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Key factors for advancing innovations to scale: Evidence from multiple country case studies of agricultural innovations

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Innovation pathways can be defined as a sequence of innovation, going to scale, and implementation at sustainable scale, where innovation is a new product, service or systems change not previously introduced in a specific context. They can take the form of new products or services, institutions, or systems change. Such pathways can play a lead role in transforming agri-food systems in low- and middle-income countries. To get us to our global goals, these pathways have to lead to impact at a scale that matches the size of the challenge. Unfortunately, while there are many proposals in the published and gray literature for integrated, transformative approaches to innovation pathways, few have yet either gone to scale or been implemented sustainably at large scale. Here we assess whether there is evidence to support these proposals about how agricultural innovation pathways should be pursued. In this paper we identify from the literature and case studies 10 potentially key factors for advancing scaling along the innovation pathway: participation, inclusion, leadership, iteration, adaptation, the specific attributes of innovation design, funding models, implementation models, systems change, and partnerships. We test these factors against a collection of innovation and scaling case studies from Bangladesh, Brazil, India, Kenya, Senegal, Uganda, and Zambia. While the cases are somewhat limited in their quantitative measures of successful implementation at scale, the qualitative evidence presented in the cases confirms both the general importance of these factors in action and that their importance varies depending on the innovation and context. While confirmation of the importance of these factors is not surprising in itself, we also demonstrate their specific design and implementation (or absence) in different contexts, how each element contributes to success at large scale, and actionable examples to be applied in practice. The paper concludes that integrating these factors will likely require changes to traditional approaches to development, innovation and scaling in agri-food systems. Specifically advancing along an innovation pathway to large scale will require a commitment of greater resources over longer time horizons. In the absence of greater overall resources, this implies focusing on fewer innovations at each phase and a greater appetite for risk and failure in individual cases, suggesting adoption of a portfolio rather than a project approach in evaluating success. This may lead to more unsuccessful individual efforts, but those will be offset by a few transformative successes which will change the lives of hundreds of millions, if not billions.

KEYWORDS

innovation pathways, scaling, sustainable agricultural intensification, systems change, scaling up, case studies, agricultural innovation, bundling

1. Introduction

Innovation pathways are composed of a sequence of activities that start with basic innovations, continue with efforts to go to scale, and end with sustainable impact at large scale (see Figure 1 below).[1] Innovations are a new product, service or systems change not previously introduced in a specific context.[2] In recent years, however, the agri-food systems literature has seen mounting discussion on the poor performance of innovations in achieving their potential impact at scale, and sustainable agricultural intensification (SAI) in particular. This suggests that the study of what drives success, and failure, of innovations to advance along an innovation pathway is particularly timely.

While it is widely recognized that the innovation and particularly scaling parts of innovation pathways are flawed, diverse authors use different language to describe both the problem and the solutions. They may locate the problem in the innovation process itself, scaling, the way those two are sequenced and integrated, or how important aspects that contribute to success are missing or inadequate, e.g., the role of systems change or participation. Their proposed solutions are often similar in substance but presented in different terms: sustainable systems change at scale (Woltering et al., 2019); adaptive scaling (Minh et al., 2021); scaling principles (Kohl and Linn, 2021); sustainable intensification (Pretty et al., 2011); end-to-end innovation (Koerner and Duda, 2021); scaling science (Shilombenia et al., 2019); bundling innovations (Barrett et al., 2020); agro-ecology; agricultural innovation systems; social-ecological systems; or political ecology (all covered in Foran et al., 2014).

There are three reasons why this discussion is happening so broadly right now. First and foremost, there is a consensus that innovation can play a lead role in transforming agri-food systems in low- and middle-income countries (see, for example, World Bank, 2019; Butler, 2021; Khan et al., 2021). Secondly, this belief has been accompanied by significantly increased investments in agri-food innovations following the food crisis of 2007–2008. These investments has been heavily influenced by the increased prominence of the technology sector in the global economy overall. There has been a particular focus on technology innovations as a way of circumventing the resource, institutional and governance challenges that have made achieving large-scale impact in low-resource settings challenging.

Lastly, it is generally acknowledged that if the current rate of progress toward the Sustainable Development Goals—particularly those that relate to agriculture, nutrition and food security—continues, those goals will not be met in most lower-income countries (see FAO, 2021). The same is true for addressing and reducing agri-food systems' contribution to climate change and achieving the Paris Agreement's objectives. This has created a global sense of urgency and recognition that existing approaches are not working. Given that vastly increased resources are not likely to be forthcoming to fill the gap, better approaches to innovation and scaling are needed that achieve much greater impact with existing resources. This implies either greater efficiency and effectiveness in the innovation and scaling process itself, or achieving economies of scale at scale. These are among several issues we address in this paper.

1.1. A new consensus on scaling innovations

The numerous reforms that authors have proposed in response have several claims in common:

- For innovation to be meaningful it should lead to sustainable change at *large scale*. Large scale needs to be defined relative to the size of the problem or the denominator: millions reached, while important for those people, is irrelevant if the problem affects and SDG goals involvebillions of people.
- This needs to occur through a combination of scaling of technological innovations in products or services and *systems changes and institutional innovations*. It is a rare case where scaling of an innovation occurs without systems change. At best, when scaling is defined in its narrowest sense of getting more end users to adopt an innovation, the innovation is likely to be limited impact in terms of sustainability or addressing other issues besides productivity and food security, such as nutrition, health, income inequality, gender equity, and environmental sustainability. It may also have unintended negative consequences, especially if complexity is ignored.
- The need for *systems changes and institutional innovations*, either as stand-alone changes, or as accompanying traditional innovations in products and services, implies that the traditional diffusion of innovation pathway and success criteria, e.g., innovative adopters, early adopters, early majority, etc. is only relevant to some types of innovations and innovation pathways. More importantly, the diffusion of innovation approach doesn't take into account the need for systems change, the role of context or differences between scaling of tangible vs. intangible (components of) innovations e.g., products vs. behavior change. If anything by focusing on the number of adopters encourages neglect of both the need for systems change and the need to put in place institutional, individual behavioral and changes in community and social norms. These can be invaluable for large scale impact on their own or so as to facilitate spontaneous growth in the number

1 It is common in the literature to see innovation and scaling as anywhere from a three to six phase process. For example, the International Development Innovation Alliance (IDIA), a consortium of international development funders, uses six: (i) Ideation; (ii) Research and Development; (iii) Proof of Concept; (iv) Transition to Scale; (v) Scaling; and (vi) Sustainable Scale. For the purposes of this article, three phases suffice; our Innovation phase contains IDIA phases 1–3, Going to Scale contains IDIA phases 4 and 5, and Sustainable Implementation is equivalent to the IDIA phase 6. See International Development Innovation Alliance (IDIA) (2017).

2 This definition of innovation is also taken from the International Development Innovation Alliance (IDIA), which defines innovation as "a solution new to a given context with the transformative ability to increase impact". See International Development Innovation Alliance (IDIA).

