Agriculture for development ten years later

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The puzzle of neglect of agriculture for development

- The World Development Report (WDR) *Agriculture for Development* (World Bank, 2008) was released ten years ago. It has been one of the bestsellers among WDRs, indicating interest in the subject.
- The WDR's main message was that agriculture-based countries, i.e., countries with a high share of agriculture in GDP growth and a high share of rural poverty in total poverty, that basically include all Sub-Saharan Africa (SSA) countries, should invest more in agriculture in order to fully capture its potential for growth and poverty reduction.
- Following 2008, there was a short-term positive response by governments, international organizations, and the donor community. Investment in agriculture increased sharply in the context of the food crisis. The number of countries meeting the CAADEP (Comprehensive Africa Agriculture Development Program) goal introduced by NEPAD (New Partnership for Africa's Development) of allocating 10% of government expenditures to agriculture increased from 3 in 2007 to 10 in 2009. Overseas development assistance to agriculture increased by 60% between 2007 and 2009.
- But this response was not sustained. In 2014 (latest data) only 2 SSA countries (Malawi and Mozambique) out of 43 exceeded the CAADEP goal. The modal SSA country spends only 5% of its public expenditures on agriculture. No country spends on agriculture as much as agriculture contributes to GDP, and 75% of the countries spend less than half that amount (Goyal and Nash, 2016).
- NEPAD also sets a goal for public spending on agricultural R&D to reach 1% of agricultural GDP. Returns to investing in agricultural research are typically in excess of cost, indicating under-investment. This takes extreme forms in SSA where investment is by far the lowest among regions and has been declining over the last decade. In 2011, only six countries (Swaziland, Cabo Verde, South Africa, Botswana, Namibia, and Mauritius) met the NEPAD goal (IFPRI, 2018). As we will see later, this is important to secure the supply side of technological innovations customized to the unique SSA environment and its considerable local heterogeneity.
- With failure to invest in agriculture, the yield gap on cereals has continued to increase between SSA and other regions of the world. This growing yield gap is correlated to a growing chemical fertilizer gap and a large deficit in irrigation (Table 1).

Region	Country	Year	% land
SA	Bangladesh	2006	52.6
	Pakistan	2011	51.8
	India	2013	36.8
EAP	Indonesia	2005	15.2
	China	2011	10.5
	Philippines	2011	9.3
LAC	Chile	2007	7.0
	Mexico	2014	5.5
SSA	South Africa	2011	1.7
	Ethiopia	2011	0.5
	Malawi	2008	0.5
	Rwanda	2005	0.4
	Ghana	2014	0.2
	Niger	2011	0.2
	Uganda	2013	0.1
	Kenya	2009	0.04

Source: World Bank, World Development Indicators

Table 1. Agricultural irrigated land (% of total agricultural land)

- Today, the WDR's main message remains valid for institutions such as the WB, the FAO, and IFAD that continue to advocate more investment in agriculture. This is motivated by the observation that 51% of the world extreme poor live in SSA (a rising share) and 78% of the world extreme poor still work in agriculture in spite of rapid urbanization. Agriculture-based countries must invest more in agriculture to meet the Sustainable Development Goals 1 and 2 on poverty and hunger and to induce industrial and services growth, especially in rural areas (World Bank, 2016).
- Investing in agriculture where the poor work has proven more effective for poverty reduction than taking the poor out of agriculture and to an urban-industrial environment, i.e., through a Lewis-type structural transformation. Hence, the poor are not found in agriculture due to adverse selection. Poverty reduction, where it has happened, has been more effective through productivity growth where the poor work (in agriculture and rural areas) than through structural transformation (Christiaensen and Todo, 2014; McMillan et al, 2017)
- A Solow-type decomposition of sources of growth shows that agricultural output growth in SSA in the 1985-2012 period originated for 63% from area expansion compared to 8% from factor deepening and 29% from productivity growth. This is not sustainable due to an effective land constraint and declining farm size in most countries as a consequence of rapid population growth. Take Malawi as an example where agricultural land for households engaged in agricultural production fell from 2.3 acres in 2004, to 1.8 in 2010, and 1.4 in 2016 (LSMS-IZA data). Productivity growth and factor deepening consequently have to be the main sources of growth as in the rest of the developing world where they account for 83% of agricultural output growth.
- In spite of this, there is rising agro-pessimism in the development community. Collier and Dercon (2014) and Gollin et al. (2014) argue that poverty reduction has to come from employment creation in the urban-industrial environment. And governments have been

voting with their feet by not investing public resources in agriculture to the recommended levels.

