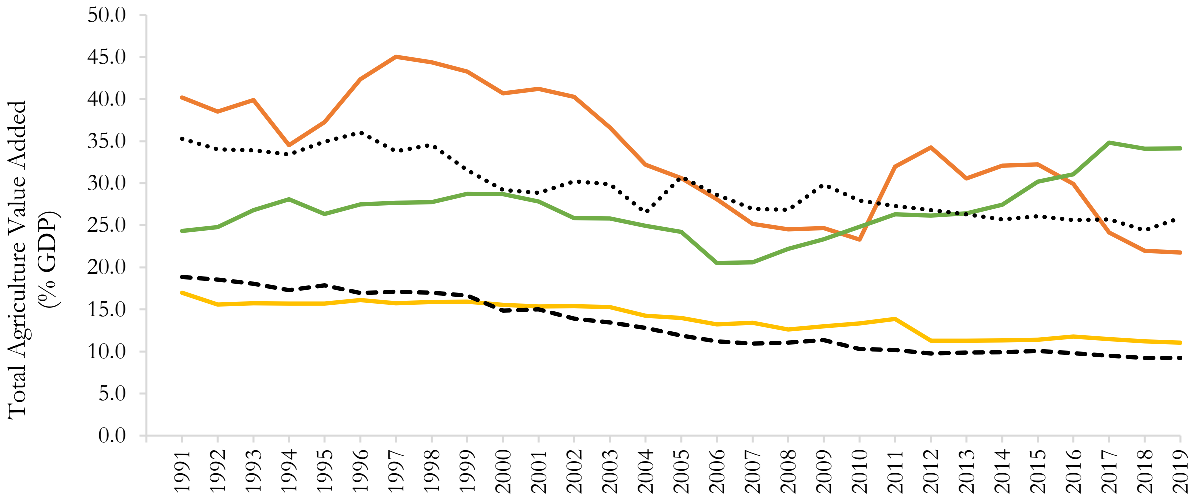
4. The Case of Sudan: Where does it Stand?

4.1. Agricultural Productivity in Sudan

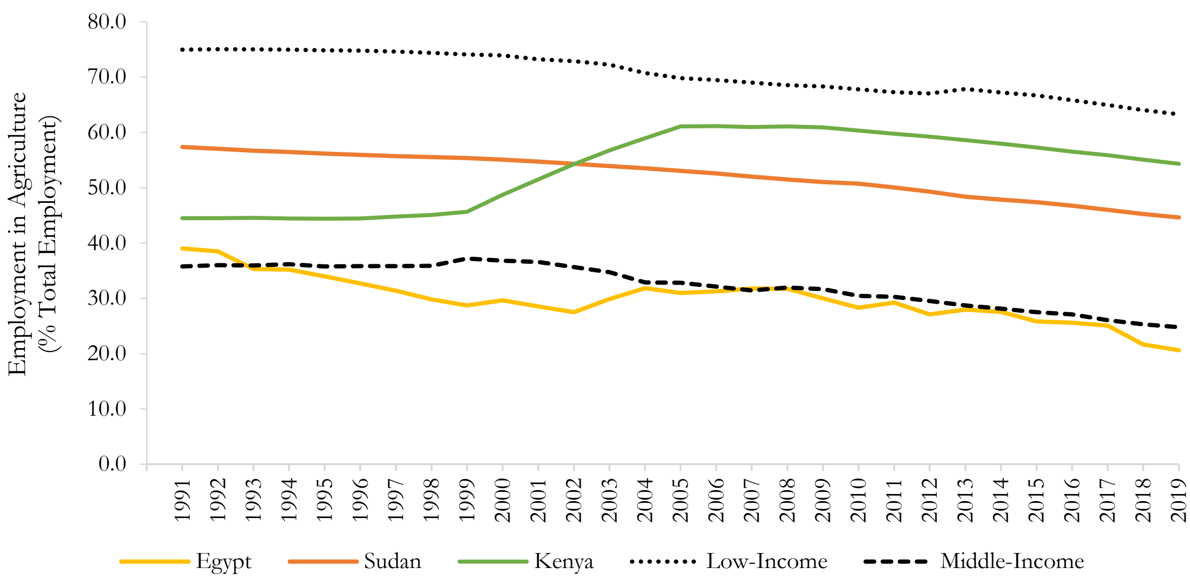
Like many other low-income countries, Sudan's economy is still highly dependent on agriculture. As shown in Figure 4, Sudan's agricultural sector contributed around 20% to GDP in 2019, compared to only 11% in Egypt. Although the share of Sudanese agriculture in GDP has been falling over time, as compared to Kenya for instance, its proportion is still at the high end of the spectrum. Moreover, the agricultural sector is a major driver of employment in the country. Almost 45% of employment in 2019 was in agriculture, compared to a mere 20% in Egypt.

Figure 4. The Economic Contribution of Agriculture to Output and Employment

Panel A: Total Agriculture Value Added (% of GDP)



Panel B: Employment in Agriculture (% of Total Employment)

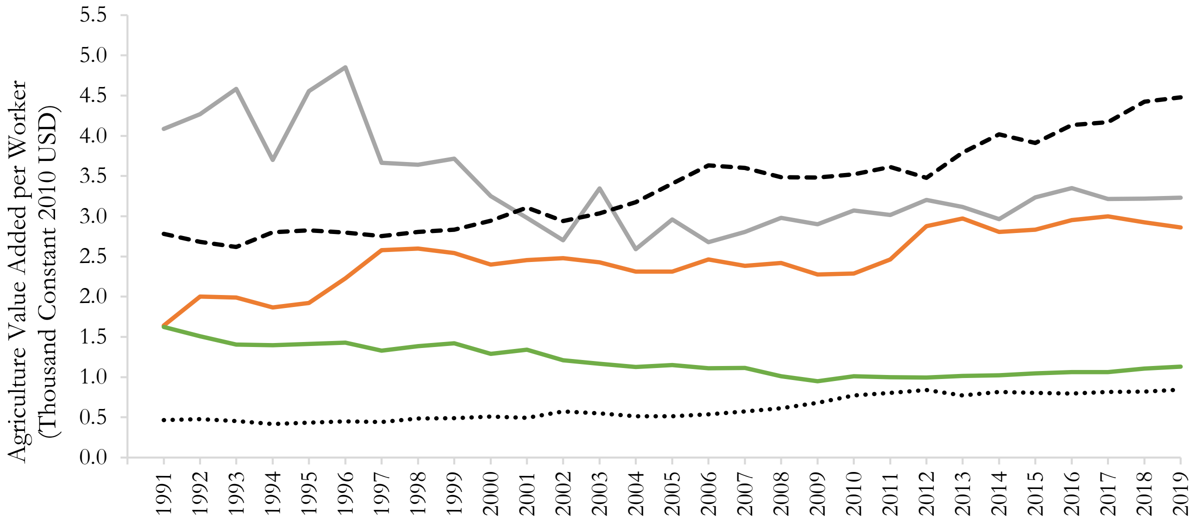


This figure presents the evolution of the economic contribution of agriculture, over the period 1991-2019, for Egypt, Sudan, Kenya, in addition to the median of low-income and middle-income countries as defined by the World Bank. Panel A presents total agriculture value added as a percentage of GDP. Panel B presents the employment in agriculture as a percentage of total employment.

