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The effects of agricultural R&D investments on poverty and undernourishment in sub-Saharan Africa

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The analysis explores the relationship between agricultural R&D investments, and rural poverty and undernourishment in sub-Saharan Africa (SSA). Agricultural R&D knowledge stocks (KS) account for the lagged effects of research. Causal mediation analysis assesses the impacts of KS and measures the effect of KS-induced productivity growth on poverty and undernourishment. Evidence suggests that growth in KS helped in reducing rural poverty and undernourishment, with elasticities estimated at 0.218 and 0.146, respectively. Mediation analysis indicates that 20% of the KS effect on extreme poverty and a quarter of the effect on moderate poverty are attributed to KS driven gains in labor productivity. KS growth reduces undernourishment with an estimated elasticity of 0.132. About 40% is mediated through gains in land productivity. These suggest that KS supports poverty and hunger reduction through benefits on-farm and beyond. They also suggest that the role of R&D KS productivity enhancing innovations can be strengthened. Given the currently low investments in R&D and resulting KS, increasing its levels will be critical, but that alone is not sufficient. It is important to rethink the way innovations from R&D get scaled up and pay attention to complementary policies and investments that enable a sustainable pathway to inclusive productivity growth.

Key words: Agriculture, knowledge stocks, mediation, poverty, research and development, undernourishment.

INTRODUCTION

Poverty and hunger are major challenges confronting Africa south of the Sahara (SSA). While the rate of extreme poverty has dropped significantly in recent decades (World Bank, 2020), SSA still positions itself behind other regions. Food insecurity and malnutrition rates are also considerably higher than in other regions of the world with the prospects to zeroing it by 2030, in line with the Sustainable Development Goals (SDGs) targets, seriously in question if current trends persist (FAO, 2020). Poverty and malnutrition rates are typically more accentuated in rural areas where livelihoods significantly depend on agriculture and related activities.

Given the significant role agriculture plays in SSA economies and the growing evidence that indicates that growth in the sector is more effective at reducing poverty than that in other sectors, particularly in less developed

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countries (Fan et al., 2002; Ravallion and Datt, 2002; Ferreira et al., 2010; Christiaensen et al., 2011; Benfica and Henderson, 2021), investments in agricultural R&D are acknowledged as potentially playing a key role in promoting pro-poor growth and food and nutrition security.

Over the years, countries in SSA have invested resources in agricultural R&D but at levels (and pace) that are considerably lower (and slower) than other regions, with some countries even experiencing reductions overtime. Inconsistent growth in agricultural R&D spending overtime coupled with the persistent prevalence of poverty and hunger calls for continued investments (Nin-Pratt, 2011). In that context, understanding the effect the knowledge generated by those investments has on rural poverty and hunger is of paramount importance to inform the design and targeting of interventions.

While the availability and quality of R&D investment data for a wide range of countries has improved significantly over the years, particularly through the Agricultural Science and Technology Indicators (ASTI) program, poverty estimates used in cross-country studies looking at the implications of agricultural investments on poverty in sub-Saharan Africa, suffer from several limitations. First, they tend to focus on national rather than the rural level due to the lack of disaggregated Purchasing Power Parity (PPP) poverty data. Rural poverty numbers rely on estimates at the country specific poverty lines, not adjusted for PPP, and therefore inadequate for deriving cross-country comparisons or regional estimates. Second, poverty impacts derived for such studies tend to focus on elasticities rather than semi-elasticities, that is, proportionate rather than absolute poverty reduction. As argued by Klasen and Misselhorn (2008), conceptually, policy makers are likely to be more interested in percentage point changes rather than percentage changes. For example, a 10% point change in the poverty rate is substantial, but whether a reduction in the poverty rate by 10% is large depends on the actual starting level of the headcount (Benfica and Henderson, 2021).[1] Finally, little attention has been placed on the mechanisms through which R&D investments relate to poverty and hunger reduction, and the implications of closing the investment gaps.

This study uses knowledge stocks (KS) to account for the lagged effects of research through depreciation and age-efficiency over a gestation period of agricultural R&D investments and applies causal mediation analysis (Baron and Kenny, 1986; Howell, 2009; Hicks and Tingley, 2011) to estimate the total effect of KS on poverty and undernourishment and understand and measure the extent to which agricultural productivity mediate the effect. KS effects on poverty and undernourishment are assumed to take effect through alternative mechanisms linked to the performance of farming, broader food systems, and non-farm sector activities.

It was found out that R&D KS have contributed to reducing rural poverty and undernourishment in SSA. A 1% increase in R&D KS reduces rural extreme poverty by 0.218% points annually, moderate rural poverty by 0.146, and the rate of undernourishment by 0.132% points per year.

Mediation analysis indicates that a fifth of the effect on rural extreme poverty (and a quarter on moderate poverty) is attributed to resulting gains in labor productivity. While the effects of knowledge stocks on undernourishment are relatively smaller than those on poverty reduction, a relatively larger share, about 40% of the effect is mediated through gains in agricultural land productivity. Given the currently low levels of investments in R&D (and resulting KS), and prevailing low levels of productivity in the region, these results suggest that increasing its levels and reducing the investment GAP will be critical, but that alone will not be sufficient. Policy makers will have to re-evaluate and rethink the way innovations from R&D investments get scaled up and put in place complementary policies that enable for a sustainable pathway characterized by greater productivity growth and development impacts.

METHODS AND ECONOMETRIC APPROACH

This analysis uses econometric approaches to understand the effects of R&D investments on rural poverty and the prevalence undernourishment, and some of the mechanisms that underline those relationships in SSA. The first challenge is on how to best represent and measure R&D investments, particularly the lagged effects of research. Previous studies have tried to model research lags using econometric methods which were mainly selected for empirical reasons rather than based on some positive theory (Esposti and Pierani, 2003; Alston et al., 2011; Griliches, 1979). This means that in many cases, short lag effects of research were included in econometric models not because this was expected but because of data constraints, like for example, the length of the available time series. To overcome this potential limitation and strengthen the robustness of the results, we use the perpetual inventory method (PIM), in analogy to physical capital, to represent the lagged effect of research through Knowledge Stocks (KS) of agricultural R&D investments.

KS are particularly relevant to regions such as SSA with high poverty levels, facing natural resource degradation, depreciation of technologies and rising temperatures (ASTI, 2021). KS contributes to poverty reduction through alternative mechanisms related to outcomes on-farm, e.g., agricultural productivity, as well as beyond the farm, through more efficient marketing, non-farm activities, and improved policies. In this analysis, we use mediation analysis to look specifically at the relative contribution of KS-induced productivity gains on rural poverty and undernourishment.

Knowledge stocks of agricultural R&D investments

The PIM approach assumes an infinite lag distribution that depends

[1]Semi-elasticities can be more precisely estimated as they do not rely on arbitrary assumption on dealing with countries with low poverty rates, and do not require to drop spells where the poverty rate change is abnormally high in relative terms (Bourguignon, 2003).

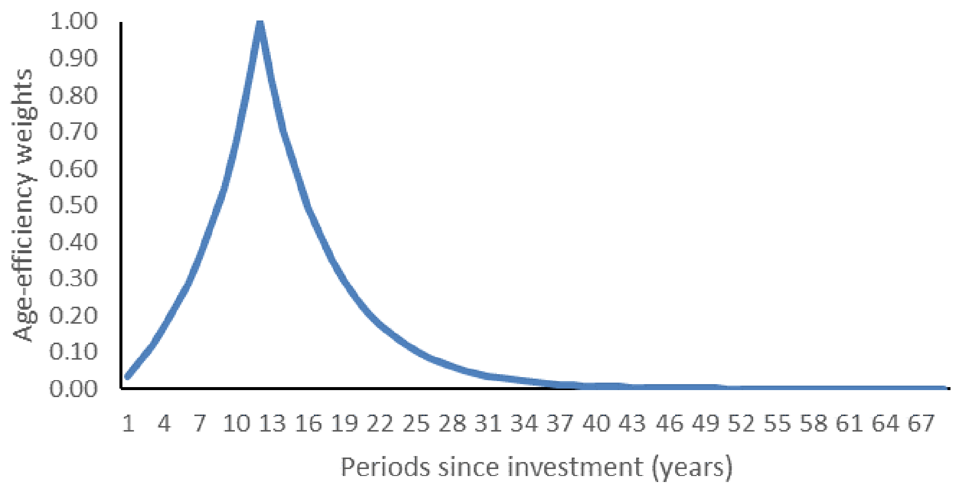

Figure 1. Age-Efficiency Curve for sub-Saharan Africa
Source: Nin-Pratt and Magalhaes (2018).

on the R&D investment characteristics. It has been extensively used in the R&D literature (Hall et al., 2009), and applied to the analysis of agriculture by Esposti and Pierani (2003) and Nin-Pratt and Magalhaes (2018) to calculate knowledge stocks (KS) from agricultural research (Nin-Pratt, 2021).

The key underlying assumption behind the measurement of the returns to R&D is that a string of R&D investments creates a stock of knowledge (KS) that yields returns into the future (Hall et al., 2009). To calculate the knowledge stock, we need to determine how fast R&D investment enters and exits the stock of knowledge, and how the stock depreciates. Little information is required by this approach: the series of R&D investments, an initial value of the knowledge stock, and three key parameters: a geometric depreciation or decay rate of the stock (δ), a gestation lag period (G), and a parameter (β) that defines the shape of the gestation period (Nin-Pratt, 2021).