- Hence the puzzle in using agriculture for development is: why has the WDR/CADEP recommendation not been followed? Premise to a response is that it is not a mistake but is due to legitimate disappointment with achieving success in investing in agriculture for development. The question to be answered is thus: how to be more successful with development when investing in agriculture?

Lessons from attempts at modernizing SSA agriculture

- While there has not been success in enhancing public expenditures in agriculture, there has been considerable progress with data collection and with rigorous experimentation how to use agriculture for development. Hence, we know more today about how to use agriculture for development than we did 10 years ago, even though it has not been put into practice to the desirable level and in the desirable form. Hence, it is important to start by reviewing what we have learned.
- There starting point in characterizing how to use agriculture for development is to recognize that there is considerable heterogeneity in the rural population. As a consequence, differentiated approaches to poverty reduction must be designed for different segments of the population. A typology of rural households typically uses land endowments, labor allocations, and food product disposition as classificatory indicators (Schejtman, 1982; WDR, 2008; de Janvry and Sadoulet, 2016) (Table 2).

	Land	Labor allocation			Food product disposition	
	endowments	Off-farm	On-farm	Hire & supervise	Net buyer	Net seller
Rural worker	0	++	0	0	++	0
Sub-family farmer	+	+	+	0	+	0
Pure family farmer	++	0	+	0	0	+
Small commercial farmer	+++	0	+	+	0	++
Large commercial farmer	++++	0	0	++	0	+++

Off-farm labor includes employment in both agriculture and the rural non-farm economy

Table 2. Typology of rural households

- The main argument in support of the need for a structural transformation as the mechanism to reduce poverty is that there is a large labor productivity gap between agriculture and non-agriculture (Gollin et al., 2014). An important observation, however, based on the LSMS-IZA data for SSA is that while the gap in NonAg/Ag labor productivity per person per year is indeed large (typically 3.5 to 1), the gap in NonAg/Ag labor productivity per hour worked is relatively small (typically 1.5 to 1) (McCullough, 2017). This suggests that the labor market works relatively well in allocating agriculture between Ag and NonAg on a per hour basis, and that the main cause of poverty in agriculture is the labor calendar: there are extensive periods of idleness in agriculture due to seasonality of cropping patterns, especially in rainfed agriculture which is the case for most of SSA. Typically, the average number of hours worked per worker per year is 2.6 times higher in NonAg than in Ag. The difference in labor use across months of the year is illustrated in Figure 1 for Malawi using a rural-urban classification instead of the Ag-NonAg contrast, which is more correct in characterizing households due to cross-sectoral labor engagements. Else than at peak time (planting is in month 13), there is larger unemployment for rural than urban households.

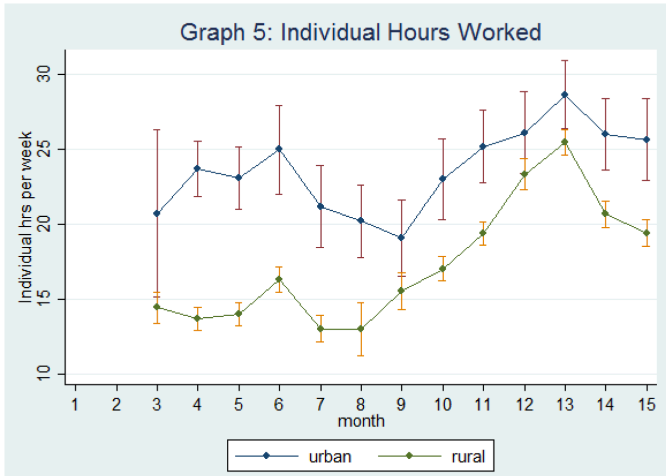


Figure 1. Urban and rural household labor calendars in Malawi
Data source: LSMS-IZA