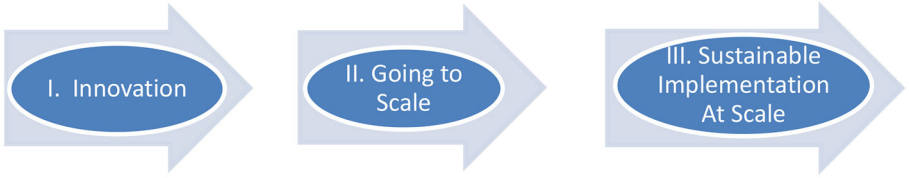

FIGURE 1
Three phase approach to scaling.

of adopters of products and services as well as sustainability. It also neglects necessary tradeoffs between numbers, impact, sustainability, equity and other factors like participation (e.g., LaMorte, 2022).

- Rather than scale in the narrow sense of numbers of adopters, the goal needs to be *optimal scale* to sustain systems change, recognizing that there are necessary trade-offs between multi-dimensional impact, scale, sustainability and equity.
- Last and most importantly, the *innovation process itself* needs to integrate considerations of scaling, systems change and institutional innovation. From the very start of the pathway, innovation processes need to "treat scaling as a systemic change process" (Minh et al., 2021).

An implication of the consensus is that the development of an innovation needs to start with analyzing systems, clearly identifying the problem(s) to be addressed and setting a vision and clear goals as to what sustainable large-scale change might look like, especially in terms of resources and implementation or delivery capacity (Hubeau et al., 2017; Klerkx and Begemann, 2020). The various phases of problem definition, innovation, scaling and institutionalization need to be both adaptive and iterative *and* participatory and inclusive so as to be effective in achieving impact, responding to demand and local circumstances, and accomplishing the necessary local buy-in and ownership (Table 1).

This requires specific kinds of leadership, well-resourced intermediary actors who facilitate scaling—i.e., helping innovations cross the "valley of death" between pilots and proof-of-concept and institutionalization, champions, and some form of multi-stakeholder consultative process. At the same time, it is necessary to recognize that increased attention to complexity, systems change, participation and equity can greatly increase the time, effort and resources required to do all of this and needs to find a reasonable balance (see Seelos, 2020; Kohl and Linn, 2021; Seelos et al., 2021; Starr, 2021).

2. Materials and methods

Unfortunately, few proposals for an integrated broad, inclusive, transformative systemic approach have actually been implemented at large scale. They have certainly not been tested with multiple types of innovations in different contexts. Even if such applied research is under way, scaling and systems change is commonly acknowledged to take 10–15 years. It is still too early to assess whether (or under what circumstances) such research can shed light on the claims and methodologies.

We have taken at least a first step in terms of assessing whether there is evidence to support proposals about how agricultural innovation pathways should be pursued, and what those hypotheses look like beyond high-level generalizations. We started by looking at the recent literature that proposes principles and approaches to achieving large-scale SAI in agri-food systems. While most of these sources propose comprehensive approaches, we disaggregated these into individual components and drew out six testable hypotheses (Table 2):

1. Innovation pathways must be participatory and inclusive.
2. Leaders, intermediaries and champions are key to innovation pathways.[3]
3. Innovation pathways should be iterative, adaptive and flexible.
4. Innovations should have characteristics that facilitate progress along innovation pathways and achieving large-scale SAI.
5. Innovations must be packaged with viable funding and implementation models and bundled with systems change.[4]
6. Partnerships are critical for innovation, scaling and systems change.

While some of these hypotheses are not new, this study and the underlying case studies upon which it draws, adds value by describing how these principles were, or were not, applied in practice, and what the consequences were. This institutional detail will provide the reader with some examples to follow in implementing these principles, should they so choose.

We then looked to case studies of innovation pathways, trajectories, scaling and other attempts at achieving large-scale SAI (Table 3). Our first source of cases was three country studies—from Brazil (Chiodi Bachion et al., 2022), India (Khandelwal et al., 2022) and Kenya (Mati et al., 2022)—commissioned by the Commission on Sustainable Agriculture Intensification (CoSAI), each of which contained three to four individual cases. All of these cases were

3 These are defined under Hypothesis 2 in Results. Intermediaries fulfill brokering and scaling roles where innovators might lack the skills, capacity, resources, motivation or incentives. Champions are people in a position to influence the behavior of others in the relevant sphere.

4 Packaging and bundling are defined under Hypothesis 5. These are used, with overlapping meanings, in referring to elements of an innovation beyond a single core technology or institutional characteristic. We use packaging to refer to funding and implementation models and bundling to refer to systems change. Other literature may use the same words for combinations of technical innovations, which is not the intended meaning in this paper.

TABLE 1 Changes needed in three phases of innovation pathways to improve outcomes.

Innovation process itself	Going to scale	Sustainable implementation at scale
• Integrate scale and systems change into the innovation process itself	• Accompanied by systems change to allow for sustainability and maximize impact	• Must reach LARGE scale, signifincan share of the problem
• Start with defining large scale goals and a scaling strategy	• Recognize that scaling is a dynamic and emergent process	• Make trade-offis between impact, scale, sustainability & equity i.e. optimal scale
• Leadership and champions are essential in all three phases		
• Partnerships are important in all three phases, and importance increases from Phase I to II to III		
• Participation, Inclusion and creating local buyin and ownership is necessary in all three phases		
• Expect that scaling is a funnel, with a steadily decreasing percentage of innovations achieving Phase III. Requires greater tolerance for risk in innovation; higher risk should yield higher returns on aggregate in terms of scale		
• Analyze with systems at large scale, align with constraints	• Follows an adaptive, iterative, participatory and inclusive strategy	• Achieve economies of scale
• Align with known criteria that facilitate scaling and sustainability	• Is inherently political, requires achieving buy-in and ownership	• Sustainabiliy involves financing and other resources, implementation capacity, and political
	• Intermediaries are necessary with scaling-specific skills and resources	• Sustainable financing implies a viable business model or funding aligned with fiscal resources

identified by the study authors based on several criteria developed by COSIA, perhaps which the most important that there was clear evidence of ongoing adoption and utilization of innovations at large scale, i.e., sustainability. These case studies have strengths and weaknesses: they provide valuable insights and detailed stories and examples of how these factors apply to innovation pathways. While the study authors did attempt to assess the role of local context and conditions, since all of these cases only occurred in one country, this does not allow for any conclusions about cross-country (or context) replicability of the approaches used (in one of the Brazilian cases, the approach was scaled up to both other sub-sectors in agriculture and to other Latin American countries). That said, the study authors all did comment that relatively strong public sector capacity did likely play an important role in Brazil and India, and strength of Kenya's agricultural market systems and institutions, at least as compared to the rest of East Africa, were similarly important.