Formally and assuming that there is no contribution of R&D expenditure (*R*) to knowledge stock during the gestation period, the knowledge stock (KS) in period *t* can be represented as follows:

$$KS_t = KS_{t-1}(1-\delta) + R_{t-G} \quad (1)$$

where *t* is the current period, δ is the decay rate or "depreciation" and *G* the gestation period.

The more general representation of the R&D stock is as follows:

$$KS_t = KS_{t-1}(1-\delta) + \sum_{s=1}^{G} \Omega_{G-s} R_{G-s} \quad (2)$$

with $\Omega=1$ *if* $s=G$; $\Omega=[(1-\beta)s] / [(G-\beta s)]$ if $s<G$.

where *s* is the investment age and *Ω* represents the age-efficiency weights (the contribution of investments to knowledge stocks in year n), and *β* defines the shape of the contribution of investment to knowledge stock during the gestation period.

Esposti and Pierani (2003) argue that there is a conceptual link between values of the parameters of the PIM model and the type of research the model represents. They distinguish three main types of research: basic, applied, and developmental research and report that few studies in the literature explicitly estimate the decay rate δ (Alston et al., 2000) and that none of them refer to agriculture. The values for δ that Esposti and Pierani (2003) found in the literature go from 0.12 to 0.36, with 0.15 as the most frequently assumed value in empirical research. They also found that, in general, the more basic the research, the smaller the δ and the larger the *G.* The literature does not give clear-cut indications on the *β* parameter (Nin-Pratt, 2021).

In our case, to resemble the SSA context, the following parameters are used: δ=0.13, G=12 years, and β=0.73 as estimated in Nin-Pratt and Magalhaes (2018). Those parameters result in the Age-Efficiency curve represented in Figure 1.

Figure 1 shows the proportion of $1 invested in year 0 that contributes to total knowledge stock in year n after investment in the case of SSA countries. With investments occurring in every period, the knowledge stock in a particular period result from adding up all investment from previous years, each multiplied by the age-efficiency weight determined by the number of periods since investment.

Assessing the mediation effects

This was started by estimating the direct effects of annual growth in agricultural R&D knowledge stocks (KS) on the outcomes of interest through standard panel data methods. Subsequently, we apply mediation analysis (Baron and Kenny, 1986; Howell, 2009; Emsley and Liu, 2012; Hicks and Tingley, 2011) to assess the impact of KS on poverty and hunger and measure the relative contribution of KS-induced agricultural productivity growth on those outcomes.

Consider the unobserved effects model,

$$y_{it} = \alpha_1 + x_{it}\omega_1 + z_{it}\emptyset + c_i + u_{it} \quad (3)$$

where y is the dependent variable, that is, annual percentage point change in the outcome of interest (separate models estimated for rural extreme poverty, rural moderate poverty, and prevalence of undernourishment); *x* is the main independent variable of interest – annual percentage change in agricultural R&D Knowledge Stocks (KS); z is a vector of other independent variables (changes in inequality and natural resource dependency for the poverty models; and changes in fertilizer consumption per arable land, and cereals producer price index for the undernourishment model); c_i captures all unobserved time-constant factors that affect y; u is the idiosyncratic time-varying error.

In our quest to explain the relationship between changes in KS and changes in poverty and undernourishment, we need to explore and clarify the potential channels through which the relationship and its magnitude can be explained. In this analysis we look particularly at the mechanism through agricultural productivity. For that, we use the mediation model (Baron and Kenny, 1986; Howell, 2009; Preacher et al., 2007; Emsley and Liu, 2012; Hicks and Tingley, 2011). The model requires that we identify a variable that can be hypothesized to mediate the relationship between our dependent variable *y* (changes in the development outcomes) and the independent variable *x* (growth in agricultural R&D knowledge stocks). Such variable is referred to as the mediator (mediating or intervening) variable (*m*) and is defined in this case as the average annual growth rate in agricultural productivity, measured as (i) the annual growth in agricultural value added per worker for the poverty models, and (ii) the annual growth in cereal yields (tons per hectare) for the undernourishment model. These mediators reflect the extent of an intensive transmission path of KS to the development outcomes of interest.

To set the stage for the analysis, the first step is to run Equation 3 to confirm that x (annual growth in KS) is a significant predictor of *y* (the annual average percentage point drop in poverty and undernourishment).

The second step consists in fitting regressions (Equation 4) and (Equation 5):

$$m_{it} = \alpha_2 + x_{it}\omega_2 + z_{it}\emptyset_2 + c_i + u_{2it} \qquad (4)$$

$$y_{it} = \alpha_3 + x_{it}\omega_3 + m_{it}\gamma + z_{it}\emptyset_3 + c_i + u_{3it} \qquad (5)$$

where *m* is the mediator; *y* (outcome of interest); x (main independent variable of interest); z (vector of other independent variables); ci (time-constant factors); u_{2it} and u_{3it} are idiosyncratic time-varying errors.

The estimates from Equation 4 confirm/reject the validity of the mediator in the relationship, that is, whether x (in this case R&D Knowledge Stocks) is a significant predictor of the mediator *m* (level of agricultural productivity). It is a necessary condition, therefore, that ω_2 is plausible with the underlying assumption of the relationship with the independent variable x, and that it is statistically significant. Equation 5, a regression of *y* on both x and *m*, sets to confirm that (a) the mediator *m* is a significant predictor of *y*, that is, *γ* is statistically significant, and (b) the strengths of the effect of x on *y* is greatly reduced, that is, ω_3 smaller than that ω_1 in Equation 3, if not even not statistically significant. The Average Causal Mediation Effect (ACME) is calculated by multiplying coefficient ω_2 from Equation 4, that is, the effect of the x on the mediator m, by γ from Equation 5, that is, the effect of the mediator on the outcome y, controlling for the independent variable x.

The model is estimated using the STATA *medeff* command that returns the parameters α_2, α_3, ω_2, ω_3, *γ*, $\emptyset_2$, $\emptyset_3$, from the models and then the summary estimates of the ACME ($\omega_2\gamma$), that is, the average effect of the independent variable that operates through the mediator, the direct and total effects.

Applied in the context of our question, mediation analysis will help us discern the extent to which the estimated effect of KS on poverty and undernourishment is mediated through gains in agricultural productivity. This analysis will help to inform an important policy question: to what degree does the payoff of R&D investments in SSA materialize via intensification (agricultural productivity)? Weak transmission via productivity gains will entail that factor beyond farm productivity, such as extensive mechanisms to agricultural output growth[2] or KS-induced benefits in post-harvesting or non-farm activities resulting in higher incomes.

Data

This analysis uses four sets of measures: Agricultural R&D investment variables and derived indicators from ASTI, development outcomes related to poverty and undernourishment, mediators, and other control variables. The definitions and data sources for all variables are presented in Table 1.

Agricultural research and development investment data come from the Agricultural Science and Technology Indicators (ASTI) database.[3] This set includes several variables. The level of spending in agricultural R&D in PPP US$ 2011 (RD) is directly extracted from the ASTI database. The other ASTI related variables are derived measures. First, the R&D Intensity Index (RDI) refers to R&D spending as a share of agricultural GDP each year. Second, the ASTI Intensity Index (AII) is a multifactor R&D intensity measure that calculates the R&D investment of a particular country relative to the main structural factors affecting intensity, namely GDP, Agricultural GDP, income per capita, specialization, and potential spill overs. It is essentially calculated with respect to the "overall" frontier for the period 1981-2016, measuring therefore for each country in each year the distance to that unique frontier. Third, the ASTI Intensity gap measure (GAP) is calculated relative to an annual AII frontier, that is, the distance to the frontier of a country is calculated comparing that country to other countries in that particular year only. Finally, to overcome the potential shortcomings of the RD measure in the econometric analysis, we use the Knowledge Stocks (KS) measure, computed as defined previously.

Development outcomes used in this analysis include poverty rates and the prevalence of undernourishment. Internationally comparable poverty measures were compiled by the PovcalNet team of the World Bank.[4] We focus on headcount ratios defined on the basis of an "extreme" poverty line ($1.25 per person per day in 2005 PPP), but also consider a "moderate" poverty line ($2.00 per person per day in 2005 PPP). The poverty outcome variables are calculated as the annual change in rural and urban extreme and moderate poverty rates, respectively. The rural and urban poverty rates are adjusted for cost-of-living differences using the procedure outlined in Ravallion et al. (2007). The prevalence of undernourishment comes from FAO. It is a measure of food deprivation based on a comparison of usual food consumption expressed in terms of dietary energy (kcal) with certain energy requirement norms. The share of the population with food consumption below the energy requirement norm is considered undernourished (FAO, 2020).

As discussed earlier under methods, we also use several *mediator variables* in the analysis: agricultural labor productivity measured as agricultural value added per worker for the R&D knowledge stocks and poverty relationship; and land productivity measured as cereal yield for the R&D and undernourishment relationship.

The final set of data consists of variables related to *country characteristics* used as controls. Those include inequality through the GINI coefficient, and NR dependency ratio, used in the poverty models; and fertilizer consumption per arable land and cereals'

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[2]The dominance of this particular extensive mechanism may imply limitations in sustaining long run gains without depleting or exhausting available resources.

[3]ASTI is hosted by the International Food Policy Research Institute (IFPRI).