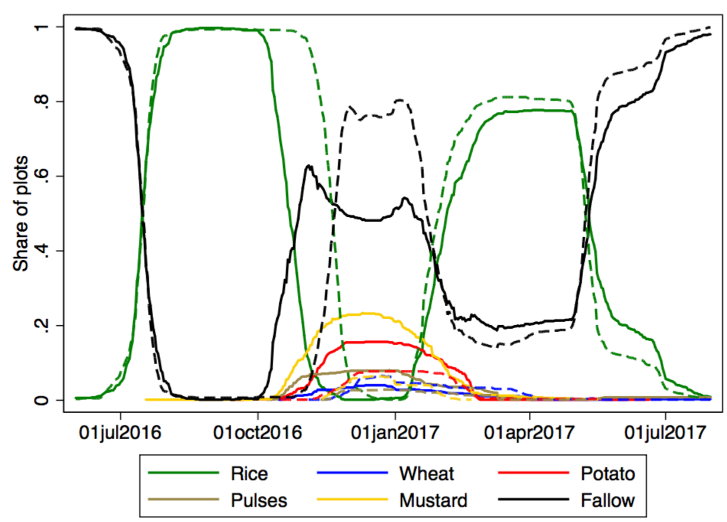
- With high urban unemployment in Malawi limiting the option of reducing rural poverty through permanent or seasonal rural-urban migration, this suggests that a key instrument for rural poverty reduction is to have less idle time for land and labor through the monthly calendar. For Bangladesh, Lagakos et al. (2017) proposed to spread the labor calendar for rural households through migration during the lean season. When this option is not available due to high urban unemployment as in Malawi--in addition to seasonal migration being potentially detrimental to agricultural practices in the home plot (Fink et al., 2014)--filling and smoothing labor calendars in the rural areas is the key to poverty reduction. This can involve both employment in agriculture and in the local rural non-farm economy (RNFE).
- Based on work done for the 2016 IFAD Rural Development Report (led by Hans Binswanger), for China by Wang (2016), by BRAC on graduating the ultra-poor (Banerjee et al., 2015), and for the ATAI project (ATAI, 2018), a strategy out of rural poverty would involve the following five steps: Asset building, Green Revolution, Agricultural Transformation, Rural Transformation, and Structural Transformation as described in Table 3.

Stages of transformation	Processes
Asset building	Access to land and human capital for the landless and sub-family farmers
Green Revolution	Adoption/diffusion of HYV seeds and fertilizers for staple crops
Agricultural Transformation	Access to water for irrigation Ag diversification toward high value crops Development of value chains and contracting
Rural Transformation	Mechanization and land concentration Development of land and labor markets Growth of a rural non-farm economy (RNFE)
Structural Transformation	Rural-urban migration Urban-based industrialization and services

Table 3. The AB-GR-AT-RT-ST sequence

We refer to this theory of agriculture for development as the AB-GR-AT-RT-ST sequence.

- A key objective of the AT is to spread labor and land calendars over as much of the year as possible through multiple cropping (diversification in agriculture), which requires water control, the development of value chains for new crops, and contracting among agents in these value chains. An example is introduction of short duration rice varieties in Bangladesh that frees the land for an additional crop, typically high value crops such as potatoes and onions. This makes an important contribution to filling land and labor calendars. Necessary for this third crop is water control so cultivation can happen beyond reliance on the monsoon and risk is reduced for costly investments (Emerick et al., 2017).



Land calendar: Before (dashed line) and after (full line) introduction of short duration rice variety

Source: Emerick et al. 2018

- A key objective of the RT is to give access to smallholder farm households to sources of income beyond agriculture, contributing to the diversification of sources of income in what has often been referred to in rural sociology as “pluriactivity”. In Ghana, income derived from the RNFE (including seasonal migration) for rural households is about 40%, a share that increases as land endowments fall (WDR, 2007). It is indeed the case, that with land limitations, smallholder farmers will rarely exit poverty with agriculture alone. This requires the development of land markets (to allow for gradual land consolidation and mechanization) and of labor markets (with different members of the household specializing in farm and non-farm activities rather than switching activities over the labor calendar). This process will happen in the more favorable areas where a RNFE linked to agriculture (as it undergoes a RT) through forward, backward, and final demand linkages can develop. This is the ADLI (Agriculture Demand-Led Industrialization) strategy advocated by Adelman (1984) and Mellor (1998) that is actively pursued in countries such as Ethiopia. The RNFE can also be propelled by labor release from agriculture through labor-saving technological change in agriculture (Bustos et al., 2016).

- Matching the household typology to the steps of transformation gives a more specific policy agenda, as in Table 4:

Rural households	Policy
Rural worker	Assets
Sub-family farmer	Assets, GR
Pure family farmer	GR, AT
Small commercial farmer	AT, RT
Large commercial farmer	AT, RT

Table 4. Heterogeneity and transformation

How to make the agenda work?