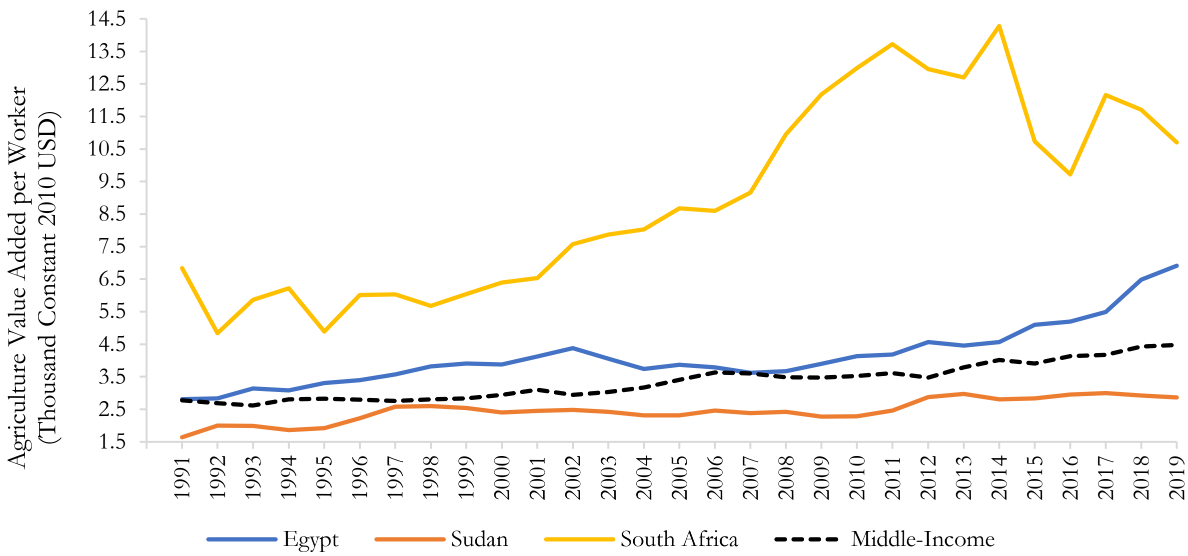
Despite the sector's relative importance to the Sudanese economy, agricultural productivity remains low. Figure 5 shows the evolution of agriculture labor productivity, measured as agriculture value added per worker.

Figure 5. Agricultural Labor Productivity

Panel A: Lower Agricultural Labor Productivity



Panel B: Higher Agricultural Labor Productivity



This figure presents the evolution of agriculture labor productivity, over the period 1991-2019, for different country groups. Panel A presents agriculture labor productivity measured as agriculture value added (in thousands of constant 2010 USD) over the number of employees in agriculture, for Sudan, Mauritania, Kenya, in addition to the low-income and middle-income medians. Panel B presents agriculture labor productivity for Sudan, Egypt, South Africa, and the middle-income median. Low-income and middle-income countries are defined according to the World Bank classification.

Panel A of Figure 5 shows productivity for Sudan in comparison to the medians of low-income and middle-income countries, as well as other countries with relatively low productivity, such as Kenya and Mauritania. Unlike Kenya and Sudan, Mauritania has one of the poorest agricultural lands in the world. The area of arable land in Mauritania is no more than 2% of that in Sudan.

While Mauritania's labor productivity was much higher than that of Sudan in the 1990s, it has been on a continuous decline since then. Although in 2019, the gap has been much narrower, Sudan's agricultural productivity still lags behind despite its natural endowments of ample arable lands. Kenya, on the other hand, is a country with more tropical climate and higher agricultural potential than Mauritania. Yet, its labor productivity is still remarkably low compared to Sudan. This is despite the fact that Kenya's agricultural sector has been gaining more importance in the later years. In 2019, agriculture accounted for 34.1% of GDP and 54.3% of employment, both of which are higher than in Sudan. While Sudan's agricultural productivity exceeds the median of low-income countries, it is still lower than that of middle-income countries.

Panel B of Figure 5 shows the evolution of agricultural productivity for some middle-income countries, with relatively higher productivity levels. Egypt's labor productivity is slightly above the median of middle-income countries and has shown some remarkable increase in recent years. Between 2000 and 2019, agricultural productivity in Egypt has increased by around 80% compared to 19% in Sudan. Yet, Egypt is still a country with many challenges and many potential areas for improvement. South Africa is a country that could represent the next level for both Egypt and Sudan as its agricultural productivity has shown remarkable improvement over time. Between 1995 and 2014, agricultural productivity in South Africa grew by around 190%, before it slightly declined in the wake of the 2016 South African crisis. Despite that, in 2019, South Africa's labor productivity was almost 2.4 times that of Egypt and the middle-income median, while 4.2 times that of Sudan.

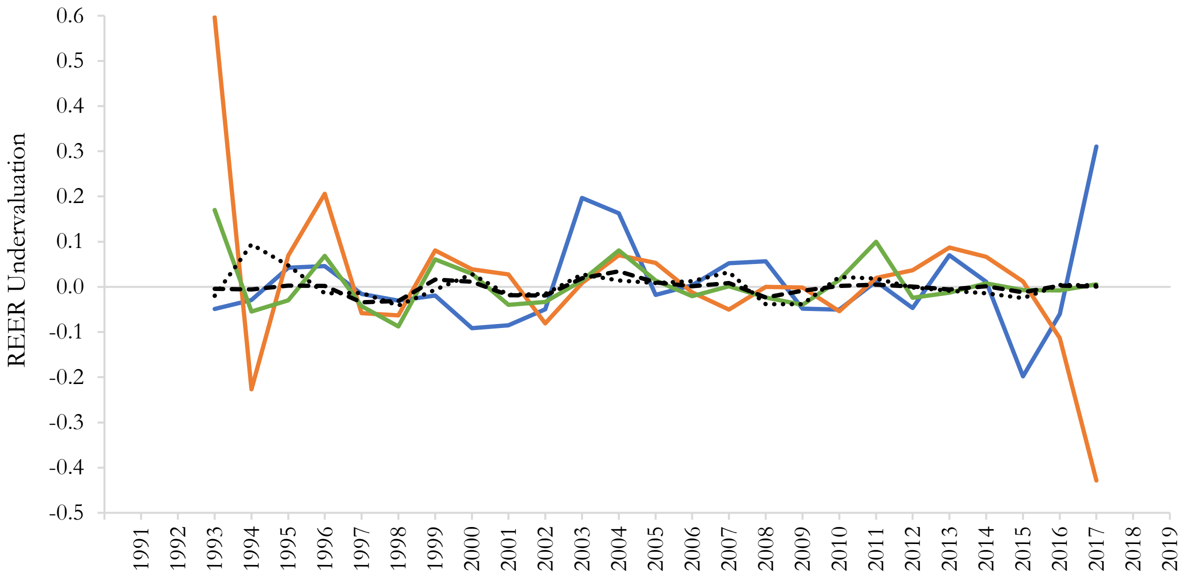
4.2. Potential Areas of Improvement for Sudan

Figures 6 through 9 present the Sudanese situation, compared to other countries, with respect to the determinants of growth in agricultural productivity, as previously analyzed in the regressions. All figures show the case of Sudan between 1991 and 2019, compared to Egypt, Kenya, as well as the medians of low-income and middle-income countries as benchmarks, with the exception of the infrastructure plots (Figure 7) that show trends up to 2010 due to the limited availability of data.