At the same time, they are largely qualitative in nature. The quantitative data they contain on issues like costs, unit costs, impact on productivity or other outcomes, the scale reached and how that compares with potential scale, is often missing or at best uneven.[5] Even guestimates of scale reached would suggest that in terms of direct participants, it is likely that in none of these cases did the innovation reach a scale of more than 15% of total potential, and in most cases probably <5%. As in traditional diffusion of innovation frameworks "innovators" are the first 2.5% of adopters, and "early adopters" are the next 13.5%, these innovations at the very best all innovators and early adopters, let alone an early majority. However such figures can be misleading; the lack of accurate data is further complicated by the fact that potential adopters who did not themselves participate in the program may have benefited because they learned from the example of their neighbor.[6] Measuring scale is particularly challenging when an innovation has multiple components; neighbors may have adopted some parts of an innovation package but not others. A similar question arise for both direct and indirect adopters regarding sustainability; for how many years or seasons must an adopter continue to practice or implement an innovation for it be counted as "adopted"? In the absence of truly thorough, ongoing evaluations, we have no way of knowing the extent of spontaneous or indirect adoption and scaling, whether the whole package or individual components are adopted, and for what period.[7]

Our second source was a set of five case studies commissioned by the United States Agency for International Development (USAID) Bureau of Resilience and Food Security, similarly seeking to identify drivers of successful scaling of agricultural innovations (Foy and Wafula, 2016; Kohl, 2016a,b,c; Foy, 2017). Because these

5 This is explained by the fact that these studies deliberately looked at scaling through public or private pathways but not development projects funded by international donors; the latter often do much more extensive monitoring and evaluation than the public sector. Private data is often proprietary and either completely unavailable to researchers as well as, in many cases, require gathering it from multiple enterprises, e.g., solar irrigation pumps in Kenya.

6 For example, the One Land and Two Waters model in Brazil was replicated by municipal governments, but those figures were never counted in national totals.

7 For example, Balde Cheio in Brazil assisted dairy farmers in improving production. It contained six *categories* of intervention: fodder production; production systems; farm management; genetics; agronomics; and administration issues. Each category in turn contained multiple activities and options. There are roughly one million dairy farms in Brazil. Balde Cheio began in 2003 and continues to this day, working in 21 of Brazil's 26 states. In any given year the program was working with between 500 and over 4,000 farmers, with 3–4,000 in the peak years of 2009–2013 and 1,626 farms in 2020, the most recent year for which data is available. As the annual totals include farms from previous and future years, there is no accurate estimate in the study of the total number of farmers reached; a generous guestimate would put the total number of farmers *participating* at a maximum of 40,000, or four percent of the total dairy farms. However if 3–4–5 or more farms learned from participants, the impact could have affected 12%–20% of dairy farms or more.

TABLE 2 Hypotheses considered and tested.

Hypothesis	Evidence available from cases	Evidence supports/ contradicts	Decision
Innovation should follow a planned, explicit, well-thought-out and **deliberate process** based on identification of the problem (**mission driven**), **a solution** and **a clear theory of change**	No	Not Relevant	Not assessed
Innovation pathways should **begin with the end in mind**	Some	Unclear	Not assessed
Innovation pathways should specify **what** is being scaled or effecting systems change, a **vision** of scale/impact, and a **clear strategy and pathway** to achieve them	Little	Unclear	Not assessed
Innovation pathways must be **participatory and inclusive** from the beginning, especially of end users, in terms of co-creation of innovations and/or systems changes, and identifying a vision and goals for large-scale change	Yes	Supports	Assessed (#1)
Leaders, intermediaries and champions are critical to successfully achieving sustainable impact at large scale	Some	Supports	Assessed (#2)
Innovation pathways should be **iterative, adaptive and flexible** using rapid testing and failing fast apply a cycle of experimentation, learning and strategic adjustments	Yes	Supports	Assessed (#3)
Innovations should have **characteristics aligned with criteria that facilitate scalability,** especially the needs, context and constraints faced by end users	Yes	Supports	Assessed (#4)
Institutional and individual **incentives** of all stakeholders, from end users to private value chain actors and the public sector, **must be aligned** with innovation and scaling goals	Some	Supports	Not assessed
Viable financial and/or business models and **implementation mechanisms** are necessary; product and service innovations need to be packaged with financing and delivery mechanisms. **Who** will play key roles of Payer and Doer (operationalizing or implementing) needs to be specified	Yes	Supports	Combined into one hypothesis (#5)
Innovations must be **bundled** with analysis and changes in markets, value chains and policy enabling environment institutions and systems	Yes	Supports	
Analyze systems taking into account complexity and unintended consequences. Identify **systemic opportunities, constraints and risks**; plan to align with them or address them through system change along the scaling pathway	Some	Supports	
Partnerships are critical to innovation pathways, both for innovation, systems change and scaling; bringing multiple perspectives to the table; mobilizing resources beyond those of one actor; and aligning incentives and political support	Yes	Supports	Assessed (#6)
Social capital needs to be leveraged and/or created where necessary e.g., farmers' organizations, women's organizations	Yes	Supports	Not assessed
Diverse types of **evidence** are necessary for successful scaling and innovation well beyond standard proof of concept or proof of impact	Some	Mixed	Not assessed
Innovation and scaling affect, and are affected, by **considerations of power, equity and other ethics**. These should be considered in addition to impact on goals like productivity, income and food security	No	Not Relevant	Not assessed

studies cover only one innovation or group of related innovateons and interventions, were both of USAID projects and financed by USAID projects, they have much greater depth. Nonetheless, even though the initial intention was to include in these studies estimates of scale achieved, how that compared to normal diffusion of innovation curves, and what that implied for tipping points, they were not able to achieve that goal. The USAID projects themselves, despite a huge investment in monitoring and evaluation, did not collect the necessary data to provide even rough estimates of scale and tipping points. For the sake of brevity, for each hypothesis tested below, we give examples from only those cases which seem to be have the most significant evidence.

Our chosen case studies are not examples of perfect success in taking innovation pathways to scale. While some have reached 5 or 10% of potential users, others have only scaled to much smaller levels. Nonetheless all reached or affected thousands of people or farms and in many cases this was in the tens or hundreds of thousands. Indeed, an important finding of our review is that most scaling efforts lack either a vision or measure of success,[8] rather they have tended to make it up as they go along, with reaching "more" people in places being the operative phrase in those cases where there were deliberate scaling efforts and strategies. While the majority of cases had scaling strategies in some operational sense, most were not based on any explicit set of principles, factors or a strategic approach in advancing innovations along scaling pathways (the Bangladesh and Senegal USAID cases did embody such factors). Despite these considerations, we believe that the

8 In none of the CoSAI studies and only two of the five USAID studies did the scaling efforts have explicit vision or goals for success; the Brazilian government did consider the three public sector cases as successes though it is not clear what the criteria for that assessment was.

TABLE 3 Summary of cases.