- While theory is well in place, and successes in using agriculture for development have been achieved in countries such as China, Vietnam, Chile, and Brazil, positive results have still largely been elusive in most countries of SSA, though with a great deal of heterogeneity (Jayne et al., 2018). Achieving A Green Revolution for Africa (AGRA) still shows modest outcomes. According to LSMS-IZA data, some countries have made headways with 77% of cultivating households reported using chemical fertilizers in Malawi (under heavy subsidization), 56% in Ethiopia, 41% in Nigeria, but still only 17% in Niger and 3% in Uganda (Christiaensen, 2017). In spite of these localized gains, there is no visible reduction in the aggregate fertilizer and yield gaps between SSA and other regions of the world. This creates the puzzle of technology adoption, motivating research to identify the role of constraints such as market failures in credit, insurance, and product/factor markets on adoption of existing technologies such as chemical fertilizers and improved seeds. A lot of experimentation using randomized controlled trials has explored constraints on demand coming either from behavior or from the context where demand applies, particularly under ATAI. These results are effectively reviewed in Bridle et al. (2018). A consistent result is that relaxing demand constraints on adoption of existing technology is important, and that many creative institutional innovations have been devised for this purpose, but that there is a low ceiling on adoption even when constraints are relaxed (Magruder, 2018).
- On credit, results show that a majority of farmers are not concerned with a credit constraint. When credit that must be repaid is offered, 17% of farmers used it in Morocco (Crépon et al., 2015), 21% in Mali (Beaman et al., 2015), and 36% in Ethiopia. In Malawi input credit for high-yielding maize and groundnuts was taken by 33% of the farmers (Giné and Yang, 2009). When credit vouchers are randomly assigned, 28% of the

farmers who won the lottery redeemed their vouchers. In Mozambique, only about 1/3 of farmers respond to the availability of subsidized fertilizer (Carter 2013). Magruder (2018) thus concludes that "credit is a barrier to technology adoption, but one that binds only for a minority of farmers." While uptake is low, relaxing credit when it is an effective constraint is effective for technology adoption. Thus it works when available and needed, but is not needed for adoption most of the time.

- On risk, a similar result is obtained with the uptake of index insurance that typically does not exceed 6 to 18% at market price (Schickele, 2016). This is not because farmers are not exposed to uninsured risks that deter technology adoption, but largely because the index insurance product still requires much improvement in design and marketing to be adopted (Carter et al., 2017). More promising is to reduce risk through resilient technology such as drought and flood tolerant seed varieties. Uptake of SwarnaSub1 a superior rice technology with flood resilience is however still only adopted at 10-15% among farmers exposed to flooding in Orissa (Emerick et al., 2017). Also more promising is contingent credit lines indexed on events such as flooding as introduced by BRAC in Bangladesh (Lane et al., 2017). Altogether, however, uptake of risk-reducing options is low, again hitting at best the 30% ceiling. As multiple studies have shown, reducing risk when it is an effective constraint is important for technology adoption. It induces adjustments in farmer risk-management behavior that lead to higher investments and additional adoption in normal years.
- On markets, results show that profitability conditions vary widely over space and time (Rosenzweig and Udry, 2016). While markets tend to be relatively competitive (Dillon and Dambro, 2017; though this is contested by Bergquist, 2017, for Kenya), transaction costs can be huge due to poor infrastructure and limited information. Local markets tend to be shallow with the implication that prices collapse as soon as supply increases. Aggarwal et al. (2017) show that adoption of fertilizer in Tanzania is much lower in remote areas as input prices rise and product prices fall. Vandercasteelen et al. (2018) similarly find that proximity to a large city creates strong incentives to agricultural intensification and the use of modern inputs. In general, use of fertilizer is unlikely if the fertilizer/grain price ratio exceeds 4, i.e., if a farmer needs to produce on average more than 4 kg of grain for a kg of applied fertilizer. Yet, in many countries (Uganda) and especially in remote regions within country due to poor infrastructure, this ratio is well in excess of 4. Markets may also not reward quality, as with onions in Senegal due to lack of grading, which in turn discourages adoption of quality enhancing technological changes (Bernard et al., 2017). Finally, contracting in crops with local markets tends to be limited by the temptations of side-selling by producers and by hold-up behavior by commercial partners. Providing information to farmers about prices on markets may not help if there are high transaction costs on markets and incomplete value chain development (Fafchamps and Minten, 2012). Geographical market failures thus limit successful technology adoption to privileged locations, and hence to a subset of geographically privileged farmers, again possibly a potential 1/3.
- Finally on information, it is clear that learning in agriculture about the benefits of a new technology and the nature of the production function is both necessary for adoption and very difficult to achieve. This is due to heterogeneity of conditions in rainfed farming that limits social learning and to large annual fluctuations in weather conditions with short time horizons and eventually shifting probabilistic conditions under climate change.