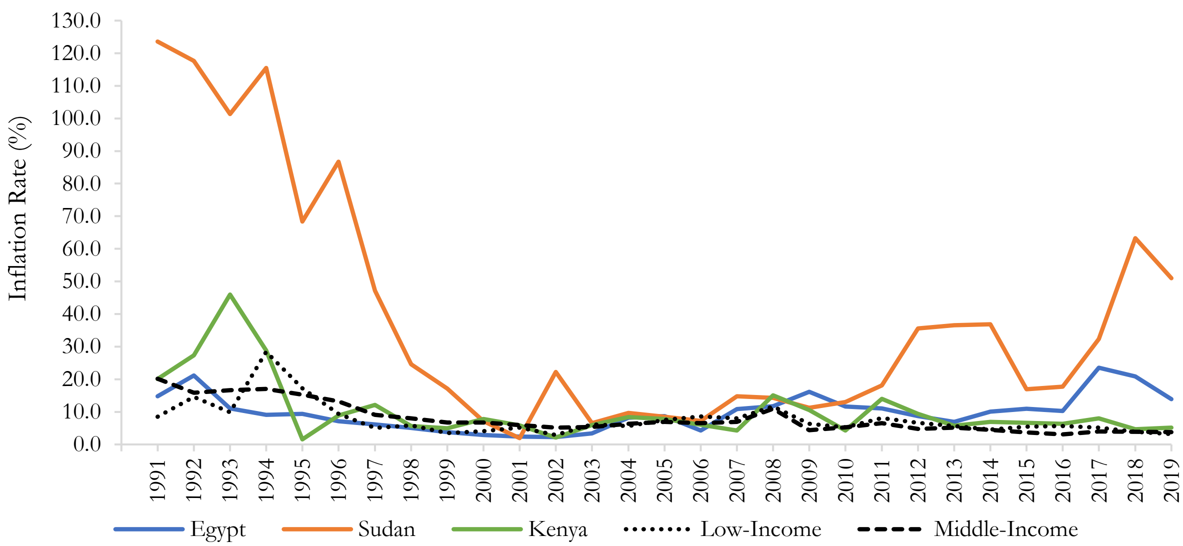
Figure 6 looks into the policy variables. Panel A presents the evolution of the REER undervaluation, while Panel B presents the evolution of the inflation rate. The Sudanese real REER undervaluation seems to hover in the area below zero more often than other countries, indicating a relatively overvalued currency. In general, inflation rate in Sudan is also high. While there seems to have been an improvement in price stability in the early 2000s, both exchange rate and inflation reflect the deterioration in macroeconomic stability since the partitioning of Sudan. The average annual inflation rate in Sudan was as high as 51% and its REER was almost 1.5 that of the five-year moving average.

Figure 6. Policy Variables: Real Exchange Rate Undervaluation and Inflation Rate

Panel A: Real Effective Exchange Rate Undervaluation



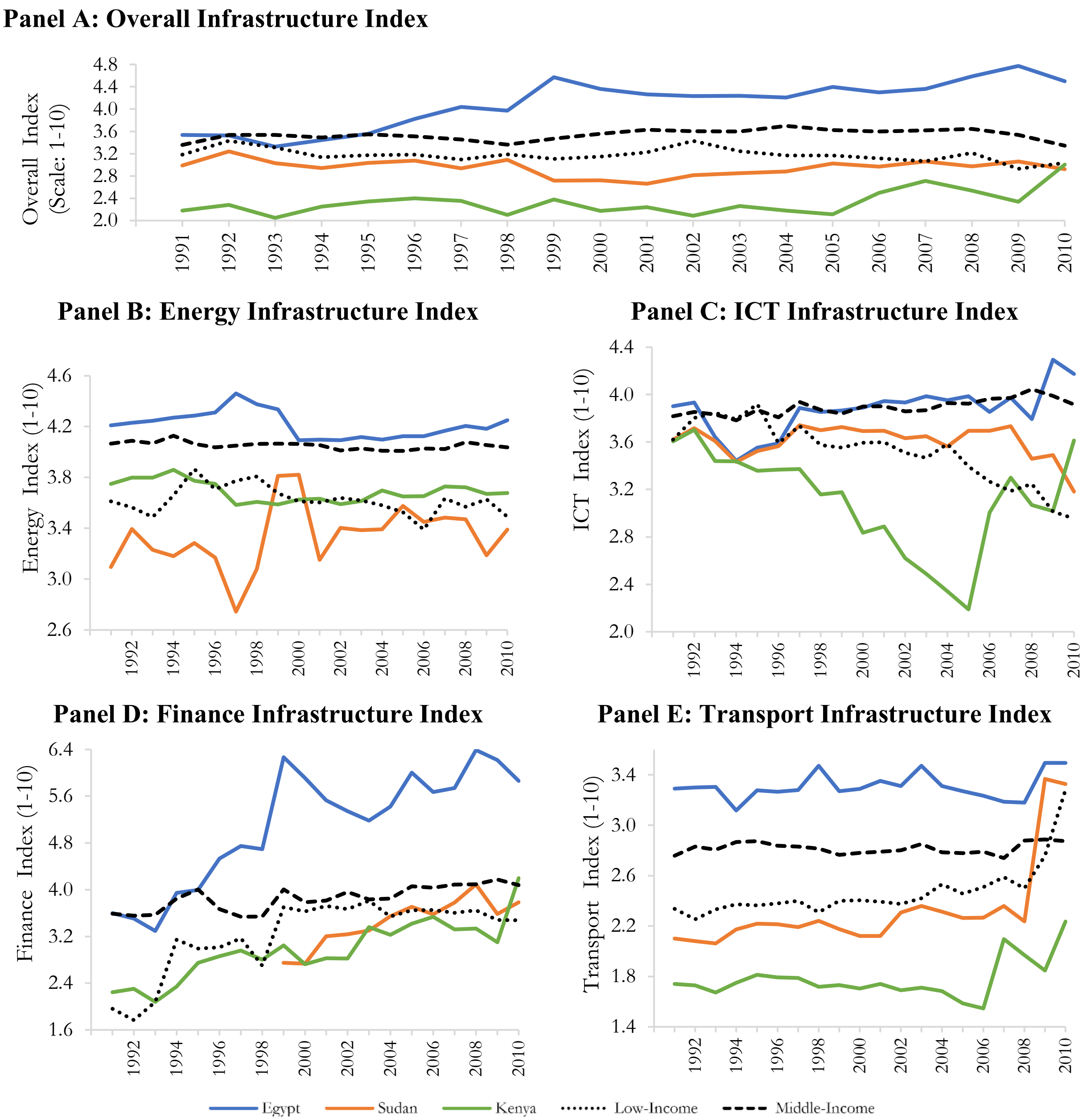
Panel B: Inflation Rate



This figure presents the evolution of the real effective exchange rate (REER) undervaluation variable and the inflation rate, over the period 1991-2019, for Egypt, Sudan, Kenya, in addition to the median of low-income and middle-income countries as defined by the World Bank. Panel A presents REER undervaluation, whereas Panel B presents the inflation rate. REER undervaluation is computed as the log of the ratio of the five-year moving average to the contemporaneous value of REER. Inflation rate is the annual consumer price index, average-of-period value.

Figure 7 shows the evolution of all the infrastructure indices. Since data for indices is only available until 2010, we present their data over 1991-2010. The level of infrastructure in Egypt is much higher than that of Sudan and Kenya. In 2019, the overall infrastructure index was almost 1.5 times that of Sudan and Kenya. The level of overall infrastructure in Sudan is not only lower than the middle-income median, but also the low-income median. The story is not much different when looking at the individual sub-indices. Kenya seems to have consistently better infrastructure than Sudan when it comes to energy. Moreover, there has been a boost in transport infrastructure in Sudan after 2008. Between 2008 and 2019, the Sudanese transport index has increased by around 50% from 2.2 to 3.3, which might be reflecting the growth in road development.