[4]Work commissioned for IFAD's 2016 Rural Development Report. Our poverty data differs from that publicly provided in the World Bank's PovcalNet database.

Table 1. Variable sources and definitions.

Variable	Source	Definition
ASTI variable		
Research & Development Spending (RD)	ASTI	Research & Development Spending in millions of PPP 2011 US$
R&D Spending Intensity Ratio (RDI)	ASTI	Share of R&D Spending in Agricultural GDP
ASTI Intensity Index (AII)	ASTI	Measured as investment level relative to 4 main structural factors divided by a unique overall AII frontier in the period 1981-2016 (0 to 1)
ASTI Intensity Gap Index (GAP)	ASTI	ASTI Intensity GAP measure is calculated relative to an annual AII frontier (0 to 1)
R&D Knowledge Stocks (KS)	ASTI+	KS that reflects how fast R&D investment enters and exits the stock of knowledge, and how it depreciates
Poverty and undernourishment		
Extreme Rural Poverty	WB	Rural Extreme Poverty rate ($1.25 per person per day, PPP 2005)
Moderate Rural Poverty	WB	Rural Moderate Poverty rate ($2.00 per person per day, PPP 2005)
Prevalence of Undernourishment	FAO	Percentage of undernourished population (%)
Causal mediators		
Agricultural value added per worker	WDI	Agricultural valued added per worker (in US$)
Cereal yield	WDI	Cereal production per hectare (kg/ha)
Other control variables		
GINI coefficient	WDI	Gini coefficient of income/consumption
NR rents	WB	Total natural resource rents, including oil, natural gas, coal, mineral, and forest rents (share of GDP)
Fertilizer consumption	FAO	Fertilizer consumption (kg/hectare of arable land)
Cereals PPI	FAO	Producer Price Index of Cereals
Spell		Poverty spell (yearly space between 2 poverty data points)

WB=World Bank, WDI=World Development Indicators, FAO=Food and Agriculture Organization.
Source: Authors.

producer price index, used as controls in the undernourishment model. The estimates of the GINI coefficient of income or consumption are drawn from the WDI database. There is considerable overlap with our poverty measures since each is often derived from the same underlying data source. [5]Natural resource rents correspond to the share of NR in GDP and come from the WDI. The variable spell, expressed in years, is simply the difference between the initial and final year of a given poverty change data point (Table 1).

[5]The Gini coefficient estimates nevertheless need to be approached with caution, as there are concerns about data comparability. For example, some Gini coefficients are calculated with income data while others are calculated with expenditure data (Milanovic, 2014).

RESULTS AND DISCCUSSION

Descriptive analysis of trends and correlations

Here, we look at the trends in agricultural research and development spending, ASTI derived measures, knowledge stocks, and poverty and undernourishment outcomes across developing regions. We also use simple bivariate analysis to look at the correlation between R&D spending and KS, and the relationships between them and poverty outcomes to inform the robustness of the relationships across space (area of residence) and alternative poverty lines and set the stage for the econometric analysis.[6]

Assessment of trends in R&D investments and development outcomes

Agricultural R&D investments and knowledge stocks: In the early 1980s, Asian countries both

[6]ASTI Data runs from 1981 to 2016, while poverty data runs from mid-1990s through 2014. While we use those time frames to assess trends, the overlapping 1995 through 2014 period is used in the statistical and econometric analysis.

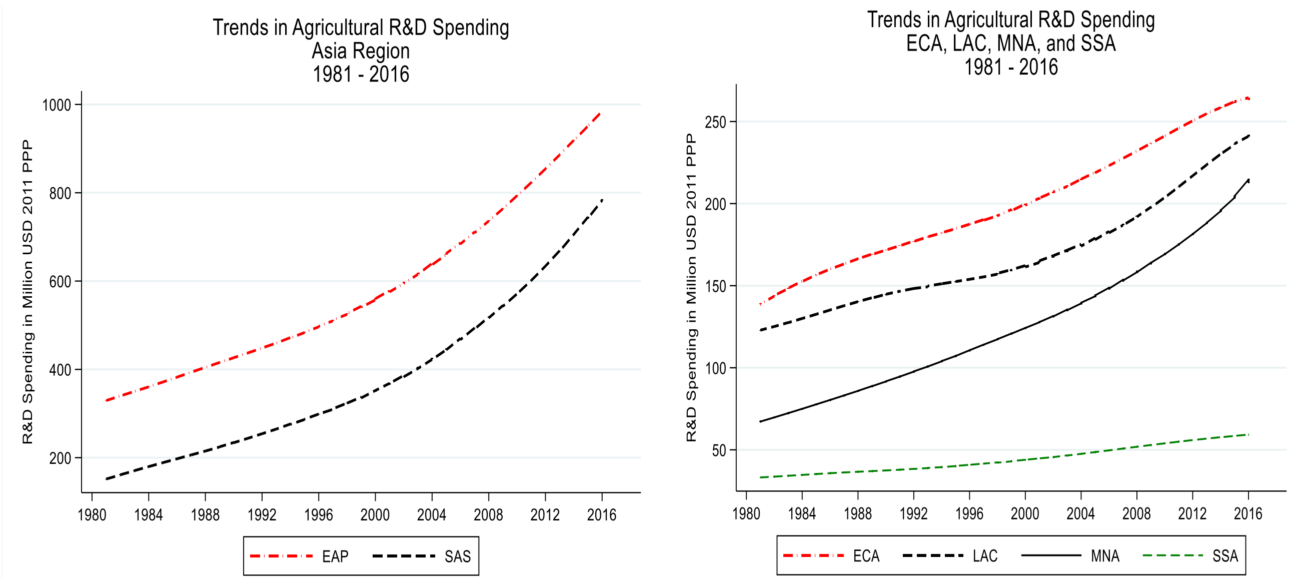

Figure 2. Assessing the trends in RD Spending by region. EAP=East Asia and Pacific; ECA=Europe and Central Asia; LAC=Latin America and the Caribbean; MNA=Middle East and North Africa; SAS=South and Southeast Asia; SSA=sub-Saharan Africa.
Source: ASTI Database.

in EAP and the SAS sub-regions already had relatively higher levels of R&D spending than other developing regions, at over 300 million and 200 million, respectively. Over the next two decades, given the relatively higher growth rate experienced, those regions achieved levels of spending that were substantially higher, with SAS surpassing the 600 million USD (PPP 2011), and EAP reaching well over 800 million in 2010-2014. Despite some growth observed, from about 40 million in mid-1990s to over 60 million in 2014, the SSA region lagged systematically behind over the period (Figure 2).

We now turn to the trends in other ASTI derived measures, namely R&D spending intensity, ASTI Intensity Index and Investment GAP, and Knowledge Stocks over the period 1981-2016.

The R&D spending intensity represents the weight of agricultural R&D spending in the agricultural sector output (e.g., total agricultural R&D spending as a share of agricultural GDP). Growth has occurred for all regions, except Asia (EAP and SAS), where the spending intensity have stagnated over the period (reflecting that the region managed to keep up the initial high R&D spending levels with agricultural sectoral growth), and SSA, where it has dropped over the period (reflecting a reduction in the relative levels of spending) in the region, that is, agricultural spending did not keep up with growth in the agricultural sector (Figure 3). As argued by Nin-Pratt (2021), the RDI is a misleading measure of countries efforts in R&D, as it depends on the levels of structural variables, that is, country characteristics not controlled by policy makers.

The ASTI Intensity Index (AII) is an alternative measure suggested as more adequate for international comparisons as it accounts for key structural factors affecting R&D spending intensity in individual countries. By this measure, EAP and SAS also stand out with relatively high levels in the mid-1990s, and ECA experiences the greatest improvements overtime reaching comparable levels at the end of the period. SSA is the only region that experiments a drop in AII (Table 2).

Looking at the trends in the ASTI Intensity Index gap (GAP) in Table 2, we note that all regions have experienced some improvement in the share of realized potential R&D investments over the period.

While these trends and comparisons are informative and position SSA in the global context, our analysis is centered around the measure of agricultural R&D knowledge stocks, an unbiased measure that accounts for the lagged effects of research through depreciation and gestation period of investments. Figure 4 illustrates agricultural R&D knowledge stocks in SSA over the period 1980 - 2016, derived using R&D spending data for the period, and the assumptions described in the methods section on the decay rate of the stock (δ), the gestation lag period (G), and the β that defines the shape of the gestation period. Notice that growth of the KS after 2000 is driven by the relatively slow growth of R&D investment in the 1980s and 1990s. Spending in agricultural research accelerated in the 2000s but only a small proportion of that growth in investment is reflected in the KS during that period. We should see faster growth of the KS after 2016 although this might be short-lived as the most recent data shows a slowdown in SSA's R&D spending in recent years.