Information is however key to adoption if what is offered is new and different (Glennerster and Suri, 2016). The traditional extension models simply has not worked as it can never be cost effective to individually service such a dispersed population with heterogenous needs for technological advice. As a consequence, access to traditional extension services is typically low, only reaching some 6% of farmers in India in spite of a strong national extension program (Glendenning et al., 2010). IT-based extension models are still in their infancy and have to deal with a poorly educated and ill equipped population. Entry points in social networks in choosing contact farmers (seed farmers) can make a difference. Multiple entries through the socially most central farmers in a community may be useful (Beaman et al., 2017). Large farmers have also proved repeatedly to be relatively more effective entry points (Emerick et al., 2018). Training and incentivizing contact farmers have also proved effective (BenYishay and Mobarak, 2017). Gaining information through social networks is however limited by heterogeneity of circumstances across farmers (Tjernström, 2016) and by communication breakdowns across genders and castes. Using agro-dealers as sources of information in value chains can complement what public extension agents do (Emerick et al., 2018). However, designing effective information systems for locally available new technologies still remains a huge challenge.

- A common difficulty for technology adoption under rainfed conditions is heterogeneity of circumstances and conditions. At the household level, this applies in three dimensions: Agro-ecological conditions, farmer objectives, and farmer capacity. If these dimensions are immutable or too costly to change, technological innovations must be customized to fit these dimensions.
- Farmer circumstances: Agro-ecological conditions vary widely over short distances and across years in particular regarding rainfall patterns and soil fertility (soil acidity, organic matter). For Zambia, Burke et al. (2017) show that only 8% of farmers can benefit from basal chemical fertilizer applications due to lack of a complementary factor, in this case lime to achieve the desirable level of soil acidity. In Western Kenya, Marenya and Barrett (2009) find that only 55% of plots can use chemical fertilizers profitably due to lack of a complementary factor, in this case soil organic matter as measured by carbon content. Barghava et al. (2018) similarly find that there is complementarity between soil organic carbon and modern inputs.
- Farmer objectives are different from breeders who typically focus on maximum yields in experimental plots, meaning highly favorable controlled conditions. Farmers, by contrast, maximize profit or utility to weight return and risk. They may also have labor calendar objectives such as labor-saving at peak periods and labor-smoothing in the rest of the year. Labor constraints may come from involvement in rural non-farm economy activities and seasonal migration, requiring to fit farming systems to accommodate complementarities between on- and off-farm engagements, including a gender division of tasks. The household will have nutritional objectives if part of the harvest is home consumed. These specific objectives must feed into the design of new customized technological innovations.
- Farmer capacity may be improved through the acquisition of information and skills, but other dimensions of capacity are fixed factors to which technological innovations must adapt. T.W. Schultz (1964) and Foster and Rosenzweig (2010) have shown that farmers' education matters for technology adoption. Low skills may reduce the capacity and the

speed of learning (Laajaj and Macours 2016). They may also affect the capacity to notice in using available information for decision-making (Hannah et al., xx). Again, limits on capacity must be taken into account on the supply side of technology if it cannot be addressed as a demand-side constraint that can be relaxed. Technology must be kept relatively simple to use. An example is SwarnaSub1 that requires the same agronomic practices as the widely used Swarna rice variety.

- It is thus possible that available technology is not adapted to the circumstances and demands of a majority of farmers. Either it has to be adapted to the lack of key complementary factors, or the complementary factors have to be jointly delivered as a technological package. The same applies to objectives and capacity. Unless this is done, lack of technological upgrading for a majority of farmers may not be an adoption issue (i.e., a demand-side constraint) but a supply-side issue concerning the existence, local availability, and information on technologies that are profitable and adoptable by the 2/3 farmers who are beyond the constrained demand problem. Lack of investment in R&D to address the specificity and heterogeneity of Sub-Saharan conditions noted above adds credibility to this interpretation. This is documented by Pardey et al. (2016) who show that there is both under-investment in agricultural research in SSA with an estimated average internal rate of return for 25 countries over the 1975-2014 period of 42%, and a continuing deterioration of the situation. Goyal and Nash (2016) observe a net decapitalization of agriculture R&D capacity in SSA over the last decade.