Figure 7. Infrastructure and Input Variables: Infrastructure Indices

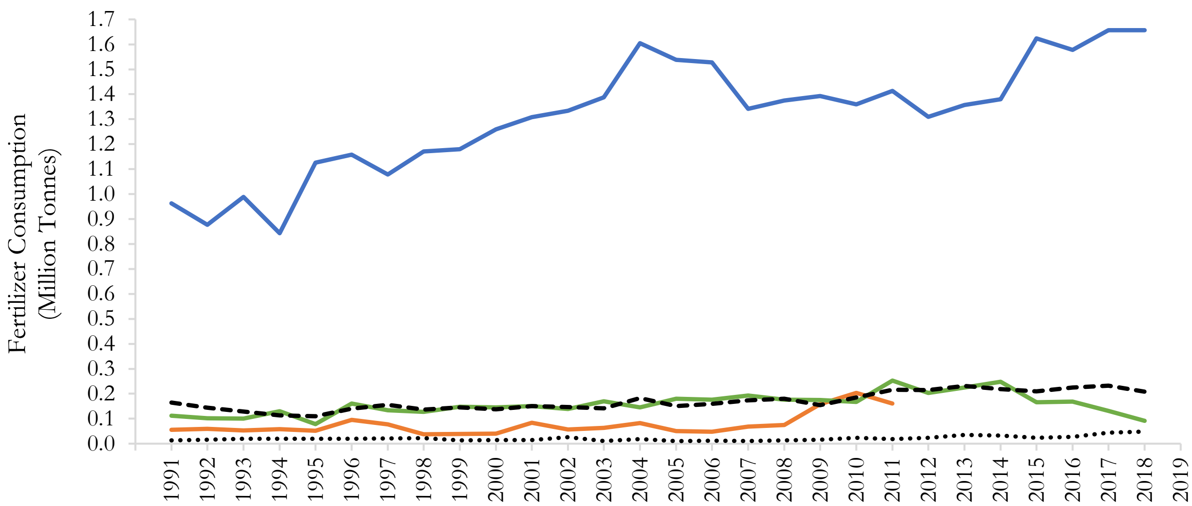


This figure presents the evolution of infrastructure, over the period 1991-2010, for Egypt, Sudan, Kenya, in addition to the median of low-income and middle-income countries as defined by the World Bank. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Panel A presents the level of overall infrastructure, whereas Panels B-E present the levels separately for energy, ICT, finance, and transport, respectively. All indices are scaled between 1 to 10 and increase with the level of infrastructure.

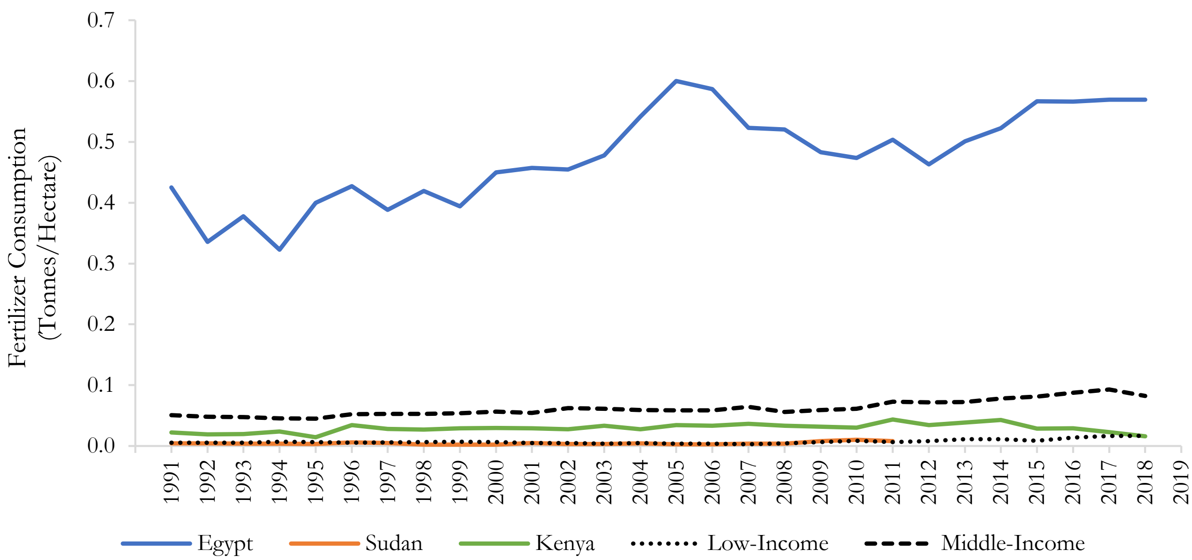
When it comes to fertilizer consumption, Egypt fares remarkably better than both Sudan and Kenya. Figure 8 shows the consumption of fertilizer in absolute tonnes (Panel A) and as a ratio to total arable land (Panel B). Egypt's fertilizer consumption is also much higher than the middle-income median. Sudan's arable land area is more than six times that of Egypt, yet its total fertilizer consumption in 2010 was no more than 15% of Egypt's consumption. While Egypt's fertilizer consumption was around 0.47 tonnes per hectare of arable land, Sudan only consumed 0.01 tonnes per hectare.

Figure 8. Infrastructure and Input Variables: Fertilizer Consumption

Panel A: Fertilizer Consumption



Panel B: Fertilizer Consumption per Arable Land

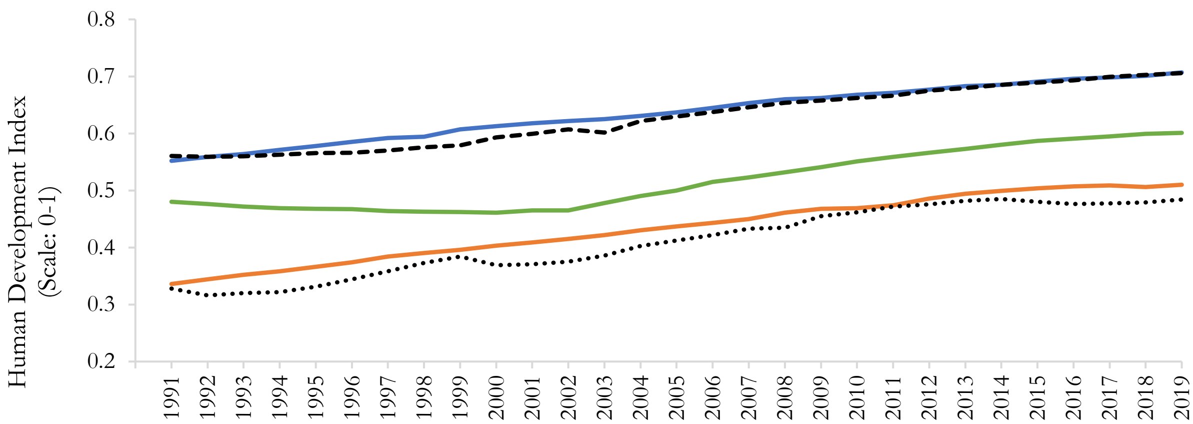


This figure presents the evolution of fertilizer consumption, over the period 1991-2019, for Egypt, Sudan, Kenya, in addition to the median of low-income and middle-income countries as defined by the World Bank. Panel A presents total fertilizer consumption, measured as million tonnes of nutrients used. Panel B presents fertilizer consumption per area of arable land, measured as tonnes per hectare.

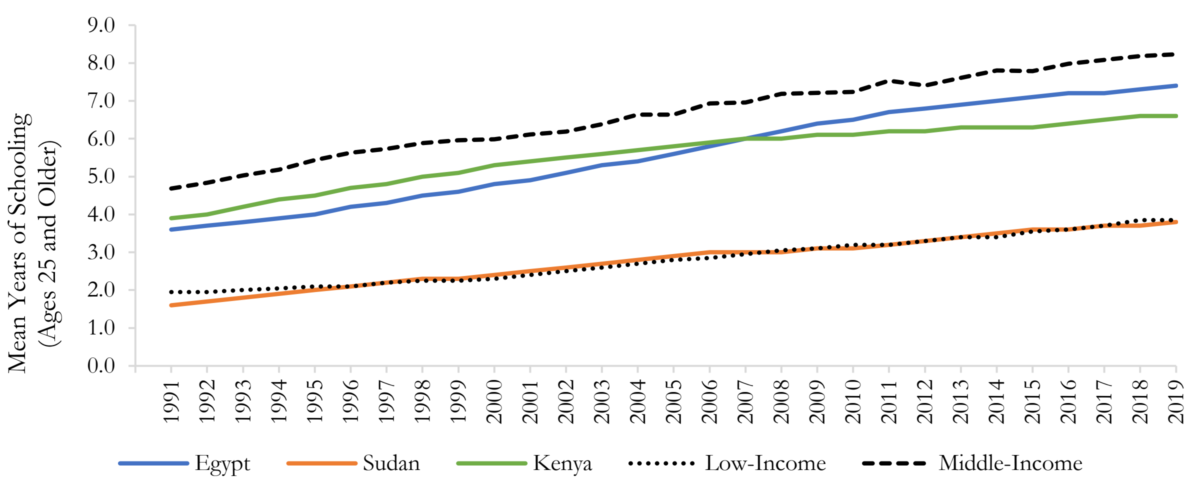
Sudan lags behind when it comes to human capital. Figure 9 shows the evolution of the HDI (Panel A) and mean years of schooling (Panel B) between 1991 and 2019. Sudan's HDI and average school attainment are close to the median of the low-income countries, while much lower than that of Kenya, Egypt, and the middle-income median. In 2019, Sudan's HDI was 0.510 (low HD) compared to 0.707 (high HD) in Egypt and 0.601 (medium HD) in Kenya.[7] Moreover, the mean years of schooling for the population aged 25 and older was 3.8 years in Sudan, compared to 7.4 years in Egypt and 6.6 years in Kenya.