Case	Innovating organization	Innovation package type and description
Balde Cheio—Full Bucket *Brazil 1998–*	Brazil Agricultural Research Corporation (Embrapa)	**Innovative extension approach.** Farmer-oriented innovation program with an experimental and incremental approach to improve dairy productivity by training local rural extension technicians, using farms as schools
One Land Two Waters (P1+2) *Brazil 2007–*	Articulation in the Semiarid Region (ASA), One Million Cisterns (AP1MC), Ministry of Social Development	**Technology, social capital.** Improved water access through harvesting and storage for farming
Integrated Livestock, Crops and Forestry *Brazil 2008–*	Embrapa, ILPF Network	**Integrated technology.** An integrated approach for livestock and crop production (ILP), in some cases also adding forests (ILPF)
Aqua Digital Irrigation Monitoring System *Brazil 2014–*	Agrosmart	**Technology, extension.** Digital monitoring irrigation system with a platform to support farmer decisions
Andhra Pradesh Natural Farming *India 2016–*	Rythu Sadhikara Samstha (RySS) (farmers' empowerment association)	**Integrated technology.** Distributed innovation to decrease or eliminate agrochemical use and adopt zero budget natural farming
Safe Harvest *India 2009–*	Safe Harvest (triple bottom line private company)	**Production, market links.** A farm-to-kitchen model for certified pesticide-free food, supporting farmers
Trustea *India 2013–*	Consortium of private tea processors and sellers with support from NGOs	**Production, standards, market links.** Verifiable standards for sustainable tea production, along with extension and capacity support for farmers
Water Harvesting *Kenya 2009–*	External innovation promoted by NGOs and county governments	**Technology.** Water storage ponds for irrigation
Solar Powered Irrigation *Kenya 2005–2021*	External innovation with multiple private sector variations	**Technology, finance.** Solar powered pumps and panels, sometimes combined in kits, and some innovative financing.
Upper Tana–Nairobi Water Fund *Kenya 2012–2020*	Multistakeholder: county governments, private sector, NGOs (Nature Conservancy)	**Technology, finance.** Partnership and coordination mechanism between water and land users to promote water conservation and management through blended financing
Sahel Rice *Senegal 2009–2015*	AfricaRice, Projet Croissance Economique (PCE)	**Technology.** Interventions to realize the production potential of improved varieties of rice that were first introduced and scaled in the 1990s
Purdue Improved Crop Storage Bags *Kenya 2013–2018*	Purdue University	**Technology.** Large hermetically sealed bags for post-harvest storage to reduce losses due to moisture, mold and rot
Kuroiler Chickens *Uganda 2010–2017*	Arizona State University, Ugandan National Animal Genetic Resource Center	**Technology.** A hybrid chicken breed introduced from India, with much higher meat and egg production in a shorter time period than local chickens
Drought Tolerant Maize for Africa/Hybrid Maize *Zambia 2006–2015*	International Maize and Wheat Improvement Center (CIMMYT), International Institute of Tropical Agriculture (IITA), African national research agencies	**Technology.** Over 200 hybrid and open pollinated maize varieties that are able to tolerate some drought conditions during certain periods of the growing season
Mechanization Initiative *Bangladesh 2013–2018*	iDE, CIMMYT, IRI; scaling by CIMMYT's Cereal Systems Initiative for South Asia (CSISA) in partnership with private machinery producers/importers	**Technology.** Innovations to improve rice production or allow for greater uptake of maize and wheat production through irrigation and cost, time and labor savings: a reaper, improved irrigation pump, planter/tiller attachment for two-wheeled tractors and a bed planter, which improved on existing machinery or replaced hand labor

progress and scale achieved, as well as the problems observed, combined to yield important insights and provide sufficient support for the conclusions drawn to be considered seriously.

The principles by which innovation pathways should be followed and connected with systems change—even those widely assumed to be important and promoted at length—are still rarely deployed to an adequate extent in any conscious, explicit or strategic sense at that was true in these cases as well, with the noted exceptions of Bangladesh and Senegal. Similarly, there is little empirical evidence on whether these fatores are in fact applicable to scaling of innovations in different contexts. Certainly factors like the relatively strong state capacity, leadership and fiscal resources

in India and Brazil is less present in low-income countries in Sub-Saharan Africa or elsewhere, and that was noted in those studies. The testing of hypotheses in this paper is only a first step in filling those gaps and projects and action research to test the replicability of these factors in different contexts, or when explicitly serving as the basis for innovation and scaling strategy, is sorely needed.

Notwithstanding all of these caveats, the case study analysis strongly suggests that the six hypotheses are indeed important to innovations moving successfully along innovation pathways and achieving large-scale SAI. While this is not surprising in itself, our intention below is to investigate their specific design and implementation (or absence) in the cases, providing examples and counter-examples of practice that contribute to success, to derive more useful conclusions about how each element contributes.

3. Results

3.1. Support to Hypothesis 1: Innovation pathways must be participatory and inclusive

Participatory agricultural research, and more broadly participatory rural development, have a literature going back to at least the early 1980s. In each decade since, a review of the literature reveals advocates calling for greater participation by end users in agricultural research for normative, ethical and instrumental reasons. Focusing on participation as a means to other ends, advocates argue that local stakeholders need to be incorporated because they have a better understanding of local needs, demands, contexts, conditions and existing practices, especially when natural resource management is at issue. At the same time, participation can be time-consuming, costly, and opposed by technical experts. While widely acknowledged by leading funders of development as important, the extent to which this is empirically true, how it is practiced in scaling in particular, and the extent to which it actually makes a difference in ultimate outcomes, is still the subject of debate.

Application of participation to agricultural innovation pathways has at a minimum meant that farmers are consulted in the innovation process, and more and more are part of learning alliances and the identification and/or co-creation of promising innovations and their testing.[9] They also participate in analysis of the larger systems as the foundation for subsequent decisions about what is to be scaled or about systems changes.

Participation in innovation and scaling can vary widely from consultation to being informed to having real power in the design of innovations and scaling strategies, as well the implementation of those strategies. This variety was very much present in the cases reviewed for this study. The extent to which our cases seemed to support or contradict this hypothesis, alongside the other hypotheses to follow, is illustrated in Table 4.

P1 + 2 (Brazil) (Chiodi Bachion et al., 2022) was the most participatory of the Brazilian public sector pathway cases, a social technology program driven by the mobilization and organization of family farmers, rural communities, the social movement ASA[10] and other civil society actors. Its express goal was "democratizing, accessing and building technological solutions that advance social inclusion". Chiodi Bachion et al. (2022) characterize the choice of technologies as a "bottom-up innovation process" that started with a number of technologies and the knowledge of local people that were then assessed and selectively chosen by public sector technicians based on their costs, longevity and benefits. The process was at least action-oriented for individual farmers, and social organizations had a clear say in decision making. Social mobilization and collective training were key parts of scaling. As a result of inclusion, innovations were highly relevant to the specific needs of people living in the semiarid region, especially increasing their resilience to food insecurity and climate change. Similarly, because of the participatory training, families understood the importance of maintaining cisterns for food security and income generation, so sustainability was a hallmark of the program.

Aqua Digital Monitoring Irrigation System (Brazil) (Chiodi Bachion et al., 2022) saw the start-up Agrosmart include early adopters—mostly large farmers—in the initial demonstration of results and subsequent adjustments. These participants conducted pilot tests and provided feedback to improve the monitoring system and its usability. In scaling up, Agrosmart retained an unofficial committee of test customers for each of their products and kept weekly contact with these farmers, who were rewarded with the opportunity to customize the service to their needs. As a result, Agrosmart's products were aligned with the specific needs and requirements of its customers.