From Red to Blue strategy

- What extensive research done under ATAI-SPIA-Basis on the constraints to adoption of existing technologies (principally chemical fertilizers and improved seeds) reveals is that (1) there are indeed multiple constraints to adoption in the Sub-Saharan context, (2) these constraints can be identified and field experiments have been particularly useful for this purpose and to design strategies to overcome constraints, and (3) due to heterogeneity of circumstances under rainfed farming conditions, there is a ceiling to adoption that rarely exceeds 1/3. This poses the question of technological upgrading for the remaining 2/3. These limits to modernization using a supply-driven/demand-constrained approach have been observed by ATAI (Policy insights, 2017), Magruder (2017), and Macours (2017).
- We propose here a complementary strategy for the remaining 2/3 that reverses the causality of the technological upgrading problem from a supply-driven/demand-constrained approach to a demand-driven approach that guides the design of technological innovations. Using the INSEAD *Blue Ocean Strategy* framework (Kim and Mauborgne, 2005), we refer to the first as a Red strategy and to the second as a Blue strategy. Under the Blue approach, modernization requires offering technologies demanded by farmers customized to their heterogenous circumstances. We discuss the logic of this approach and how it could be implemented for the modernization of agriculture in Sub-Saharan Africa. The objective is to implement the AS-GR-AT-RT-ST sequence beyond the current adoption ceiling.
- The Red Ocean business strategy starts from the perspective of the supply side: there exist technologies (fertilizers, seeds) that can be profitable, are available for adoption, but are not fully adopted. It then works on the demand side: What are the effective constraints to the adoption of available technologies? What can be done to remove these constraints? This is the approach proposed in the initial ATAI whitepaper (Jack, 2011)

that identifies seven constraints to the adoption. A comprehensive update of results following the whitepaper approach is given by Bridle et al. (2018). Cutthroat competition in promoting adoption of existing technologies turns the ocean bloody red. ATAI field experiments have shown that this approach typically peaks at 1/3 of the farm population.

- By contrast, the Blue Ocean business strategy starts from the perspective of the demand side. It asks: who are the "extreme non-adopters" (i.e., those most likely to adopt existing technology given their circumstances, and yet not adopting) and why do they not adopt? What are the technology specifications for which they have a willingness-to-pay given their particular circumstances? Once demand is identified, the approach then works on the supply side: How to generate/adapt/customize agricultural technologies to what non-adopters of existing technology would like to adopt? How to make this particular technology locally available for adoption? How to provide information on this technology to farmers so they can understand it and eventually decide to adopt? With technologies not in existence today or not locally available and informed for adoption, but with effective demand and WTP, the ocean is free of competition, and still blue.
- The supply-driven (Red) vs. demand-driven (Blue) approach to technological upgrading has a precedent in agriculture with the Brader-Stoop debate sponsored by the CGIAR's Science Council (Brader, 2002; Stoop, 2002). Brader, a CGIAR center director general, argued that technology is available for adoption, but that it is held back by constraints on demand. Stoop, an extension specialist, argued that technology is not adapted to local conditions and to heterogenous farmers' circumstances, and hence that technological upgrading is held by lack of availability matching demand. The debate is summarized in Table 5.

	Lucas Brader: Red strategy	**Willem Stoop: Blue strategy**
	IITA Director General	Wageningen University agronomist
Observation	Low adoption and low yield gains if adopted	
Positive analysis: reasons for low adoption	**Supply-side**: technology is available for adoption. Eventually adopted, but low yield gains due to lack of access to complementary inputs (fertilizers, chemicals)	**Demand-side**: No demand for standardized technologies. Demand is for technologies adapted to local agro-ecological, socio-economic/cultural conditions which have huge heterogeneity
Normative response: strategy to increase adoption	**Demand side**: Increase adoption and yields by removing constraints on access to complementary inputs: trade policies, market infrastructure, financial services	**Supply-side**: Provide technology customized to local circumstances. Role of NARS and regional coordination (CORAF). Role of farmers and organizations for informal experimentation and participatory learning (Farmer Field Schools)