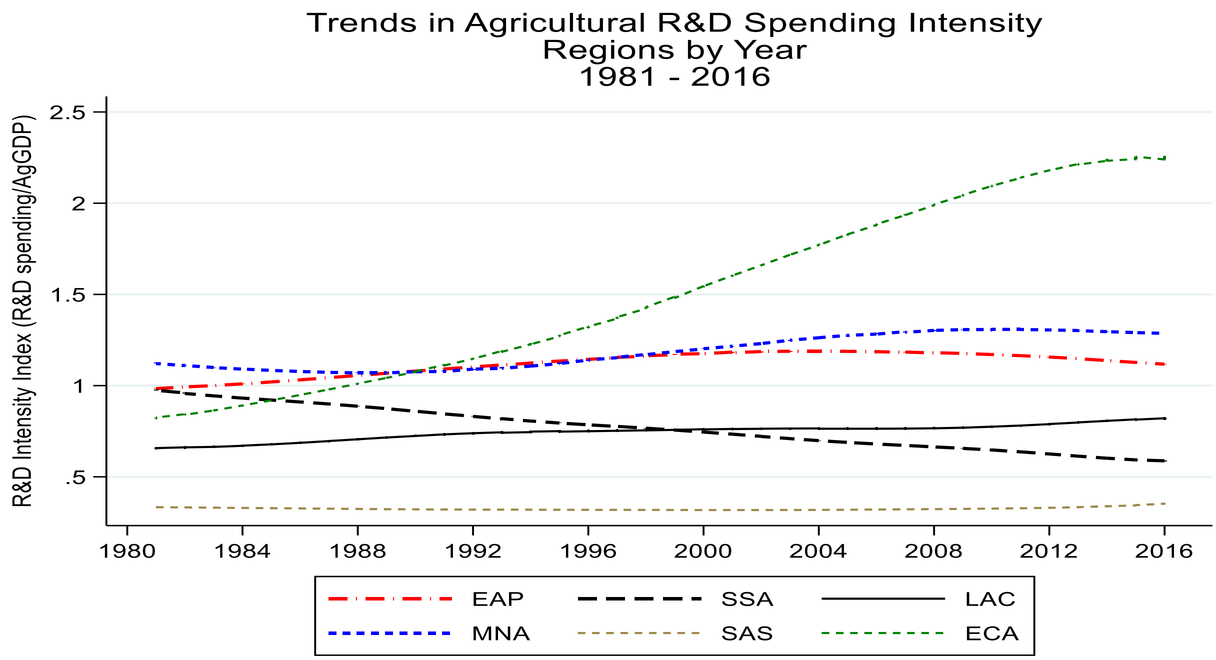

Figure 3. Assessing the trends in R&D Spending Intensity EAP=East Asia and Pacific; ECA=Europe and Central Asia; LAC=Latin America and the Caribbean; MNA=Middle East and North Africa; SAS=South and Southeast Asia; SSA=sub-Saharan Africa.
Souce: ASTI Database.

Table 2. Assessing the trends in ASTI Intensity Index and Investment GAP by region.

Variable	All and Realized Investment GAP Index		
	1981-1985	2010-2014	Growth Index (1981-1985=100)
ASTI Intensity Index (AII)			
EAP	0.39	0.39	1.01
ECA	0.20	0.34	1.67
LAC	0.21	0.24	1.14
MNA	0.22	0.26	1.22
SAS	0.33	0.35	1.05
SSA	0.31	0.21	0.70
Investment GAP Index (IGAP)			
EAP	0.52	0.56	1.08
ECA	0.26	0.48	1.84
LAC	0.29	0.44	1.52
MNA	0.31	0.40	1.29
SAS	0.48	0.51	1.07
SSA	0.46	0.52	1.13

EAP=East Asia and Pacific; ECA=Europe and Central Asia; LAC=Latin America and the Caribbean; MNA=Middle East and North Africa; SAS=South and Southeast Asia; SSA=sub-Saharan Africa.
Source: ASTI.

Trends in poverty and undernourishment: Panel (a) in Figure 5 shows that EAP, SAS, and SSA had particularly high *extreme poverty rates* in the late 1990s, while other regions maintained relatively lower levels. For example, rural poverty rates were over 60% in EAP and SSA and over 50% in SAS. While urban poverty rates were below

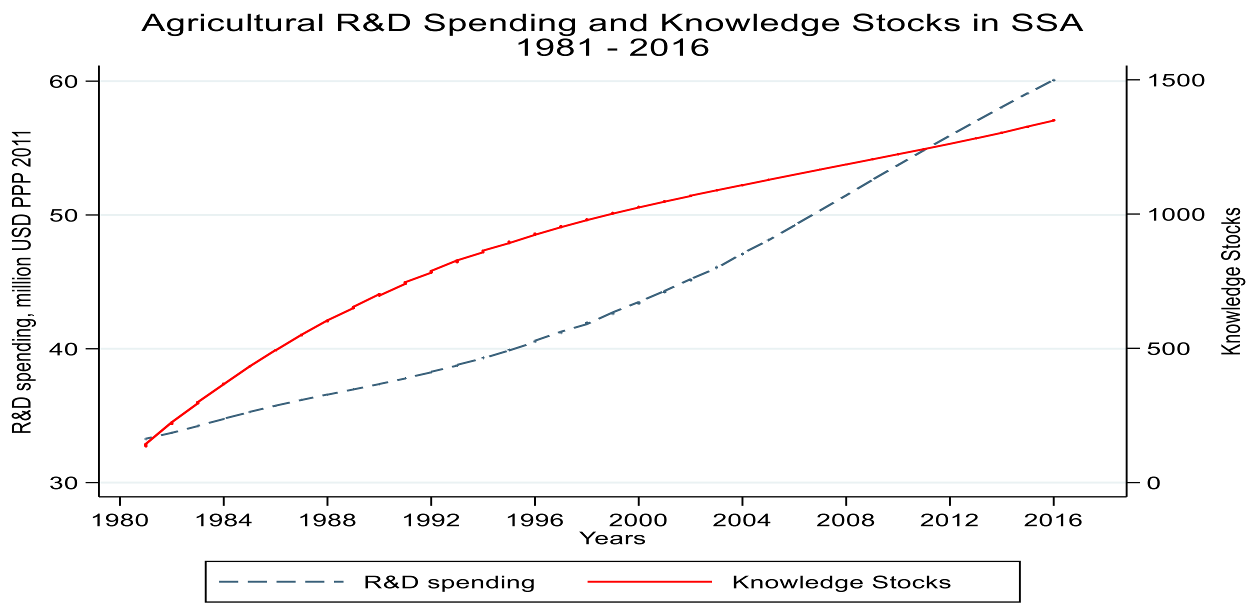

Figure 4. Agricultural R&D Spending and Knowledge Stocks in SSA.
Source: Author's computations using ASTI Database, and assumption regarding selected parameters.

20% in EAP, it was around 40% in SSA and SAS. Trends in the decades that followed were considerably different between the Asia regions and SSA. As is well known, EAP (and to a lesser extent SAS) made considerable progress in reducing poverty over the past three decades. EAP's reduction in rural extreme poverty has been particularly dramatic, falling from approximately 64 in late 1990s to 11% around 2010-2014.[7] Contrary, poverty rates in SSA have remained relatively high, particularly in rural areas, where despite the fall, rural extreme poverty rate in the most recent period remains at 49%, which accounting for population growth, amounts to a larger number of people in poverty overtime.

Panel (b) in Figure 5 shows that similar trends at higher rates are observed for *moderate poverty* in rural and urban areas in all the regions. It should be noted, however, that in each region the drops in rural extreme poverty were proportionally stronger than those in rural moderate poverty, which underscores the significant progress in overcoming initial challenges, but also the long road ahead to bring leaving standards to higher levels in the development process.

Overall, and across all regions, the *prevalence of undernourishment* has fallen since 2000 – globally from 14.8 to 10.7% in 2016. Back in 2000, SAS and SAA experienced the highest rates, 23 and 28%, respectively. EAP, LAC and MNA experienced rates of 10 to 15%, and ECA experienced the lowest rates of below 5%. All regions have made some progress in the reduction of the prevalence of undernourishment. The least progress was observed in SSA that by 2016 still had rates over 20% (Figure 6).

The descriptive analysis reveals a variation in the levels and changes in R&D and outcomes across regions. There is considerable disparity within each region. Given the relatively lesser progress overall observed in the SSA region in both R&D spending and related indicators, and in reducing poverty and the prevalence of undernourishment, the analysis gives particular emphasis to that region.

Assessment of correlations in sub-Saharan Africa countries

Knowledge stocks, R&D spending, ASTI derived indexes, and development outcomes: How do the levels of and changes in Knowledge Stocks correlate with R&D investment spending and ASTI derived indexes? Focusing on SSA countries, Table 3 presents the correlations between Knowledge Stocks and R&D spending (a relatively unrestricted measure) and ASTI derived indicators (RDI, AII, and GAP, bounded index indicators varying between 0 and 1), and between all those and the development outcomes of interest.

Several results stand out. First, KS is statistically and positively correlated with R&D spending and all ASTI derived measures.

Second, all variables are inverse and statistically correlated with the levels of extreme and moderate rural poverty, but only SK and R&D spending exhibits a

[7] China and Indonesia contributed the most for that drop. China's rural extreme poverty rate fell from 70 to 11% between 1993 and 2012, while Indonesia's rate fell from 58 to 11% over the same period.