Andhra Pradesh Natural Farming (India) (Khandelwal et al., 2022) combined technological chemical-free practices and traditional methods for increasing productivity and resilience with social technologies such as community mobilization and empowerment. For this the program used a distributed innovation approach in which "farmers become experimenters and innovators to find solutions suitable to their context" (Khandelwal et al., 2022) and a farmer-to-farmer extension model to diffuse and scale the innovations to more farmers. It was successful in lowering input quantities and therefore costs, and had clear environmental benefits. The combination of a farmer-driven design and the inclusive farmer-to-farmer diffusion approach increased the willingness of farmers to try the innovation, allowed for scaling to farmers not directly participating in training, vastly increasing its coverage.

Sahel Rice (Senegal) (Kohl, 2016c) featured the greatest involvement of end users among the five USAID cases. All of the implementation was done working closely with farmers' organizations, in this case irrigation user groups. The development of institutional innovations such as an innovative financing mechanism was done in close consultation with

9 See World Bank (2012, p. 440): "Considerable progress has been achieved in giving farmers access to innovation resources and in building their capacity." This publication also emphasizes the growing role of innovation funds available to local farmers or farmer organizations.

10 ASA was a full partner in goals, strategies and large-scale implementation. ASA is a network of more than 3,000 different types of civil society organizations, such as rural workers' unions, farmers' associations, cooperatives and NGOs.

TABLE 4 Support to hypotheses 1–6.

Case	Support to hypothesis						
	1	2	3	4	5-P	5-B	6
Balde Cheio, Brazil	Some support	Strong support	Strong support	Some support	Unclear support	Unclear support	Strong support
P1+2, Brazil	Strong support	Some support	Some support	Some support	Strong support	Some support	Strong support
ILPF, Brazil	Some support	Some support	Strong support	Some support	Counter-example	Strong support	Some support
Aqua Digital Monitoring Irrigation System, Brazil	Strong support	Some support	Some support	Some support	Strong support	Unclear support	Unclear support
Andhra Pradesh Natural Farming, India	Strong support	Strong support	Strong support	Strong support	Some support	Unclear support	Some support
Safe Harvest, India	Some support	Some support	No significant evidence	Some support	Some support	Unclear support	Some support
Trustea, India	Contradicts	Some support	No significant evidence	Some support	Some support	Unclear support	Strong support
Water Harvesting, Kenya	Some support	Unclear support	No significant evidence	Strong support	Counter-example	Unclear support	Some support
Solar Powered Irrigation, Kenya	No significant evidence	Unclear support	Some support	Strong support	Some support	Unclear support	Unclear support
Upper Tana–Nairobi Water Fund, Kenya	Some support	Some support	Some support	No significant evidence	Strong support	Unclear support	Strong support
Sahel Rice, Senegal	Strong support	Strong support	Strong support	Some support	Strong support	Strong support	Strong support
PICS Bags, Kenya	No significant evidence	Unclear support	No significant evidence	Strong support	Contradicts	Contradicts	No significant evidence
Kuroiler Chickens, Uganda	Counter-example	Strong support	Counter-example	Some support	Counter-example	Unclear support	Strong support
Drought Tolerant Maize for Africa/Hybrid Maize, Zambia	No significant evidence	Counter-example	No significant evidence	Counter-example	Strong support	Strong support	Strong support
Mechanization Initiative, Bangladesh	Counter-example	Some support	Strong support	Strong support	Strong support	Unclear support	Strong support

Hypothesis 5 is divided into sub-hypotheses on packaging (5-P) and bundling (5-B).

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farmers, rice millers, wholesale buyers and financial institutions. Farmers' organizations themselves also played the role of social entrepreneurs, developing and implementing solutions to obstacles, with USAID support and facilitation, within the rice value chain as they arose. The results of this inclusive approach was to ensure local ownership and particularly financial sustainability once donor investments ended, and to catalyze a virtuous spiral of farmers' organizations systematically addressing new challenges as scale increased.

Kuroiler Chickens (Uganda) is one telling counter-example where farmers were not involved to any degree in the initial selection and testing of technical innovations. According to Foy (2017) this proved problematic as changing from domestic breeds to Kuroilers required poultry farmers to adopt new chicken-rearing practices. At least initially, many farmers were either ignorant or misunderstood the changes required, or couldn't afford them; as a result some early adopters suffered heavy or complete losses. For example, farmers bred Kuroilers with domestic chickens, as they always had, yet as F1 hybrids the characteristics quickly disappeared in subsequent generations. In addition to the lack of inclusion of end users, the reach and resources of public extension systems were too limited to provide adequate support, meaning farmers had no one to help them deal with the problems. The **Mechanization Initiative (CSISA-MI[11] in Bangladesh)** (Kohl, 2016b) encountered a similar pitfall when four types of machines were initially imported to meet farmers' needs but they were not involved in the initial selection or testing of the machines. Project staff had to spend a few years retroactively modifying and adapting the machines using user-centered design principles, and only ended up with two of the four machines being ones that had long-term mass appeal to small farmers.

Trustea (India) (Khandelwal et al., 2022) seemed to treat farmers' organizations as passive recipients of technology packages delivered through technical assistance and extension by experts, rather than empowering farmers as innovators or as agents of diffusion. Yet participation was not, perhaps, as necessary here because this was largely a top-down diffusion of technology to produce for a market that Trustea created. While this was not strictly a case of "contract farming" it was similar, and suggests that participation and inclusion might be less important in cases where commercial actors are supplying both the technology and the market, rather than targeting food security and poverty among small farmers.

3.2. Support to Hypothesis 2: Leaders, intermediaries and champions are key to innovation pathways

Leadership is widely seen as essential to innovation pathways. Kohl and Linn (2021) specify three types of leadership as essential to scaling in particular. One type, what they refer to as *leaders*, are actors who are "committed to seeing scaling through to success, willing to make decisions, and able to mobilize others to support of scaling goals, strategy and tactics." A second type, what they call *intermediaries*, engage in "undertaking or facilitating activities like convening, systems analysis, boundary spanning, strategic planning and goal setting, advocacy and communication, process facilitation and people management, networking and coordinating, monitoring and evaluation, and financial and costing analysis."[12] Kohl and Linn, and especially other literature references *champions*,[13] people of influence in the relevant sphere because of their social status, position, power, control of or access to resources, connections and social network, or other forms of legitimacy that allow them to influence others. Many of the cases strongly illustrate the importance of leadership, particularly intermediaries.