Table5. The Brader-Stoop debate on technology adoption

- In more recent times, the epitome of the Red approach to the technological modernization of agriculture has been the ATAI approach as guided by the original whitepaper. Inconsistencies in behavior is a first source of demand constraints that has been studied. Duflo et al. (2011) explored how time inconsistency in decision-making regarding the post-harvest purchase of fertilizers when liquidity is available and investment in fertilizers is profitable can be overcome through nudges in helping commit to future purchase. Hanna et al. (2014) showed that demand can be constrained by farmers' eventual failure to notice what matters in information available to them. Demand constraints originating in credit market failures have been explored by Field et al. (2013) for the flexibilization of microfinance schemes, de Janvry et al. (2010) for the role of improved information-sharing about borrowers among lenders to facilitate the use of dynamic incentives, and Burke et al. (2017) for the effectiveness of post-harvest loans that help farmers wait for higher prices on product markets. Constraints originating in insurance market failures have been explored by Carter et al. (2017), experimenting with ways of improving the design of index insurance, the availability of better data on weather risks, the marketing of the insurance product, and the delivery to farmers for example through group coverage (Powell et al., 2018). Constraints originating in product and input market failures have been explored by Aker (2012) for information to traders in Niger, Ashraf et al. (2009) and Casaburi and Reed (2017) for contracting in Kenya, Bergquist (2017) for competitiveness of traders in Kenya, and Bernard et al. (2017) for transparency and quality recognition of onions in Senegal. Innovations in institutional design have followed identification of these market constraints on demand, leading in general to the 1/3 achievement noted above.

- The potential payoff of a Blue approach has been evidenced by those who looked at the circumstances of non-adopters in spite of overcoming ATAI-type constraints. Those are farmers for whom the available technology does not offer sufficient profitability for them to decide on adoption in spite of constraint removal. This was noted by Marenya and Barrett (2009) for maize-bean producers in Western Kenya. The key complementary factor to the level of chemical fertilizer marginal value product is soil organic matter as measured by soil carbon content. In this case, no less than 45% of the plots cultivated by a random sample of farmers in the region could not use chemical fertilizers profitably at market prices. For them, a Blue approach would require packaging chemical fertilizer with applications of organic fertilizer such as animal manure or with recycling biomass from crop residues, green crops, or fallows. Low and variable profitability of chemical fertilizers for many farmers was also noted by Burke, Jayne, and Black (2017) for Zambia even when market constraints had been relaxed. In this case, response to chemical fertilizer is a complement to soil acidity. Chemical fertilizers can be applied either as top dressing urea or as a basal NPK compound. At market prices, only 8% of farmers can apply basal fertilizer and 64% top-dressing fertilizer given the state of soil acidity. In this case, the complementary factor is lime to improve soil pH or organic matter that can come from agronomic practices such as animal manure applications, green crop recycling, and agroforestry inter-cropping. Complementarity is also affected by microclimate, with considerable geospatial and annual heterogeneity. A key additional dimension of complementarity for technological upgrading is evidently water control (Dinar et al., 2008).
- The Blue approach in a sense stresses giving closer attention to the complementarity between agronomy and market factors, and to the need to elicit demand for technological innovations that correspond to the considerable heterogeneity of farmer circumstances, including their stochastic time variation. The technological response can either overcome the need for the missing complementary factor, such as developing crops adapted to low

soil carbon and acidity, or deliver the complementary factor as a joint package with the chemical fertilizer application. But it will also take new forms of precision agriculture with unexpected dimensions of desirable technological and institutional innovations. This is the challenge of implementing a Blue approach to go beyond what the Red approach can do.

- A Blue approach to technological upgrading starts with an assessment of potential users' needs in using an innovation in the context of their own particular overall objectives and circumstances (Norman, 1988). This is an approach typical of the User Experience Design (UXD) approach taught in business schools (Levine, Lesniewski, and Agogino, 2017). It uses an inter-disciplinary team to work with clients in finding out what their needs are for new products. It consists in interviews, observations, and surveys with private and social (governments, donors) users. In agriculture, it has been used under the form of participatory research and of the CIAL (Local Agricultural Research Committees) approach (Ashby and Sperling, 1995). This assessment is expected to generate insights and ideas for the design of a solution. If low profitability or high risk is an issue for farmers, it would result in their specification of desirable traits for new seeds and of the nature of complementary factors to fertilizer use. With heterogeneity of objectives (see the typology of farmers) and of circumstances (external validity), it would lead to demand for customized technological packages. If there are economies of scale in R&D, this will raise the issue of external validity, with the need to identify mega-domains over which the innovation can be used at scale. It can also be the case that mega-domains are insufficient in size or unable to mobilize effective demand for the innovation to be justified, requiring an orphan-good approach with corresponding donor subsidies. Once the demand for what designers (breeders, agronomists) have to satisfy has been identified, the Blue approach follows with the supply side, helping scientists satisfy demand within the innovation possibility frontier. If there are market failures and institutional gaps/voids that limit the demand for the innovation, constraints on adoption must be identified and overcome, following the Red approach.
- The proposed sequence for research on technological upgrading of SSA agriculture would thus be as in Figure 2, including both Blue and Red phases.