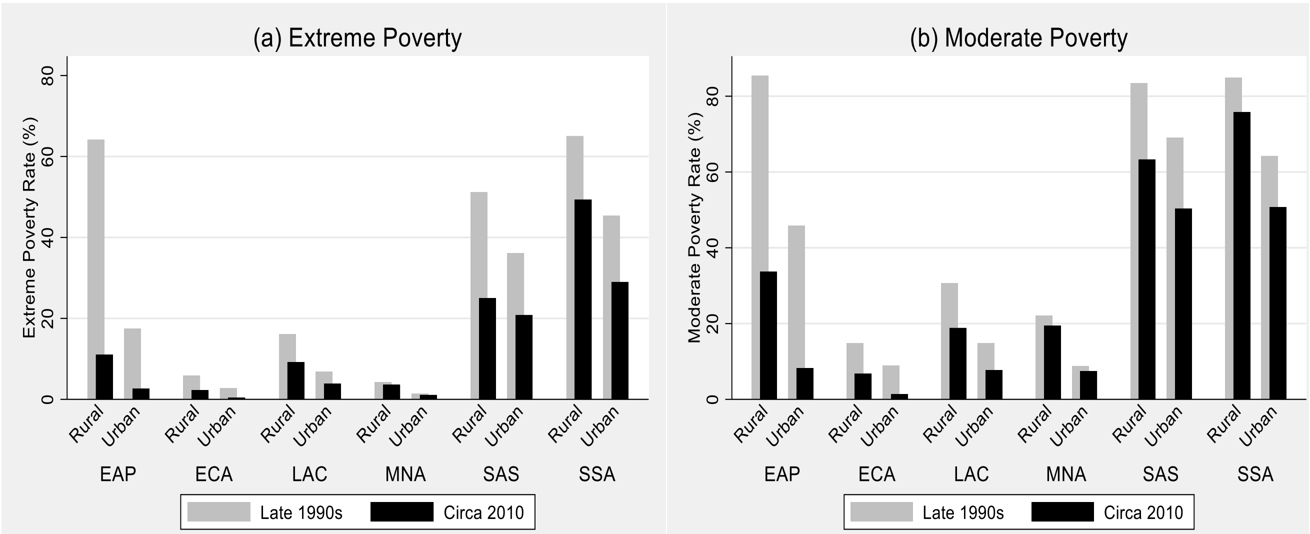

Figure 5. Trends in poverty, urban and rural, by region, Late 1990s – Circa 2010. EAP=East Asia and Pacific; ECA=Europe and Central Asia; LAC=Latin America and the Caribbean; MNA=Middle East and North Africa; SAS=South and Southeast Asia; SSA=sub-Saharan Africa.
Souce: World Bank.

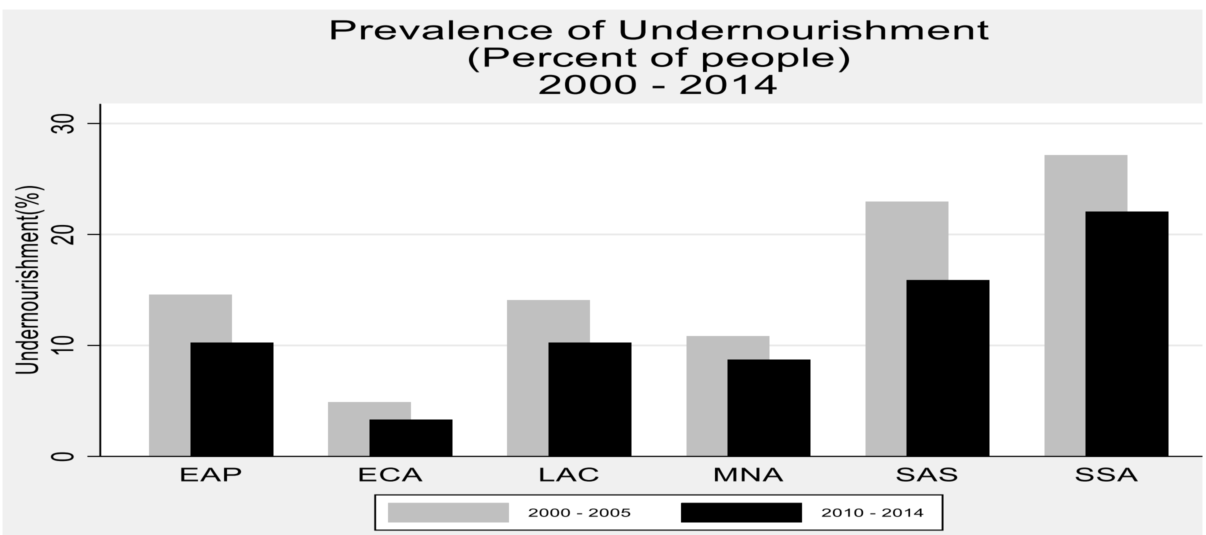

Figure 6. Prevalence of Undernourishment, by region. EAP=East Asia and Pacific; ECA=Europe and Central Asia; LAC=Latin America and the Caribbean; MNA=Middle East and North Africa; SAS=South and Southeast Asia; SSA=sub-Saharan Africa.
Source: FAO (2019).

statistically significant correlation with changes in extreme and moderate rural poverty. Finally, changes in R&D spending are strongly and statistically correlated with drops in both poverty and undernourishment.

As we are particularly interested in assessing the effects of changes in R&D investments and the rates of reduction in poverty and undernourishment, the analysis is focused on R&D knowledge stocks as the less unrestricted measure that better captures the variability in countries efforts in R&D investments and the impact of R&D on the target indicators of poverty and undernourishment. To further define the focus of the analysis, we get a glimpse on: (a) the R&D KS versus poverty relationship by area of residence, that is, rural versus urban, to highlight why a focus on rural poverty is warranted; (b) the robustness of the correlations by poverty line, that is, extreme versus moderate; and (c) the distribution of the relevant relationship across the

Table 3. Correlation of KS, R&D Spending, ASTI Indexes, and Development Indicators, SSA.

Correlation	Knowledge Stocks	R&D spending	RDI	AII	GAP
Knowledge stocks					
Levels	1.0	0.969***	0.340***	0.540***	0.368**
Rural extreme poverty					
Levels	-0.223	-0.286	-0.491***	-0.386**	-0.191
Changes	-0.277*	-0.363**	0.299	0.072	-0.216
Rural moderate poverty					
Levels	-0.243	-0.306*	-0.655***	-0.482***	-0.244
Changes	-0.314*	-0.220*	0.262	0.149	-0.053
Prevalence of undernourishment					
Levels	-0.291***	-0.332***	-0.043	-0.084**	-0.045
Changes	-0.236***	-0.216***	-0.097**	-0.106**	-0.039

Significance level *p < 0.10, **p < 0.05, ***p < 0.01.
Source: Computed from ASTI Database and WB.

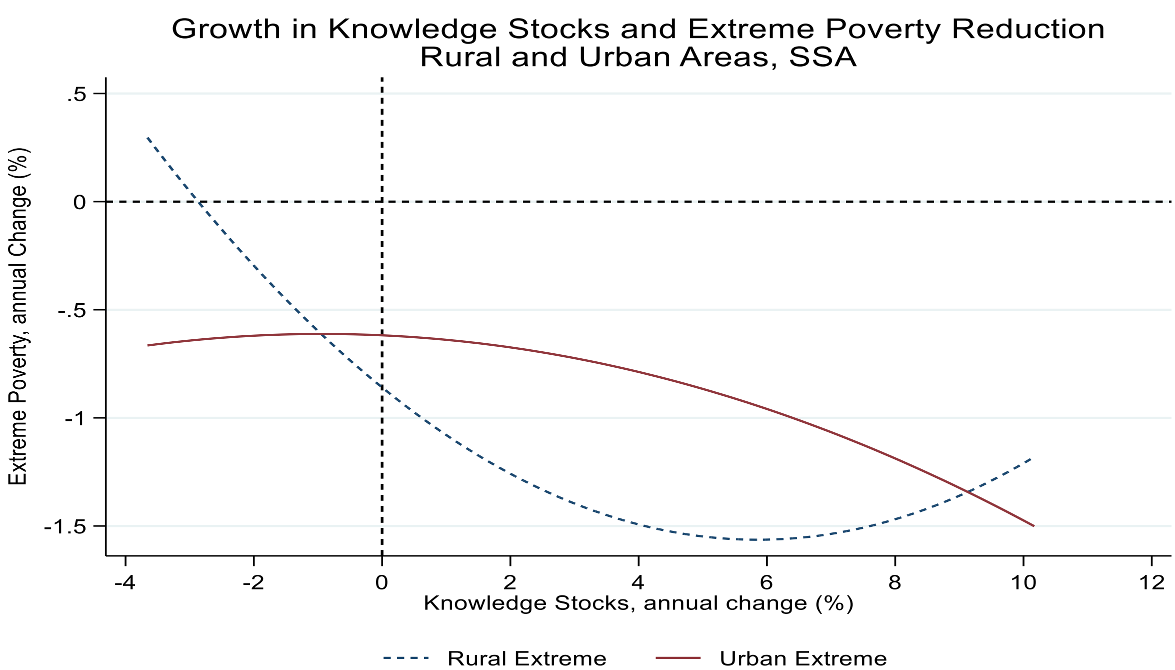

Figure 7. Knowledge stocks and poverty by area of residence.
Source: Computed from ASTI Database and WB.

SSA countries in the sample.

R&D knowledge stocks and extreme poverty by area of residence: The available data allows us to look at the relationship between growth in knowledge stocks and poverty reduction in rural versus urban areas in SSA. We found that while knowledge stocks contribute to poverty reduction in both areas, the effects are stronger in rural areas. In Figure 7, we see that the poverty reduction rates associated with the same increases in KS systematically higher for rural extreme poverty. The relatively steeper rural line suggests that there is a relatively faster rate of poverty reduction as KS growth rates increase.