Figure 9. Human Capital Variables: Human Development Index and Years of Schooling

Panel A: Human Development Index



Panel B: Mean Years of Schooling



This figure presents the evolution of the Human Development Index (HDI) and mean years of schooling, over the period 1991-2019, for Egypt, Sudan, Kenya, in addition to the median of low-income and middle-income countries as defined by the World Bank. HDI and mean years of schooling are obtained from the United Nations Development Program (UNDP). HDI is a composite index measuring average achievement in three dimensions (life expectancy, education, and standard of living). Average schooling years are for those 25 years of age or older.

[7] The UNDP classifies the HDI of a value above 0.800 to be very high, a value between 0.7 and 0.799 to be high, a value between 0.550 and 0.699 to be medium, and a value below 0.550 to be low (UNDP, 2020).

The picture of the Sudanese economy is one of many challenges and potential areas of improvement, with respect to policy indicators, infrastructure, input, and human development. The Sudanese government and central bank should increase its efforts to stabilize prices and exchange rates. The Sudanese annual inflation rate was remarkably high in 2019 at around 51%. Moreover, the coefficient of variation of its REER was around 0.48 compared to only 0.18 in Egypt and a median of 0.05 for low-income countries. Efforts should also be spent to address the issue of the overvalued exchange rate. Optimistically, the government of Sudan is starting to show more appetite for macroeconomic reform as it started cooperating with international institutions to stabilize the economy. Only recently has Sudan announced a managed floating exchange rate regime. Nevertheless, for the nominal exchange rate flexibility to lead to real exchange rate depreciation, which is a necessity for enhancing the profitability of investment in agriculture, authorities must work on bringing down the currently rampant inflation to single digits.

As in many developing countries, Sudanese agriculture has been subjected to two types of taxes. Elbadawi (1992) documents the evidence on the rather heavy direct and indirect taxation of Sudanese agriculture. This has been corroborated by more recent contributions to the literature on Sudanese agriculture, lending further support to the evidence provided by Elbadawi (1992).[8] First, agricultural prices are generally suppressed through marketing boards, forced procurement, export taxation, etc. This is a direct form of taxation, which creates a wedge between farmgate and border prices. The second is indirect, but no less impactful. This impinges through overvalued real exchange rates, associated with unsustainable macroeconomic policies in general, especially excessive deficit financing. It is pertinent to mention that some governments have attempted to affect or partly neutralize the negative effects on agriculture by investing in agricultural supply, such as irrigation, as well as investing in research and extension, by subsidizing input prices or extending cheap credit to farmers. However, successful agricultural transformation has been largely confined to Asian developing countries, which avoided overvalued real exchange rates and indirect taxation on one hand, while combined modest direct taxation with investment in agricultural supply on the other.

Despite its recent improvement in road infrastructure, evident by the improvement in the transport index, more efforts still need to be expended in the areas of infrastructure. The value of the overall infrastructure index was 2.9 in Sudan in 2019. If Sudan were to increase its infrastructure index by 1.6 units, to reach that of Egypt's (4.5), this could contribute to an increase in the growth rate of agricultural productivity by around 0.7 percentage points. Special emphasis needs to be located in energy and financial development, where Sudan especially lags behind. ICT improvements would also be of great benefit to improving productivity. Increasing fertilizer consumption could also play an important role in boosting Sudan's agricultural productivity. Although Sudan's arable land area is more than six times that of Egypt, Egypt's fertilizer consumption is almost 8 times that of

[8] See, for example, Elbashir and El Faki (2013), Hag Elamin and El Mak (1997), and El Faki and Taha (2007).

Sudan. This is especially an important area of improvement for the Sudanese agricultural productivity. If Sudan was to only double the amount of fertilizer it uses, this could contribute an extra 0.21 percentage points in labor productivity growth. Reaching the level of Egypt's fertilizer consumption could improve the growth rate by almost 1.6 percentage points.

Finally, when it comes to human capital, spending more on education and health could help lift up agricultural productivity in Sudan. In 2019, Sudan's HDI was 0.5 compared to 0.7 in Egypt. Working on improving the HDI to reach that of Egypt (an increase of 40%) could push up productivity growth by around 1.48 percentage points.

5. Concluding Lessons for Sudan

In view of the analysis of productivity in agriculture and the assessment of where Sudan stands relative to other comparators, we propose three guiding principles for a design of an agricultural development strategy for Sudan: (1) Investing in agricultural supply; (2) Empowering rural communities; (3) Avoiding excessive taxation of agriculture, at both the direct and indirect levels.

First, investing in agricultural supply. As shown by Diwan et al. (2013) and as confirmed in this paper, unlike industry, the agricultural growth process is actually divergent, but similar to countries' income it tends to converge conditionally. A pertinent insight from their work is that agriculture could be developed as an industry along a variety of emerging business models for commercializing agriculture and strengthening forward linkages to agro-industries, such as building growth corridors centered around productive cities, contractual agriculture in the form of partnerships between farmers' associations and modern private sector entities, marketing boards, etc. It is clear, therefore, that the government should directly invest in as well as promote private-sector investment in areas that are likely to enhance conditional convergence towards higher value-added in agriculture. In such context, the public sector would build the agricultural research and extension capacity and invest in capital-intensive fertilizer and pesticides industries, irrigation systems, power generation, etc. Moreover, with proper regulations, the private sector and cooperative associations could undertake key complementary functions, such as distributions and marketing of seeds and fertilizers, maintaining and managing secondary irrigation canals and facilities, as well as contributing to the more ambitious transformative agenda of making "agriculture looks like an industry".

Second, the critical importance for agricultural development of empowering small farmers through cooperatives associations, the provision of basic services, and direct cash transfers. From a human development perspective, fighting rural poverty and making progress on other sustainable development goals (SDGs) are of course important on their own right. Moreover, healthier and better educated farmers are more productive because they are more capable of absorbing new knowledge and technology. Also, better organized farmers through various kinds of associations would facilitate their access to services and finance.

Third, ending the legacy of excessive direct and indirect taxation of agriculture. As discussed, Sudanese agriculture has been heavily taxed both directly, through sectoral taxes, and indirectly, through overvalued real exchange rate and inflationary macroeconomic policies. Sudanese policy makers need to learn from the experience of the historical Asian state to design macroeconomic policies with a perspective of agricultural transformation. Those countries managed to stabilize their macroeconomic environments and maintain competitive real exchange rates, while modestly taxing agriculture at the sectoral level in order to finance investment in agricultural supply (research and extensions, infrastructure, provision of finance and fertilizers, etc.). These Asian states, therefore, managed to achieve robust structural transformation within the agricultural sector, and between agriculture and industry, by avoiding indirect taxation and measuredly taxing agriculture at the sectoral level, so as to resolve market-coordination failures and finance the much-needed investment in agricultural supply.[9]

[9] This is because, left to their own devises, private farmers are not likely to invest in non-excludable public goods, such as roads, agricultural research, etc.