Blue phase

User Needs Assessment: observations, interviews, surveys, diagnostics

↓

Insights and ideas for the design of a solution

↓

Design on an innovation: prototype, business model

↓

Testing, willingness-to-pay experiment, piloting

↓

Fail fast, feedback, improvement, re-design

Red phase ↓

Adoption RCT: identification and removal of constraints

↓

Impact RCT and natural experiment: private and social,
including GE effects and dynamics (treadmill and transformations)

Figure 2. An approach to design, adoption, and impact analysis for technological upgrading

From adoption to transformation

- Much of past Red-style research has focused on the adoption of existing technological innovations (seeds, fertilizers) in support of a Green Revolution for Africa (AGRA), addressing the key constraints to adoption, namely credit, risk, information, land, labor, product and factor markets, and externalities. Extensive use has been made of an RCT approach for the rigorous identification of causalities. Pushing adoption beyond the typical 1/3 ceiling suggests using a Blue approach to characterize the demand for idiosyncratic innovations and the design of customized innovations that meet demand. We suggested a methodology to implement this approach.
- To address rural poverty in the context of rural areas, research must go beyond the Green Revolution and also address how to achieve an AT and a RT. Key to addressing the AT is to shift the research from crops to competitive farming systems that include high value crops (diversification) and to address the filling of labor and land calendars for rural households. This requires research on the creation and performance of value chains, the design of contracts for smallholder farmers (individually or collectively) in these chains, access to services for quality certification, etc. Important is access to water to extend labor calendars and allow the introduction of high value crops. Accessing water during dry seasons goes beyond water harvesting to enhance and secure yields. Infrastructure investments are needed and the management of water typically requires collective action (Ostrom, 1992). RCTs need to be complemented by the use of natural experiments as broader/meso transformations are at play and the time dimension can be substantial.
- Research on the RT needs to focus on the forward, backward, and final demand linkages to agriculture. Big-push effects with sectoral complementarities are important. This will typically require the use of natural experiments and structural modeling such as regional SAMs and CGEs. Emergence of land and labor markets, seasonal migration, growth of secondary towns, and local/territorial governance are important dimensions of a RT (Schejtman and Berdegué, 2004).

Conclusion

The WDR 2008 stressed the need for agriculture-based countries to invest more in agriculture in order for them to take advantage of its potential contributions to growth and poverty reduction. In the context of the food crisis, this effectively happened, but it has not been sustained. Today, the potential of agriculture for development is still incompletely captured. Extreme poverty remains extensive where agriculture has failed to deliver. The thesis of this paper is that many countries have tried to invest more in agriculture, but have met with difficulties in implementation and with disappointments in outcomes. Low quality of public expenditures in agriculture can be used to justify low quantity. The World Bank has argued that low quality came from extensive diversion of public expenditures toward private subsidies instead of public goods (Goyal and Nash, 2016). We argue additionally that public expenditures have not been met by unleashing technological upgrading and economic transformations beyond a modest ceiling due to the approach followed.

In the meantime, research has made significant advances in understanding how to use agriculture for development. This has been facilitated by better data, advances in research methods such as the use of field experiments to rigorously identify causalities, and donor support to this research. We discussed how lessons from research can be used to design a fresh start to investing in agriculture for development. This has led to identifying the sequence AS-GR-AT-RT-ST as a potentially effective strategy in using agriculture for development, tailored to heterogeneity of circumstances. The basic tenets of implementation are (1) taking stock of adoption research using a Red approach to overcome constraints originating in market failures and institutional gaps, (2) going beyond the adoption ceiling of a Red approach by pursuing a Blue approach to the design of new technologies that effectively meet unmet user demands in a context of considerable heterogeneity, and (3) going beyond access to assets (AS) and adoption toward a Green Revolution (GR), to the implementation of an AT and RT strategy. Research in support of AT and RT should make use of RCTs, but needs extend the use of methods to natural experiments and structural modeling due to the time and space dimensions of the transformations. It requires focusing on control over water to fill in labor and land calendars, and to the development of land and labor markets to facilitate gains in labor productivity. It requires focusing on value chain development and contracting for high value crops. And it requires going beyond agriculture to territorial development driven by labor release from agriculture and demand-led industrialization and services. This implies a better understanding of the role of governance both for local development and nationally in support of agriculture for development. The research agenda is thus broad, but with promise of helping achieve higher returns to investing in agriculture for development.

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