Balde Cheio (Brazil) (Chiodi Bachion et al., 2022) had Embrapa as its lead agency, and one particular individual was cited as "the initiative's major unifying factor, because of his tremendous charisma, passion for the subject, proactivity, easy communication with farmers, great motivational skills, and solid theoretical and practical knowledge" (Chiodi Bachion et al., 2022). These comments imply that the relevant leadership skills were *technical*, to guide the innovation process; *personal*, to inspire innovators with an idea and potential impact; networking and advocacy, to mobilize and engage with partners; and *boundary spanning*, to effectively facilitate collaboration and cooperation between diverse actors and constituencies, and particularly to form

11 Cereal systems initiative for South Asia—Mechanization and irrigation.

12 Intermediaries are similar to the concept of brokers introduced by Klerkx and Gildemacher (2012) (see also Klerkx et al., 2009), but much more broadly defined. Klerkx and Gildemacher assign brokers three principal roles in innovation: bringing together actors, facilitating their interaction (including building coalitions or partnerships), and promoting the flow of information. As applied to the scaling phase, we find that intermediaries do play these roles *and also* undertake many other tasks that innovators might lack the skills, capacity, resources, motivation or incentives to do. This concept was first developed by Cooley and Kohl (2005), simultaneously with a similar concept, the resource team, developed by WHO ExpandNet (2010) in their scaling approach. As an example, Klerkx and Gildemacher (2012, Box 3.25) call iDE a broker in the same case we refer to here as the Mechanization Initiative in Bangladesh. We agree, but maintain that iDE went much further: it arranged partnerships with agricultural machinery companies, managed those relationships, promoted demand, refined the business and delivery model, advocated with the government for political and in-kind support and cooperation, developed the local service provider business case, identified local entrepreneurs to act as service providers, and arranged microfinance support. In roles like these intermediaries come closer to the role that venture capitalists play in helping investments go to scale, except they don't bring investment capital with them.

13 Champions are particularly present in the literature on scaling and impact pathways in global health, where the public sector plays a large role and advocacy for policy and budget are necessary. However, they also appear in agriculture and other more commercial sectors. They play a prominent role in the widely used ExpandNet/WHO scaling framework; see Simmons et al. (2021), who note, "one of the key principles from ExpandNet guidance is to seek to identify and nurture champions and to engage them early and continuously in ongoing dialogue" and the need to sustain support in the face of turnover by high level champions. See also Kohl and Linn (2021), for whom champions are closely linked to participation and inclusion; the greater the latter, the more champions can be identified with the motivation to advocate for the innovation.

and manage effective partnerships. However, it is not possible to determine how much of a role each played. What is clear is that Balde Cheio would not have been successful and replicated to other sectors in agriculture without "the strong leadership of Embrapa researchers … from its inception to the present … building a clear vision of the organization's potential and [addressing] the problems around technology transfer."

Andhra Pradesh Natural Farming (India) (Khandelwal et al., 2022) hinged on leadership both at the top of RySS (the organization driving the innovation and scaling), and at the community level. Looking more closely at the community level, this type of leadership comprised local farmers who championed the approach, served as examples to other farmers, and shared the technology and practices and helped adapt it as needed. A role for champions was particularly appropriate for a distributed innovation approach and farmer-to-farmer dissemination and scaling. Kohl and Linn (2021) explicitly acknowledge this role in calling to "complement leaders with champions at all levels and parts of the ecosystem to support advocacy."

Aqua Digital Irrigation Monitoring System (Brazil) (Chiodi Bachion et al., 2022) was developed by a business administrator, a graphic designer and an electrical and electronics engineer who came up with the innovation, created a company and mobilized funding. The CEO has been particularly important in media, marketing and fundraising, drawing on her skills as a speaker and communicator. This type of leadership seems to be particularly important in the cases of scaling that occurs through social enterprise growth. **Safe Harvest (India)** (Khandelwal et al., 2022) is another example of an innovation pathway through social enterprise growth. The company itself both led the effort and served as an intermediary. It organized farmer organizations and trained them to grow pesticide-free food for a supply chain; developed a credible certification system; and established downstream marketing and distribution linkages to consumers and stores. The original leaders of Safe Harvest came from a well-established NGO, bringing years of hands-on experience working with small and marginal farmers and farmer networks to build partnerships (referred to as collaborative capacities in the case study) for implementation and financing.

Other cases illustrate the roles that large external actors can play in absorbing costs and reducing risks for smaller actors and partners—key leadership and intermediary roles. The scaling of **Sahel Rice (Senegal)** (Kohl, 2016c) was led by a USAID project (Projet Croissance Economique) whose Chief of Party and project team partnered with organizations or groups to innovate and implement solutions to address bottlenecks; convened and facilitated multistakeholder partnerships; and engaged in risk mitigation to incentivize private actors to develop and implement their innovations. **Trustea (India)** (Khandelwal et al., 2022) leadership came primarily from Hindustan Unilever and a few other large tea processors and sellers. They also worked as intermediaries training and organizing farmer organizations to grow tea, developed a credible certification system and created demand. Much of this involved mobilizing partnerships with a variety of growers, NGOs involved in certification and the public sector. These large commercial actors were essential to organizing and managing those partnerships; while the big companies benefited, they were able to create synergies and a positive-sum game so that the gains were widely distributed.

The **Upper Tana–Nairobi Water Fund (Kenya)** (Mati et al., 2022) was built by partners convened under the leadership of The Nature Conservancy, a large international NGO. In addition to organizing, convening and facilitating a win-win partnership between stakeholders who normally would not collaborate, this NGO led and managed the initial proof-of-concept phase, leveraging its international expertise in water funds. Lastly, the **Mechanization Initiative (Bangladesh)** (Kohl, 2016b) combined leadership with the intermediary role in the USAID project team, a partnership between the research organization CIMMYT and the market facilitation NGO iDE. CIMMYT identified technologies and engaged in action research to modify, adapt and improve them. iDE worked primarily as an intermediary. Initially their role was to mobilize partnerships with large private agricultural machinery companies. Subsequently they supported those companies in creating demand and filling in gaps in the value chain, e.g., creating viable repair services and parts supply. One of the key lessons from the Mechanization Initiative that was representative of the intermediary role is the amount of "invisible" work and resources that was required to manage these partnerships on an ongoing basis. The project eventually had to hire one full-time staff member for each private company partner.

Kuroiler Chickens (Uganda) (Foy, 2017) again provides a counter-example. Arizona State University led the introduction of this Indian poultry breed in Uganda and worked closely with Uganda's National Animal Genetics Research Center. As both were primarily research organizations—the latter an example of a National Agricultural Resource System (NARS), neither had the mandate, motivation or resources to function as an intermediary or direct implementer for commercialization. They initially failed in their leadership role to engage other actors to fill these roles, e.g., commercial partners that could address gaps in the value chain and provide hands-on technical support to adopting farmers. It was not until those gaps threatened the entire scaling effort that a commercial partner was successfully brought in to fill these roles. This case illustrates a common problem for CGIAR centers and other agricultural research organizations: their local partners are usually NARS that have complementary research capacities but not the ability to support commercialization.