References

Aguirre, A. and C. Calderon (2005). “Real Exchange Rate Misalignments and Economic Performance.” Central Bank of Chile Working Paper No. 315.

Elbashir and Faki. (2013). Role of Agriculture in Poverty Reduction and Food Security in Sudan: A policy Background Paper.

Barro, R., and Lee, J.W. (2013) “A New Data Set of Educational Attainment in the World, 1950-2010.” Journal of Development Economics,104, 184-198.

Diwan, I., Gaddah, O., and Osire, R. (2013). “Looking like an Industry: Supporting Commercial Agriculture in Africa.” CID Working Paper No. 266. Center for International Development, Harvard University.

Donaubauer, J., Meyer, B., and Nunnenkamp, P. (2016) “A New Global Index of Infrastructure: Construction, Rankings and Applications.” World Economy, 39(2), 236-259.

Elbadawi, I. (1992). "Real Overvaluation, Terms of Trade Shocks, and the Cost to Agriculture in Sub-Saharan Africa", Policy Research WPS #831, The World Bank, January.

Ibrahim Elbadawi, Linda Kaltani and Raimundo Soto (2012), “Aid, Real Exchange Rate Misalignment and Economic Growth in Sub-Saharan Africa,” World Development, Vol. 40, No. 4, pp. 681-700.

Elbadawi, I. and G. Helleiner (2004)."African Development in the Context of the New World Trade and Financial Regimes: The Role of the WTO and its Relationship to the World Bank and IMF," (forthcoming) in A. Oyejide and W. Lyakurwa (editors). Africa and the World Trading System, Volume I: Framework Paper. MacMillan: chapter 9.

El Faki, Hamid and Abdelmoneim Taha (2007),” Distortions to Agricultural Incentives in Sudan,” unpublished mimeo, Agricultural Economics and Policy Research Center, Agricultural Research Corporation, Khartoum.

Fowowe, B. (2010). “The Effects of Financial Inclusion on Agricultural Productivity in Nigeria.” Journal of Economics and Development, 22(1), 61-79.

Hag Elamin, N. A. and E.M. El Mak (1997), “Adjustment Programs and Agricultural Incentives in Sudan: A Comparative Study”, African Economic Research Consortium, AERC Research Paper 63, Nairobi, November.

Lio, M., and Liu, M.C. (2006). “ICT and Agricultural Productivity: Evidence from Cross-Country Data.” Agricultural Economics, 34(3), 221-228.

Rehman, A., Chandiob, A., Hussainc, I., and Jingdonga, L. (2019). “Fertilizer Consumption, Water Availability and Credit Distribution: Major factors Affecting Agricultural Productivity in Pakistan.” Journal of the Saudi Society of Agricultural Sciences, 18(3), 269-274.

Rodrigue, J.P. (2020). “Diminishing Returns of Transport Investments.” in The Geography of Transport Systems, 5th ed., Chapter 3. Routledge Press: Oxfordshire.

Rodrik, D. (2011). “The Future of Economic Convergence.” NBER Working Paper No. 17400. National Bureau of Economic Research.

Rodrik, D (2008), “The real exchange rate and economic growth,” Brookings Papers on Economic Activity, Fall: 365-412.

Shen, L. (2013). “Financial Dependence and Growth: Diminishing Returns to Improvement in Financial Development.” Economic Letters, 120(2), 215-219.

Vandenbussche, J., Aghion, P., and Meghir, C. (2006). “Growth, Distance to Frontier and Composition of Human Capital.” Journal of Economic Growth, 11(2), 97-127.

UNDP. (2020). “2020 HDR Technical Note.” United Nations Development Program. Human Development Reports. Retrieved from: http://hdr.undp.org

Darvas, Z. (2012) “Real effective exchange rates for 178 countries: A new database.” Working Paper 2012/06, Bruegel.

Appendix Table 1. Summary Statistics

This table reports summary statistics of the variables used in the analysis for 121 countries over the period 1991-2010, in five-year intervals. The dependent variable used in the analysis is the five-year average of annual growth rate in agriculture value added per agriculture labor (in constant 2010 USD). Initial agriculture value added is the first-year value of each five-year interval. Control variables are divided into policy, infrastructure and input, in addition to human capital variables, which are all computed as the five-year averages. Real exchange rate (REER) undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Human capital is proxied by the human development index, the mean years of schooling, and the mean years of primary schooling. All the control variables are computed as the five-year averages, except for mean years of secondary and primary schooling which are only available from Barro and Lee (2013) in five-year intervals starting 1990 and hence are taken as the value in the year just before the five-year period.

	Units	Mean	Std. Dev.	Median	Minimum	Maximum
Growth in Agriculture VA per Worker	Percentage	2.28	4.58	2.47	-16.08	20.61
Initial Agriculture VA per Worker	Thousand, Real	11.66	21.64	3.81	0.22	208.90
Policy Variables						
REER-Undervalue	Index	0.01	0.08	0.00	-0.21	1.11
REER-Variability	Index	0.09	0.14	0.06	0.00	1.21
Inflation Rate	Percentage	29.85	155.65	6.07	-0.71	2000.94
Infrastructure and Input Variables						
Overall Index	Index, 1-10	4.50	1.71	3.90	1.70	9.58
Energy Index	Index, 1-10	4.55	1.09	4.29	1.23	9.71
ICT Index	Index, 1-10	4.65	1.43	4.05	2.51	9.47
Finance Index	Index, 1-10	4.57	1.48	4.24	1.66	9.16
Transport Index	Index, 1-10	3.69	1.60	3.13	1.39	8.71
Fertilizer Consumption	Thousand Tonnes	1,227.50	4,441.47	181.51	0.23	46,961.16
Human Capital Variables						
Human Development Index	Index	0.66	0.16	0.68	0.24	0.94
Mean Years of Schooling	Years	7.50	3.13	7.73	0.52	13.66
Mean Years of Primary Schooling	Years	4.30	1.68	4.33	0.22	8.99
Mean Years of Secondary Schooling	Years	2.46	1.49	2.19	0.06	6.89

Appendix Table 2a. Convergence in Agricultural Productivity: Measures of Human Capital