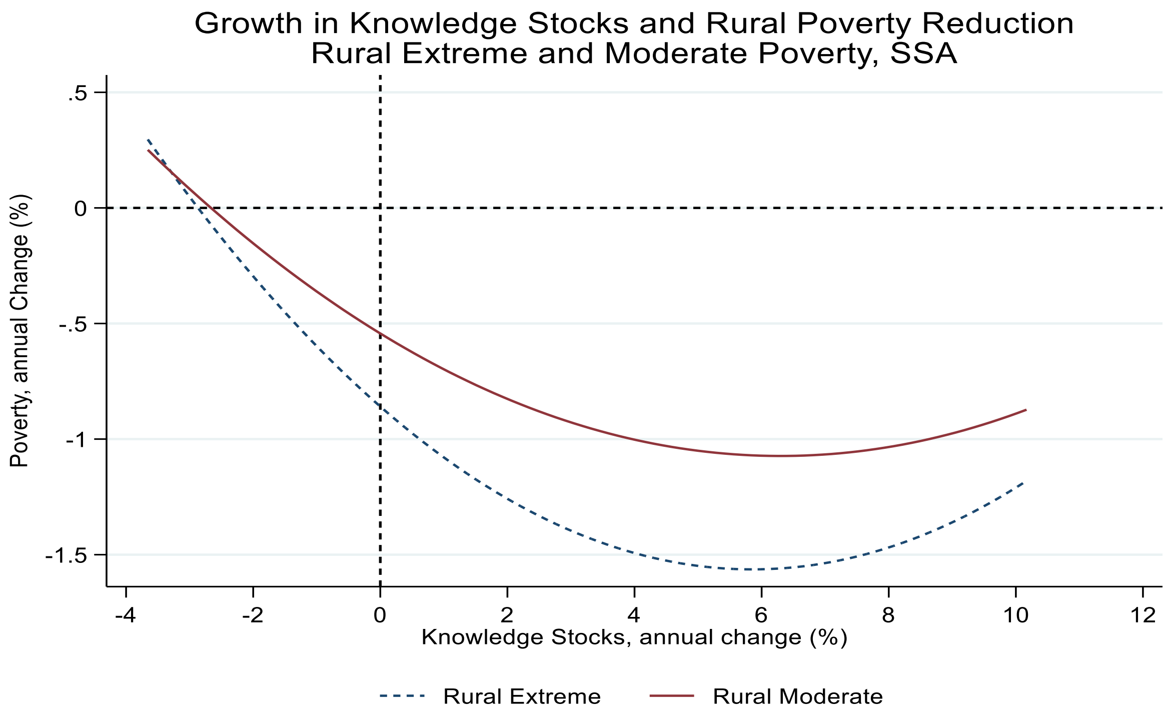

Figure 8. Knowledge stocks and rural poverty reduction, Late 1990s – Circa 2010s.
Source: Computed from ASTI Database and WB.

KS growth and rural poverty lines: Another important question to look at is on the relationship between KS and different poverty lines. We found here that KS growth effects on poverty are robust to alternative poverty lines, that is, it affects both rural extreme and moderate poverty, but the effects are significantly larger for rural extreme poverty. In Figure 8, for example, we see that a 4% increase in the average annual growth of KS is associated with reductions in rural extreme poverty of over 1.5% points, and only less than 1% point for moderate poverty.

In the econometric analysis, we look at the robustness of the results to the poverty lines, looking systematically at rural areas in SSA.

Growth in KS and poverty reduction and undernourishment in SSA countries

Growth in KS and poverty reduction in SSA countries: In Figure 9, we look at the distribution of countries in the relationship between KS and poverty reduction. It illustrates that there is a clear association between the speed of growth in KS and poverty reduction, with countries clustered around quadrant IV. The fitted line slopes downwards which indicates that faster KS growth is associated with faster poverty reduction rates. The effects are relatively stronger for rural extreme poverty than for rural moderate poverty.

Growth in KS and undernourishment in SSA countries: The relative position of SSA countries with respect to the distribution along the relationship between growth in KS and the rate of reduction in the prevalence of undernourishment is presented in Figure 10. With most countries located at the bottom right quadrant, it shows clearly that countries experiencing greater rates of growth in KS also exhibit faster rates of reduction in the prevalence of undernourishment.

Econometric results

The previous discussion points to a significant correlation between growth in KS and rural poverty reduction and undernourishment in SSA countries. Here, we undertake an econometric analysis that carefully assesses the strengths of that relationship in a multivariate context to develop an understanding of the potential mechanisms through which KS growth affects rural poverty and hunger reduction. The analysis uses the mediation analysis approach described in the methodology (Hicks and Tingley, 2011; Imai et al., 2010).

Knowledge stocks and rural poverty

Equation 3 was first used to look at a first-difference model to assess the effect of KS growth on poverty

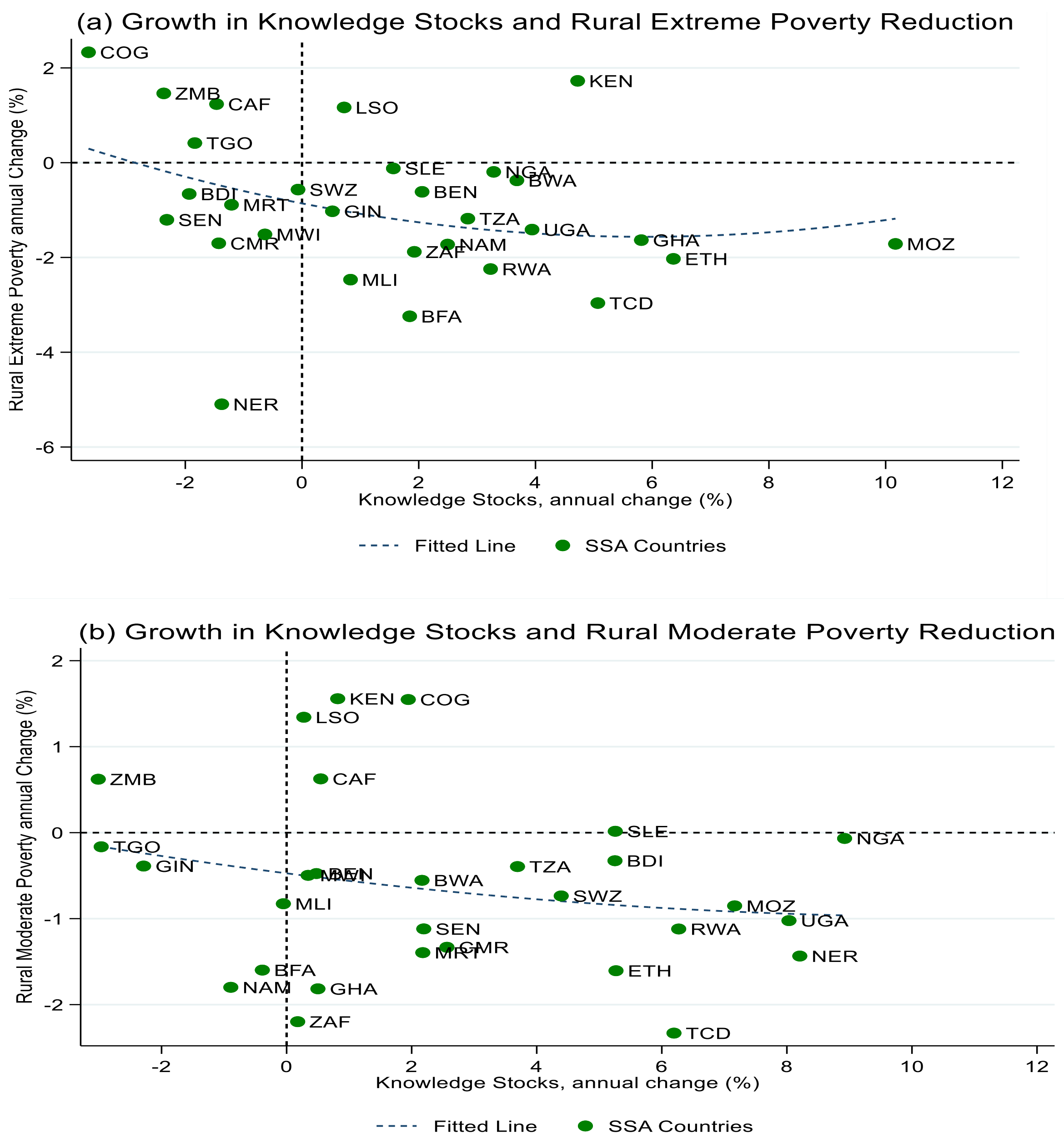

Figure 9. Knowledge stocks and poverty reduction by country, SSA, Late 1990s – Circa 2010s
Source: Computed from ASTI Database and WB.

reduction in SSA. We look specifically at rural extreme poverty and moderate poverty. The model controls for some key factors such as changes in the levels of inequality, the relative dependency on natural resources, and the spell period over the poverty data points considered for each of the 29 SSA countries included in the analysis. Since we use percentage point changes for the poverty rate and percentage change for the independent variables, the coefficients are interpreted as semi-elasticities.

Growth in KS leads to statistically significant reductions in both rural extreme and, to a lesser extent, in moderate poverty (Table 4). Controlling for changes in inequality and other factors, a 1% increase in the levels of R&D spending leads to a drop of 0.218% points in rural extreme poverty and 0.146 in rural moderate poverty, implying greater strengths of R&D investments to lift the poorest. While indicative of the importance of KS for poverty reduction, these results do not reveal the processes at play. To analyze that, we consider a hypothesis related to the strengths of the mediation assumed mechanisms.