Drought Tolerant Maize for Africa (DTMA)/Hybrid Maize (Zambia) (Kohl, 2016a) also suffered when CIMMYT, which led the development of the varieties, provided little support for commercialization and scaling in Zambia and elsewhere. CIMMYT's role was largely limited to sharing its germplasm with private and public seed breeders and providing technical assistance for seed multiplication. Scaling/commercialization, especially market creation and demand, was left to diverse mostly private actors. It became very apparent that commercial seed companies had little incentive to invest heavily in promoting DTMA as these varieties were among many maize varieties in their portfolios and not necessarily the most profitable. This lack of leadership in the scaling phase was a clear detriment to scaling up; while hybrid maize in general did go to scale because it was in the interest of the commercial seed producers in Zambia and was supported by extensive public sector subsidies for both inputs

and the purchase of output. By contrast, DTMA benefitted from neither, nor was the impact of climate change so regularly present at the time that farmers were looking for solutions to drought and its other manifestations; need doesn't equal demand. While all of these factors played a role in explaining the fact that, at the time the case study was written, DTMA represented a tiny fraction of the maize seed market, the lack of leadership by either the public or private sector were probably the most important.[14]

Lastly, **PICS Bags (Kenya)** (Foy and Wafula, 2016) is an unusual case. The bags were developed by a Purdue University research team, who also drove the initial introduction in Kenya (and several other countries) and established a foundation for scaling. This included identifying a manufacturer/wholesale distributor and supporting initial awareness building. Scaling was thereafter driven by a combination of a USAID project (Kenya Agricultural Value Chain Enterprises or KAVES) and local and international NGOs. Because of the bags' unique characteristics—affordability, huge return on investment, ease of proper use without extensive training, minimal change in existing agricultural practices, and relevance to important challenges facing farmers—spontaneous diffusion and adoption became the driving forces of scaling without a need for leadership. This illustrates a case where an innovation itself is so appealing, scaling occurs largely spontaneously. The example is problematic because innovation funders often expect this to be the typical case, whereas innovations with such characteristics are actually quite rare. Thus common practices, or the lack of them, to support innovation and scaling are premised on the assumption that most innovations are like PICS Bags, when in fact few are.

3.3. Support to Hypothesis 3: Innovation pathways should be iterative, adaptive and flexible

The notion that innovation and scaling should be iterative, adaptive and flexible has reached wide currency. In great part this is due to two reasons. First, approaches and culture from Silicon Valley around innovation and social entrepreneurship, and the technology sector generally, have increasingly influenced international development theory and practice over the past twenty years. This is especially because of the influence of large foundations whose fortunes come from the technology space play an ever more important role (e.g., the Gates Foundation was started in 2000, see Chang, 2018). Secondly, despite this, many international donors and research actors are aware that they continue to practice a rigid approach to innovation and scaling, often driven by legal, regulatory and bureaucratic contracting requirements. This has led many observers to blame their inflexible approach for the failure to advance very far along innovation pathways (e.g., Woltering et al., 2019).

To articulate a specific hypothesis regarding the importance of adaptability, we draw from Minh et al. (2021). They define five components of an adaptive scaling framework which they developed through "an iterative, action-research-for-development program on farmer-led irrigation," and we draw on two of these components to specify our hypothesis. According to these, innovation pathways should be:

- Reflective, i.e., reflects, manages and responds to dynamic and changing circumstances throughout the scaling processes.
- Adaptive, i.e., adjusts … the scope, capacity, and responses to and management of the strategy to the evolving dynamics of new system properties throughout the scaling processes.

It is important to note that in some cases adaptation and iteration was confined to either scaling or to innovation, in other cases both. The evidence below suggests that to some extent they are substitutes, as the more an innovation is adapted to the local context and needs, the fewer obstacles are encountered in scaling that need to be adapted to. However, on balance, it appears that adaptation is critical throughout the innovation pathway.

In **Balde Cheio (Brazil)**, Chiodi Bachion et al. (2022) the technical assistance delivered by the demonstration units and instructors was "adapted to the regional condition, producer needs for financing, property management, content and technical assistance" and to each property. The delivery structure was shaped progressively, as those interested in technologically developing the chain organized diverse arrangements for local implementation. In sum, it appears to have been adaptive in terms of the content of the innovation, an emergent process with the technology being introduced step by step according to farmer needs and reality. As is perhaps evident, an iterative and adaptive approach is complementary and synergistic with inclusion, allowing input from participants to be integrated dynamically as new experience and lessons emerge.

Likewise, the intervention packaged introduced by **ILPF (Brazil)** (Chiodi Bachion et al., 2022) was constantly evolving, adapted to "regional characteristics, weather conditions, the local market and farmers profiles." This was also true of the financing approach, which required significant changes to existing practices and instruments by the banks involved who were not accustomed to financing an integrated systems model. The innovation was adapted through an iterative "interaction between farmers' knowledge and 'formal' knowledge" (Chiodi Bachion et al., 2022). Modifications to the funding approach were particularly critical to addressing financial obstacles that had stalled scaling; these kinds of obstacles in financing and implementation are common, and often recur and arise repeatedly as sequentially greater levels of scale lead to encounters with different or new systems.

Adaptation is inherent to the approach to innovation found in the **Andhra Pradesh Natural Farming (India)** (Khandelwal et al., 2022) case; it was distributed, co-creative and demand-driven. Farmers themselves experimented with various natural farming approaches and principles, developing their own innovations

14 Cf. Chivasa et al. (2022): "Despite the importance and benefits of accelerated varietal turnover to climate change adaptation and food security, the rate of maize varietal replacement in SSA is slow.... Slow varietal turnover is affected by complex cross-sectoral and cross-disciplinary issues that require appropriate policy interventions" (emphasis added). This confirms the importance of systems change, institutional innovation and the provision of public goods which in turn require appropriate leadership and intermediaries.

and applications, and the farmer-to-farmer diffusion and scaling approach encouraged new adopters to do likewise. "Thus, Andhra Pradesh Natural Farming evolves as farmers find new crop combinations and apply natural inputs in different ways" (Khandelwal et al., 2022). At the same time, the case illustrates one of the tensions in using an adaptive approach: constant innovation and especially adaptation to local and individual circumstances and contexts makes it difficult to achieve economies of scale and scope and if anything, can actually increase the unit costs of adoption. While not necessarily true in this case, as with systems change and optimal scaling, it illustrates the need to balance application of this and the other principles tested with these cases with the implications for costs, time, effort and resources.

During the implementation of the **Sahel Rice (Senegal)** project (Kohl, 2016c), it quickly became apparent that the core focus needed to be on addressing weaknesses in the rice value chain; the "innovation," new rice varieties had been introduced and scaled in the 1990s but without realizing anywhere close to the full benefits of their genetic potential. Managers adopted what Kohl (2016c) characterized as a virtuous spiral model, identifying and addressing the most important immediate bottleneck. When this led to increased production or throughput in the value chain, it revealed the next bottleneck, which was addressed through new institutional and systems innovations or strengthening. This appears to be a form of the plan–do–study–act approach that has become foundational to trial and learning approaches in many sectors, especially health and education (cf. Coury et al., 2017). One consequence, however, of the logic of finding enough adopters to reach a critical mass, i.e., a commercially viable market and economies of scale, was that it required starting with larger, wealthier and more commercial farmers. Once this scale had been achieved it became worthwhile for commercial actors to address additional obstacles as they arose. This alignment of social objectives with commercial realities illustrates once again that innovation pathways require an adaptive and iterative approach, in this case resetting who the target customer needed to be.