This table reports cross-country panel regressions, in five-year intervals, for 121 countries over 1991-2019 for column (1) and 1991-2010 for columns (2)-(10). Column (1) reports the unconditional regression of the five-year average of annual growth rate in agriculture value added per agriculture labor (in constant 2010 USD) on the log of initial value added. Columns (2)-(10) report conditional regressions, controlling for a set of policy, infrastructure and input, in addition to human capital variables. Real exchange rate (REER) undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Transport proximity is the log of the ratio of the transport frontier to own transport index, where the frontier is defined as the specific country-group median of the transport index, separately for low- and middle-income countries (LMIC) and for high-income countries (HIC). LMIC (HIC) are dummies equal to one if the country is of a low- or middle-income (high-income). Human capital is proxied by the log of the mean years of schooling. Conditional regressions also include country-specific controls (not reported for brevity) of the ratio of arable land to population, the log of yearly precipitation, the ratio of rural to total population, and a dummy variable equal to one if the country is landlocked. Initial value added is the first-year value of each five-year interval, while other control variables are computed as the five-year averages. Columns (2)-(10) include time dummies. Robust standard errors are in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Dependent Variable: Growth in Agriculture Productivity (%)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agricultural Productivity	0.381**	-1.043***	-1.004***	-1.281***	-0.893***	-0.791***	-0.713**	-0.787**	-0.961***	-0.964***
(In logs, Real Initial Value)	(0.18)	(0.36)	(0.37)	(0.36)	(0.32)	(0.30)	(0.32)	(0.32)	(0.33)	(0.33)
Policy Variables										
REER-Undervalue		9.126**	8.833**	8.834**	13.576***	12.449***	8.931**	9.198**	8.577**	8.679**
(Index)		(3.67)	(3.99)	(3.54)	(3.61)	(3.38)	(3.72)	(3.73)	(3.69)	(3.70)
REER-Variability		-8.204**	-7.800*	-7.914**	-12.209***	-11.169***	-8.260**	-8.375**	-7.647*	-7.659*
(Index)		(3.94)	(4.20)	(3.83)	(3.74)	(3.43)	(3.94)	(4.01)	(3.90)	(3.95)
Inflation Rate		-0.005***	-0.005***	-0.005**	0.000	0.000	-0.005***	-0.005***	-0.005**	-0.005**
(%)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Infrastructure and Input Variables										
Overall Index		0.473**								
		(0.22)								
Energy Index			0.557*							
			(0.32)							
ICT Index				0.838***						
				(0.27)						
Finance Index					0.269	3.350***				
					(0.21)	(0.86)				
$(\text{Finance Index})^2$						-0.314***				
						(0.08)				
Transport Index							0.162	1.659**	0.662**	0.734***
							(0.18)	(0.73)	(0.27)	(0.28)
$(\text{Transport Index})^2$								-0.161**		
								(0.08)		
Transport Proximity									2.856**	
									(1.12)	
Transport Proximity*LMIC										2.533**
										(1.11)
Transport Proximity*HIC										3.980**
										(1.80)
Fertilizer Consumption		0.257**	0.298**	0.303***	0.256**	0.211*	0.277**	0.264**	0.329***	0.318***
(In logs of tonnes used)		(0.11)	(0.12)	(0.11)	(0.12)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)
Human Capital Variables										
Mean Years of Schooling		0.500	0.845	0.529	1.527***	1.494***	0.565	0.279	0.671	0.597
(In logs*)*		(0.57)	(0.78)	(0.52)	(0.57)	(0.56)	(0.54)	(0.52)	(0.53)	(0.52)
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	678	412	378	421	392	392	422	422	422	422
R-squared	0.014	0.158	0.163	0.174	0.107	0.135	0.153	0.161	0.168	0.169

Appendix Table 2b. Convergence in Agricultural Productivity: Measures of Human Capital

This table reports cross-country panel regressions, in five-year intervals, for 121 countries over 1991-2019 for column (1) and 1991-2010 for columns (2)-(10). Column (1) reports the unconditional regression of the five-year average of annual growth rate in agriculture value added per agriculture labor (in constant 2010 USD) on the log of initial value added. Columns (2)-(10) report conditional regressions, controlling for a set of policy, infrastructure and input, in addition to human capital variables. Real exchange rate (REER) undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Transport proximity is the log of the ratio of the transport frontier to own transport index, where the frontier is defined as the specific country-group median of the transport index, separately for low- and middle-income countries (LMIC) and for high-income countries (HIC). LMIC (HIC) are dummies equal to one if the country is of a low- or middle-income (high-income). Human capital is proxied by the log of the mean years of primary schooling. Conditional regressions also include country-specific controls (not reported for brevity) of the ratio of arable land to population, the log of yearly precipitation, the ratio of rural to total population, and a dummy variable equal to one if the country is landlocked. Initial value added is the first-year value of each five-year interval, while other control variables are computed as the five-year averages. Columns (2)-(10) include time dummies. Robust standard errors are in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Dependent Variable: Growth in Agriculture Productivity (%)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agriculture Productivity	0.381**	-1.152***	-1.008**	-1.330***	-1.004***	-0.883***	-0.730**	-0.818**	-0.976***	-0.978***
(In logs, Real Initial Value)	(0.18)	(0.39)	(0.40)	(0.38)	(0.34)	(0.32)	(0.35)	(0.35)	(0.36)	(0.36)
Policy Variables										
REER-Undervalue		7.777*	7.624*	7.345*	12.428***	11.064***	7.667*	8.162*	7.220*	7.468*
(Index)		(4.18)	(4.25)	(4.03)	(3.68)	(3.42)	(4.22)	(4.17)	(4.10)	(4.07)
REER-Variability		-7.408*	-7.392*	-7.131*	-11.070***	-9.843***	-7.520*	-7.693*	-6.866*	-6.915*
(Index)		(3.95)	(4.10)	(3.83)	(3.79)	(3.42)	(3.95)	(4.04)	(3.85)	(3.90)
Inflation Rate		-0.005**	-0.005**	-0.005**	0.000	0.000	-0.005**	-0.005**	-0.005**	-0.005**
(%)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Infrastructure and Input Variables										
Overall Index		0.571**								
		(0.23)								
Energy Index			0.675**							
			(0.33)							
ICT Index				0.923***						
				(0.28)						
Finance Index					0.421*	3.738***				
					(0.22)	(0.87)				
$(\text{Finance Index})^2$						-0.338***				
						(0.08)				
Transport Index							0.204	1.776**	0.766***	0.845***
							(0.19)	(0.76)	(0.29)	(0.30)
$(\text{Transport Index})^2$								-0.170**		
								(0.08)		
Transport Proximity									3.195***	
									(1.19)	
Transport Prox. * LMIC										2.822**
										(1.19)
Transport Prox. * HIC										4.442**
										(1.82)
Fertilizer Consumption		0.182	0.255**	0.244**	0.184	0.140	0.221*	0.203*	0.279**	0.265**
(In logs of tonnes used)		(0.12)	(0.13)	(0.11)	(0.13)	(0.12)	(0.12)	(0.12)	(0.13)	(0.13)
Human Capital Variables										
Mean Years of Pri. School		0.583	0.352	0.615	1.581**	1.475**`	0.560	0.239	0.578	0.461
(In logs)		(0.67)	(0.77)	(0.62)	(0.70)	(0.68)	(0.63)	(0.61)	(0.62)	(0.61)
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	678	379	353	386	361	361	387	387	387	387
R-squared	0.014	0.154	0.156	0.173	0.100	0.134	0.147	0.156	0.164	0.166

Appendix Table 2c – Convergence in Agricultural Productivity: Measures of Human Capital

This table reports cross-country panel regressions, in five-year intervals, for 121 countries over 1991-2019 for column (1) and 1991-2010 for columns (2)-(10). Column (1) reports the unconditional regression of the five-year average of annual growth rate in agriculture value added per agriculture labor (in constant 2010 USD) on the log of initial value added. Columns (2)-(10) report conditional regressions, controlling for a set of policy, infrastructure and input, in addition to human capital variables. Real exchange rate (REER) undervaluation is the log of the ratio of the five-year moving average to the contemporaneous value of REER, whereas REER variability is its coefficient of variation. Infrastructure is proxied by the indices developed by Donaubauer et al. (2016), which capture infrastructure for energy, finance, information and communications technology (ICT), and transport. Transport proximity is the log of the ratio of the transport frontier to own transport index, where the frontier is defined as the specific country-group median of the transport index, separately for low- and middle-income countries (LMIC) and for high-income countries (HIC). LMIC (HIC) are dummies equal to one if the country is of a low- or middle-income (high-income). Human capital is proxied by the log of the mean years of secondary schooling. Conditional regressions also include country-specific controls (not reported for brevity) of the ratio of arable land to population, the log of yearly precipitation, the ratio of rural to total population, and a dummy variable equal to one if the country is landlocked. Initial value added is the first-year value of each five-year interval, while other control variables are computed as the five-year averages. Columns (2)-(10) include time dummies. Robust standard errors are in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	Dependent Variable: Growth in Agriculture Productivity (%)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agriculture Productivity	0.381**	-1.086***	-1.019***	-1.284***	-0.856***	-0.741**	-0.677**	-0.792**	-0.956***	-0.967***
(In logs, Real Initial Value)	(0.18)	(0.38)	(0.39)	(0.37)	(0.33)	(0.31)	(0.33)	(0.34)	(0.35)	(0.35)
Policy Variables										
REER-Undervalue		7.812*	7.646*	7.329*	11.609***	10.313***	7.666*	8.145*	7.149*	7.377*
(Index)		(4.09)	(4.41)	(3.99)	(3.58)	(3.38)	(4.18)	(4.17)	(4.16)	(4.17)
REER-Variability		-7.519*	-7.435*	-7.204*	-10.432***	-9.268***	-7.597*	-7.723*	-6.876*	-6.912*
(Index)		(3.93)	(4.19)	(3.83)	(3.71)	(3.39)	(3.96)	(4.05)	(3.91)	(3.96)
Inflation Rate		-0.005**	-0.005**	-0.005**	0.000	-0.001	-0.005**	-0.005**	-0.005**	-0.005**
(%)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Infrastructure and Input Variables										
Overall Index		0.533**								
		(0.22)								
Energy Index			0.654**							
			(0.32)							
ICT Index				0.891***						
				(0.27)						
Finance Index					0.316	3.572***				
					(0.21)	(0.86)				
(Finance Index)^2						-0.331***				
						(0.08)				
Transport Index							0.154	1.708**	0.753***	0.826***
							(0.19)	(0.80)	(0.29)	(0.29)
(Transport Index)^2								-0.165**		
								(0.08)		
Transport Proximity									3.534***	
									(1.20)	
Transport Prox. * LMIC										3.166**
										(1.22)
Transport Prox. * HIC										4.648**
										(1.80)
Fertilizer Consumption		0.177	0.237*	0.229*	0.169	0.130	0.214*	0.199	0.268**	0.255**
(In logs of tonnes used)		(0.12)	(0.13)	(0.12)	(0.13)	(0.12)	(0.12)	(0.12)	(0.13)	(0.13)
Human Capital Variables										
Mean Years of Sec. School		0.369	0.510	0.469	1.013***	0.894**	0.449	0.218	0.658*	0.603*
(In logs)		(0.35)	(0.44)	(0.34)	(0.36)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)
Time FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	678	379	353	386	361	361	387	387	387	387
R-squared	0.014	0.154	0.159	0.174	0.101	0.133	0.148	0.156	0.169	0.170