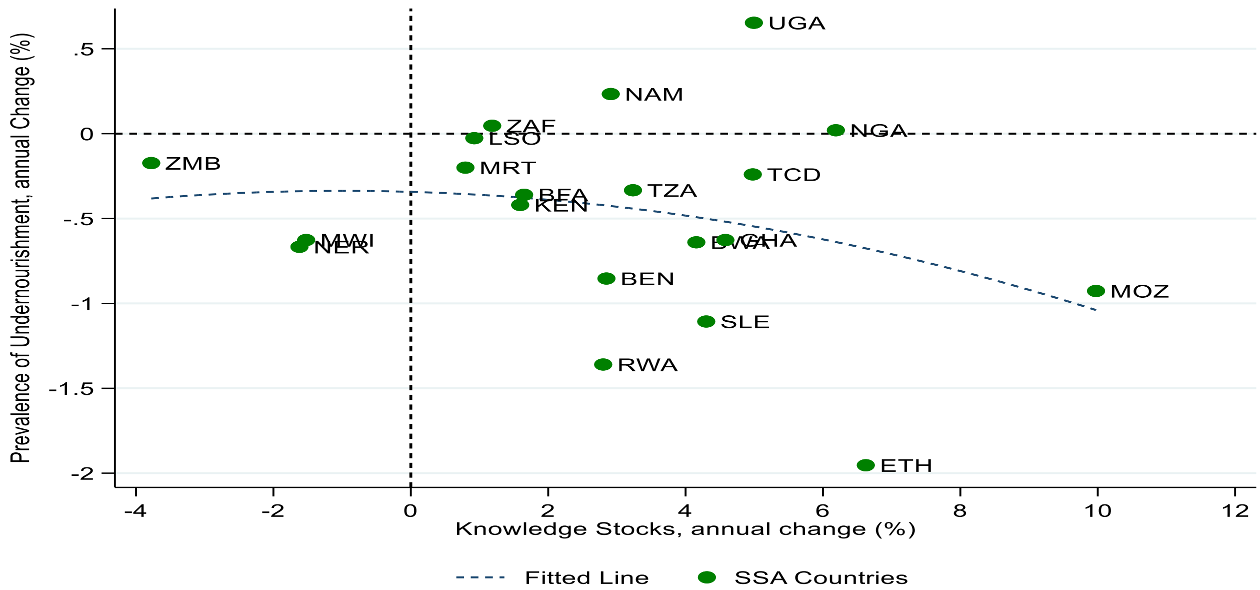

Figure 10. Growth in knowledge stocks and undernourishment by country, SSA, 2000 - 2014.
Source: ASTI Database and FAO.

Table 4. Effects of knowledge stocks on rural poverty in SSA, 1990s – 2010s.

Independent variable (annual % change)	Dependent variable: Rural poverty reduction (annual % point change)	
	Extreme poverty	Moderate poverty
Knowledge stocks	-0.218** (0.080)	-0.146** (0.059)
Gini	0.539*** (0.132)	0.179* (0.097)
NR rents	-0.045 (0.033)	-0.054** (0.024)
Spell	0.041 (0.062)	-0.010 (0.046)
Constant	-0.738 (0.720)	-0.280 (0.529)
Number of countries	29	29

Standard errors in parentheses. Level of significance *p < 0.10, **p < 0.05, ***p < 0.01.
Source: Authors using ASTI and WB.

Unfolding the mechanisms of the effects of knowledge stocks on poverty

There are alternative potential mediated effects that can be looked at to form the analysis. Knowledge Stocks contribute to poverty reduction through alternative mechanisms related to outcomes on-farm (increases agricultural production) as well as beyond the farm, through more efficient post-harvesting and non-farm activities.

Focusing on the pathways driven by increased agricultural production, there are two important potential scenarios. First, one hypothesis is that the poverty reduction effects go through a sustainable intensification pathway, that is, the gains in agricultural productivity that result from growth in KS come from added efficiency embedded in the generation of more output per unit of labor or land, and that will allow for better returns to producers and households and move them out of poverty. The second is an extensive pathway through which there is an expansion in total agricultural output that is not driven by productivity gains. This is a pathway characteristic of many African countries, where growth has occurred with an extensive use of land and labor, a trajectory that is not sustainable in the long run. In the analysis, we text the strengths of the first hypothesis and derive implications on this observed pathway.

The key mediator variable used in this analysis is annual average growth in agricultural value added per worker as a measure of agricultural productivity gains. We use Equation 4 to test the plausibility of the mediators (Table 5). KS growth is a positive and statistically significant predictor of the proposed mediator variable – a 1% increase in the growth KS per year statistically

Table 5. Effects of knowledge stocks on agricultural labor productivity, 1990s – 2010s.

Independent variable (annual % change)	Dependent Variable: Agricultural labor Productivity
	Agricultural VA per worker (annual % change)
Knowledge Stocks	0.398* (0.204)
Gini	0.151 (0.337)
NR Rents	-0.036 (0.084)
Spell	0.034 (0.158)
Constant	-0.149 (1.835)
Number of countries	29

Standard errors in parentheses. Level of significance *p < 0.10, **p < 0.05, ***p < 0.01.
Source: Authors using ASTI, FAO, and WB.

Table 6. Effects of growth in KS on poverty, through agricultural labor productivity, SSA.

Independent variable (annual % change)	Dependent variable: Rural poverty reduction (annual % point changes)			
	Extreme poverty		Moderate poverty	
	Equation 3	Equation 5	Equation 3	Equation 5
Knowledge Stoks	-0.218**(0.080)	-0.169 (0.167)	-0.146** (0.059)	-0.107 (0.061)
Agricultural VA per worker	-	-0.123** (0.053)	-	-0.098*(0.057)
Gini	0.539*** (0.132)	0.558*** (0.129)	0.179* (0.097)	0.194** (0.094)
NR Rents	-0.045 (0.033)	-0.050 (0.032)	-0.054** (0.024)	-0.057** (0.023)
Spell	0.041 (0.062)	0.046 (0.060)	-0.010 (0.046)	-0.013 (0.044)
Constant	-0.738 (0.720)	-0.757 (0.699)	-0.280 (0.529)	-0.294 (0.508)
Number of countries	29	29	29	29

Standard errors in parentheses. Level of significance *p < 0.10, **p < 0.05, ***p < 0.01. Column 1 estimates Equation 3 (summarized in Table 2), while columns 2 are “medeff” estimates related to Equation 5.
Source: Authors using ASTI, FAO, and WB.

Table 7. Effects of knowledge stocks on rural poverty mediated by labor productivity.

Effects	Effects of knowledge stocks on rural poverty	
	Mean	%
Extreme rural poverty		
Total Effect	-0.218	100.0
Average Mediation (ACME) (Mediation through labor productivity)	-0.047	21.5
Moderate rural poverty		
Total Effect	-0.146	100.0
Average Mediation (ACME) (Mediation through labor productivity)	-0.038	25.8

ACME - Average Causal Mediated Effect. Standard errors in parentheses.
Source: Authors using ASTI, FAO, and WB.

significantly increases agricultural labor productivity by approximately 0.40% annually.

In the next step of the mediation analysis (Table 6), we look at the parameters generated in Equation 5 and those from Equation 3 to determine the extent of the mediation, that is, the extent to which the mediator is associated with the development outcome, and the effect it has on the original significance of the independent variable in Equation 3. Results further confirm the adequacy of the mediators – the mediators are statistically significantly associated with rural extreme and moderate poverty and the magnitude of the KS growth is reduced in the presence of the mediator.

Following the satisfaction of the necessary condition for mediation, we look at the final causal mediation analysis. Table 7 presents the results.

Table 8. Effects of Knowledge Stocks on Poverty, through Output and Productivity, SSA.

Independent variable (annual % change)	Prevalence of undernourishment		cereal yield
	Equation 3	**Equation 5**	**Mediation Equation 4**
Knowledge Stocks	-0.132* (0.079)	-0.079 (0.084)	0.178** (0.091)
Cereal Yield	-	-0.296*** (0.063)	-
Fertilizer consumption	-0.009 (0.013)	-0.010 (0.013)	0.003 (0.014)
PPI of cereals	-0.086*** (0.018)	-0.065*** (0.018)	0.068*** (0.019)
Constant	4.341 (0.592)	5.987*** (0.665)	5.563*** (0.616)
Number of countries	21	21	21
Number of observations	234	234	234

Standard errors in parentheses. Level of significance *p < 0.10, **p < .05, ***p < 0.01. Column 1 estimates Equation 1 (summarized in Table 2), while columns 2 and 3 are "medeff" estimates related to Equation 3.
Source: Authors using ASTI, FAO, and WB.

The average total effect of the annual KS growth on rural extreme poverty reduction (-0.218 percentage points for a 1% increase in KS) that operates through agricultural productivity (ACME-Average Causal Mediated Effect) is -0.047% points, representing only a fifth (21.5%) of the total effect. The results for rural moderate poverty indicate a total effect that is relatively weaker (-0.146% points for a 1% annual increase in KS) with the average causal mediated effects playing a relatively stronger role (25.8% of the total effect). In other words, while the magnitude of the effects of KS growth on moderate rural poverty reduction are relatively smaller than those on extreme rural poverty, the way they take effect through agricultural productivity are relatively stronger.