Appendix Table 3. List of Countries

This table presents the list of countries used in the analysis according to their income groups.

Low Income	Low-Middle Income		Upper-Middle Income		High Income		
Afghanistan	Angola	Nicaragua	Albania	Kazakhstan	Argentina	Italy	Switzerland
Benin	Bangladesh	Nigeria	Algeria	Lebanon	Australia	Japan	Trinidad and Tobago
Burkina Faso	Bolivia	Pakistan	Azerbaijan	Malaysia	Austria	Korea, Rep	United Arab Emirates
Burundi	Cambodia	Papua New Guinea	Belarus	Mauritius	Belgium	Latvia	United Kingdom
Ethiopia	Cameroon	Philippines	Bosnia-Herzegovina	Mexico	Canada	Lithuania	United States
Guinea	Congo	Sri Lanka	Botswana	Namibia	Chile	Netherlands	Uruguay
Madagascar	Egypt	Sudan	Brazil	Macedonia	Croatia	New Zealand	
Malawi	El Salvador	Tunisia	Bulgaria	Paraguay	Czech Republic	Norway	
Mali	Georgia	Ukraine	China	Peru	Denmark	Oman	
Mozambique	Ghana	Uzbekistan	Colombia	Romania	Estonia	Panama	
Nepal	Honduras	Vietnam	Costa Rica	Russia	Finland	Poland	
Niger	India	Zambia	Dominican Republic	Serbia	France	Portugal	
Rwanda	Indonesia		Ecuador	South Africa	Germany	Saudi Arabia	
Senegal	Kenya		Guatemala	Thailand	Greece	Singapore	
Tajikistan	Kyrgyz Republic		Iran, Islamic Rep	Turkey	Hungary	Slovak Republic	
Tanzania	Moldova		Iraq		Ireland	Slovenia	
Uganda	Mongolia		Jamaica		Israel	Spain	
Yemen,	Morocco		Jordan		Sweden		

Appendix Table 4. Data Sources

This table presents the definitions and data sources of all the variables used in the analysis.

Variable	Definition	Source
Agricultural Value Added	Agricultural value added in constant 2010 US dollars. Value added is the net output of the agricultural sector, adding up all outputs and subtracting intermediate inputs. The agriculture sector includes the cultivation of crops, livestock production, forestry, hunting, and fishing.	World Bank's World Development Indicators (WDI).
Total and Agricultural Employment	Agricultural employment refers to the total number of persons employed in the agriculture sector. Total employment is the total number of persons employed in all economic sectors. The series represent modelled estimates. The employed constitute of all persons of working age who, during a specified brief period, were in paid employment or self-employment.	International Labor Organization (ILO), modelled estimates and projections, employment by sex and economic activity.
Agricultural Productivity	Computed as total agricultural value added (in constant 2010 US dollars) per agricultural worker.	World Bank's WDI and ILO modelled estimates.
Real Effective Exchange Rate	Annual real effective exchange rate index, based on the consumer price index and 66 trading partners.	Darvas (2012), Bruegel
Inflation Rate	Annual consumer price index inflation rate, taken as the average of period.	International Monetary Fund's World Economic Outlook (WEO)
Energy Infrastructure Index	An index on the quantity and quality of energy infrastructure, scaled between 1 and 10 with higher values indicated better infrastructure. Construction includes using data on a country's yearly per capita electric power consumption and production, as well as the percentage of electric power transmission and distribution losses to output.	Donaubauer et al. (2016).
ICT Infrastructure Index	An index on the quantity and quality of information and communications technology infrastructure, scaled between 1 and 10 with higher values indicated better infrastructure. Construction includes using data on a country's yearly number of fixed telephone lines, mobile cellular telephone subscriptions, the number of integrated services digital network (ISDN) subscriptions, and the number of faults per 100 fixed telephone lines.	Donaubauer et al. (2016).

Finance Infrastructure Index	An index on the quantity and quality of finance infrastructure, scaled between 1 and 10 with higher values indicated better infrastructure. The index encompasses measures of financial system stability, efficiency, access, and depth. Construction uses data on the banks' Z-score, stock price volatility, stock market turnover ratio, the number of per capita bank accounts, the value of all traded shares outside the largest ten traded companies as a share of the total value of all traded shares, and the number of publicly listed companies per capita, private credit to GDP, the total value traded stocks to GDP, in addition to money and quasi money (M2) to GDP.	Donaubauer et al. (2016).
Transport Infrastructure Index	An index on the quality of energy infrastructure, scaled between 1 and 10 with higher values indicated better infrastructure. Construction includes measures of land transport, sea transport, and air transport. Land transport includes the total length of road network, the percentage of paved roads, the percentage of motorways, the number of registered passenger cars and commercial vehicles, the total length of the railway route, goods transported by rail, and total railway passengers. Sea transport includes the ratios of total ships' carrying capacity to a country's geographic area and to the world's total carrying capacity. Air transport includes the number of registered carrier departures to population and the volume of air freight.	Donaubauer et al. (2016).
Overall Infrastructure Index	An index on the quality of overall infrastructure, scaled between 1 and 10 with higher values indicated better infrastructure. This is a composite infrastructure index of energy, ICT, finance, and transport, constructed using an unobserved components model.	Donaubauer et al. (2016).
Arable land Area	Arable land is the total area (in hectares) under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. This does not include land that is not cultivated for shifting crops.	Food and Agriculture Organization (FAO)
Total and Rural Population	Total population represents midyear estimates of the total number of residents in a country, regardless of their legal status or citizenship. Rural population represents the total number of residents who are living in rural areas, as defined by national statistical offices.	World Bank's WDI.
yearly precipitation	Total yearly precipitation in a country is the total water released from clouds in the form of rain, freezing rain, sleet, snow, or hail.	World Bank's Climate Change Knowledge Portal.
Landlocked?	A country is defined as landlocked if it is surrounded on all sides by other countries and without any direct coastline.	Geography Realm, Landlocked Countries. https://www.geographyrealm.com/landlocked-countries/