These findings corroborate the conclusions that KS in SSA have had an important impact on poverty reduction fueled by output growth, but that such expansion is not sustainable in the long run because it has largely not been achieved via sustainable productivity growth (IFAD, 2016).

Unfolding the mechanisms of the effects of KS growth on undernourishment

Mediation analysis is also used to assess the mechanisms through which KS growth relate to reductions in the prevalence of undernourishment. In SSA, the levels of food insecurity and undernourishment are highly dependent on the levels of production of agricultural output. In many countries, cereals are an important part of both food production and consumption. An important mediator motivated by the mission of the agricultural research sector supported by KS is the growth achieved in productivity in cereal production, that is, the growth in cereal yields. This indicator does reflect the degree of success of the R&D innovations undertaken to develop and disseminate to the market improved varieties and other bio-innovation technologies, including improved production practices and institutional innovations.

Results of the mediation analysis are presented in Tables 8 (regression results) and 9 (summary of direct, mediated and total effects of growth in KS on reductions in undernourishment). The analysis looks at the extent to which KS effects are mediated through gains in agricultural land productivity as sustainable pathway.

Table 8 indicates that growth in KS leads to a statistically significant reduction in the prevalence of undernourishment. Controlling for fertilizer consumption and the PPI of cereals, a 1% increase in the KS levels leads to a 0.132% points drop in the prevalence of undernourishment. Given that the total increase of the agricultural KS in SSA between 1990 and 2016 was 78% and that during the same period the region spent a total of $50 billion in R&D, a simple calculation shows that the region spent on average $640 million for every 1% increase in KS and about $4.8 billion in R&D for each 1% reduction in the prevalence of undernourishment. The selected mediator for this analysis (cereal yield) meets the necessary condition, that is, KS growth is a positive and statistically significant predictor of those variables (last 2 columns). Results further confirm the adequacy of the mediator as it is statistically significantly associated to the drop in the prevalence of undernourishment and the magnitude of the KS growth is reduced and rendered statistically insignificant in the presence of the mediator.

Finally, results in Table 9, regarding the mediated effects of KS growth on changes in the prevalence of undernourishment, suggest that of the total effect (-0.132% points per 1% increase in R&D KS) average causal mediated effects (ACME) through cereal yield is -0.053, or about amounting to 40% of the total effect, which is significantly larger than what we find for poverty reduction mediation of the R&D KS effects.

CONCLUSIONS AND POLICY IMPLICATIONS

This analysis explores the relationship between agricultural R&D knowledge stocks and rural poverty

Table 9. Direct and mediation effects of knowledge stocks on undernourishment.

Effects	Effects of knowledge stocks on changes in undernourishment	
	Mean	%
Total effect	-0.132	100.0
Average mediation (ACME) (Mediation through cereal yield)	-0.053	40.2

ACME - Average causal mediated effect.
Source: Authors using ASTI, FAO, and WB.

reduction and the prevalence of undernourishment in sub-Saharan Africa. It uses a panel data set of internationally comparable poverty dis-aggregated by urban and rural areas, country level undernourishment, and ASTI data on R&D investments and derived indicators. We use KS derived from the perpetual inventory model (PIM) to account for the lagged effects of R&D investments assuming a depreciation rate and a defined gestation period of such investments.

The analysis reviews trends in R&D KS and development outcomes such as rural poverty and the prevalence of undernourishment and uses causal mediation analysis to assess the impact of KS on poverty and hunger and measure the relative contribution of KS-induced agricultural productivity growth on those outcomes. The idea is to get a sense of the effectiveness of intensive and sustainable pathways to those effects, that resemble the way KS are expected to influence reduction in poverty and hunger. Poverty reduction effects of KS growth are assumed to be mediated through agricultural labor productivity, while the effects on the reduction in the prevalence of undernourishment are assumed to be mediated by land productivity.

Results indicate that while growth in R&D investments and resulting KS in SSA have been slower than in other developing regions, it has helped reduce rural poverty and undernourishment. A 1% increase in KS reduces rural extreme poverty by 0.218 percentage points, moderate poverty by 0.146 percentage points, and the rate of undernourishment by 0.132 percentage points.

Mediation analysis indicates that a fifth of the KS effect on rural extreme poverty, and a quarter of the KS effect on moderate rural poverty, can be attributed to KS driven gains in agricultural labor productivity. A more significant share, about 40% of the effect on undernourishment is mediated through gains in agricultural land productivity. These results indicate that KS supports poverty and hunger reduction through benefits on-farm and beyond it. They also suggest that there is room for streghtening the role of R&D KS productivity enhancing innovations.

Given the currently low levels of R&D Knowledge Stocks, and prevailing low levels of productivity in the region, these results suggest that increasing R&D investments can play an important role, but that alone is not sufficient. Policy makers will have to rethink the way the innovations from R&D get scaled up and put in place complementary policies that enable for a sustainable pathway characterized by greater productivity growth for boosting development impacts.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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REFERENCES

Alston JM, Marra MC, Pardey PG, Wyatt TJ (2000). Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D. Australian Journal of Agricultural and Resource Economics 44(2):185-215.

Alston JM, Andersen MA, James JS, Pardey PG (2011). The Economic Returns to US Public Agricultural Research. American Journal of Agricultural Economics 93(5):1257-1277.

ASTI (2021). Agricultural Research Expenditures and Human Resource Capacity database. Washington, DC: International Food Policy Research Institute. http://www.asti.cgiar.org/data.

Baron RM, Kenny DA (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology 51:1173-1182.

Benfica R, Henderson H (2021). The Effect of the Sectoral Composition of Economic Growth on Rural and Urban Poverty. Review of Income and Wealth 67(1):248-284.

Bourguignon F (2003). The Growth Elasticity of Poverty Reduction: Explaining Heterogeneity across Countries and Time Periods, in T. Eicher and S. Turnovsky (eds), Inequality and Growth: Theory and Policy Implications, Cambridge University Press, Cambridge pp. 3-26.

Christiaensen L, Demery L, Kuhl J (2011). The (evolving) role of agriculture in poverty reduction – An empirical perspective. Journal of Development Economics 96(2):239-254.

Emsley R, Liu H (2012). PARAMED: Stata module to perform causal mediation analysis using parametric regression models.

Esposti M, Pierani F (2003). Building the Knowledge Stock: Lags, Depreciation, and Uncertainty in R&D Investment and Link with Productivity Growth. Journal of Productivity Analysis 19:33-58.

Fan S, Zhang L, Zhang X (2002). Growth, Inequality, and Poverty in Rural China: The Role of Public Investments. International Food Policy Research Institute, Washington, DC.

Ferreira F, Leite P, Ravallion M (2010). Poverty reduction without economic growth? Explaining Brazil's poverty dynamics, 1985-2004. Journal of Development Economics 93(1):20-36.

Food and Agriculture Organization (FAO) (2020). The State of Food Insecurity and Nutrition in the World. Food and Agriculture Organization of the United Nations. Rome, Italy.

Food and Agriculture Organization (FAO) (2019). Agricultural Statistics from the Food and Agriculture Organization. FAOSTAT database. Rome, Italy.

Griliches Z (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. The Bell Journal of Economics 10(1):92-116.

Hall BH, Mairesse J, Mohnen P (2009). Measuring the Returns to R&D. NBER Working Paper w15622. Cambridge, MA, US: National Bureau of Economic Research (NBER).

IFAD (2016). Rural Development Report 2016: Inclusive Rural Transformation. International Fund for Agricultural Development, Rome, Italy.

Imai K, Keele L, Tingley D, Yamamoto T (2010). Causal mediation analysis using R. In Advances in Social Science Research Using R, ed. H. D. Vinod. New York: Springer pp. 129-154.

Hicks R, Tingley D (2011). Causal mediation analysis. The Stata Journal 11(4):605-619.

Howell DC (2009). Statistical methods for psychology (7th ed.). Belmont, CA: Cengage Learning.

Klasen S, Misselhorn M (2008). Determinants of the growth semi-elasticity of poverty reduction. Ibero America Institute for Economic Research Discussion Paper No. 176.

Milanovic B (2014). All the Ginis Dataset. Available at data.worldbank.org/data-catalog/all-the-ginis.

Nin-Pratt A (2011). Agricultural R&D Investment, Poverty, and Economic Growth in sub-Saharan Africa. Prospects and needs to 2050. Conference Working Paper 9. International Food Policy Research Institute, Washington, DC.

Nin-Pratt A, Magalhaes E (2018). Revisiting rates of return to agricultural R&D investment. IFPRI Discussion Paper 1718. Washington, DC: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/132370

Nin-Pratt A (2021). Returns to R&D Investment to Inform Priority Setting in the One CGIAR and NARS. IFPRI Discussion Paper 01559. International Food Policy Research Institute, Washington, DC.

Preacher K, Rucker DD, Hayes AF (2007). Addressing Moderated Mediation Hypotheses: Theory, Methods, and Prescriptions. Multivariate Behavioral Research 42(1):185-227. DOI: 10.1080/00273170701341316

Ravallion M, Datt G (2002). Why has economic growth been more pro-poor in some states of India than others? Journal of Development Economics 68(2):381-400.

Ravallion M, Chen S, Sangraula P (2007). New evidence on the urbanization of global poverty. Population and Development Review 33(4):667-701.

World Bank (2020). World Development Indicators. Washington, DC.