The initial failures of **Kuroiler Chickens (Uganda)** (Foy, 2017) did lead to subsequent adaptation of the scaling strategy to address them, specifically engagement of a commercial partner to produce, market and deliver Kuroiler chicks. The case highlights the importance of having in place formal monitoring, evaluation, adaptation and learning (MEAL) processes that can quickly alert implementers to obstacles that emerge and need to be addressed. In that regard this is a useful negative example of what happens when adaptation, iteration and flexibility are delayed. A comparative example is the **Mechanization Initiative (Bangladesh)** (Kohl, 2016b) case. Some of the machines selected had problems in terms of usability, but CIMMYT and iDE monitored farmers' reactions and sales data and were quickly alerted to these issues. CIMMYT worked with farmers to adapt and modify the machines to suit farmers' needs and constraints. The business model was also adapted, changing from a direct sales to farmers approach to a service delivery model and from a focus on the target crops or rice and other cereals to the agricultural products where demand had unexpectedly manifested, e.g., fish farming, garlic and onions. Recognizing the importance of being adaptive and responsive to customer demand, the project enhanced its MEAL system and put into place a dynamic, near-real-time dashboard of who was buying what machines for what crops and purposes, and adjusted its marketing targets and activities accordingly and frequently.

3.4. Support to Hypothesis 4: Innovation should have characteristics that facilitate progress along innovation pathways and achieving large-scale SAI

Ever since the seminal work of Everett Rogers in the 1960s (see Rogers, 2003), there has been a recognition that innovations may possess characteristics that facilitate successful diffusion. A vast literature has since developed on these characteristics, and in the past 20 years a number of assessment tools have been developed for application to scaling agricultural innovations in particular (see Cooley et al., 2016; Jacobs et al., 2018; Kohl, 2018; Linn, 2022 for a comparison). The Agricultural Scalability Assessment Tool (ASAT) (Kohl, 2018), developed for USAID in the context of funding for innovations provided by the Feed the Future program, is currently being applied to identify those innovations with potential scaling and worthy of further investment. The ASAT has some 40 criteria, but we developed a simplified version of nine *criteria* that seemed, *ex ante*, to be most likely to facilitate progress along an innovation pathway:

1. The innovation addresses a felt (subjective) need, i.e., real potential demand and not objective need as identified by external technical experts, that is important to potential adopters (this is best identified by participation and inclusion, illustrating again the interdependency of these hypotheses).
2. The impact is tangible and easily observable to potential adopters.
3. The innovation is relatively simple with few components, i.e., easy for users to implement without extensive training or technical support. In cases of a combination or bundle of innovations, it generates significant benefits even if the entire bundle is not fully adopted or implemented correctly.
4. The innovation is affordable for potential adopters given their wealth and income constraints, without having to rely on external financing or otherwise put at risk the working capital they need to produce for the next season or year.
5. Adopters can expect benefits along multiple dimensions, either tangible (e.g., productivity, income, time-saving, health) and/or intangible (e.g., ease of use).
6. The innovation aligns with existing social norms, agricultural practices, tools and equipment, and thus requires little behavior change or additional complementary investment.
7. The benefits are relatively robust and reliable, i.e., are relatively consistent over time with low risk or variance.
8. Superior effectiveness is established relative to current solutions and emerging alternatives in similar contexts.
9. The innovation reduces risk or increases resilience, in addition to any increase in returns it may have.

Some of these may seem like common sense, yet they remain overlooked in many agricultural innovation efforts

which tend to maximize the impact on productivity or other objectives like climate resilience rather than how easily it can be adopted and used by, and aligns with the *priorities of potential adopters*.

The **Water Harvesting (Kenya)** innovation (Mati et al., 2022) clearly met a strongly felt need among small-scale farmers practicing rainfed agriculture, had clear benefits that were better than existing alternatives, had multiple benefits (useful for crops and personal consumption), had tangible benefits in terms of reducing time for getting and carrying water, was simple to use, reduced risk and increased resilience. The ability of this innovation to reach some scale without needing strong leadership or adaptation speaks to the strength of the original design in terms of these particular characteristics. **Solar Powered Irrigation (Kenya)** (Mati et al., 2022) also did well on these criteria; it met a need and was tangible, reliable, superior to existing solutions and supportive of resilience. Perhaps the characteristics that stood out most were its relative simplicity and robustness. Providers developed complete kits that included drip irrigation and piping, as well as offering assembly and ongoing technical support, or both, to facilitate adoption.

PICS Bags (Kenya) (Foy and Wafula, 2016) aligned with almost all of the criteria. Post-harvest losses were a huge problem for farmers throughout the year, and the bags were inexpensive and highly affordable, extremely simple and easy to use with only one component. The only behavior changes were to dry the crop to low moisture content and to store it away from rodents, and the results were easily visible after a few months. The bags lasted for a few years without a loss of effectiveness or impact. By allowing farmers to store their harvest with few losses and sell when prices are higher, they significantly increased food security and resilience and improved income.

The **Mechanization Initiative (Bangladesh)** (Kohl, 2016b) formed a natural experiment, as it introduced four machines whose characteristics differed across many of the innovation criteria. Perhaps the most impactful at large scale, at least initially, were axial flow pumps, which met a clear need by rice and fish farmers for pumping water and were relatively inexpensive. They required almost no change in behavior or agricultural practices; in fact one of their attractions was that they were easier to use, especially in cold weather, and could be powered by the diesel engines already in use. By contrast, self-powered reapers were much less successful due to being more expensive, replacing the labor of workers who had been traditionally hired to do both reaping and threshing (who pushed back by refusing to do only threshing), and being difficult to use especially in muddy conditions. The clearest (negative) example were bed planters, which were so heavy and cumbersome as to make them challenging to manipulate and operate in a muddy field, especially given the height and weight of many Bangladeshi farmers. The innovations that were easier to use, affordable, simple, addressed existing felt needs, produced superior outcomes and required minimal changes in agricultural practices were more likely to be adopted than those that did not have those characteristics.

Another counter-example lies in **Drought Tolerant Maize for Africa/Hybrid Maize (Zambia)** (Kohl, 2016a) and its difficulties. In particular, it did not address a felt need, and the impact was only observable in drought conditions. The package was complex and required behavior changes, and the benefits were two-dimensional: improved harvest under poor rain conditions, and greater resilience. Even those farmers who did adopt it usually only did so after a few years of poor harvests from drought when objective need became actual demand, and even then only as part of a portfolio approach of planting different seed varieties to diversify risk.

Balde Cheio (Brazil) (Chiodi Bachion et al., 2022) addressed a felt need, had a tangible and visible impact, produced benefits across multiple dimensions, was better than current practices, reduced risk and improved resilience. The downside was that was complex with multiple components, requiring significant changes from current practices. Significant adaptation to local circumstances was required, making scaling more challenging. These latter characteristics are all consistent with the fact that implementation required significant and ongoing training, technical assistance and extension support. If this had not been supported by the public sector and substantial funding over an extended period, scaling would have proven impossible. **Aqua Digital Irrigation Monitoring System (Brazil)** (Chiodi Bachion et al., 2022) addressed a need for timely information and guidance and fit with other criteria; however, it did require significant changes in behavior, was complex and required technical support to ensure accurate application of the entire package. This, along with its high cost, is why it was best suited for more sophisticated medium and large farmers.

Because **Safe Harvest (India)** and **Trustea (India)** (Khandelwal et al., 2022) spanned the value chain from producers to consumers, they confirmed the importance of aligning innovations with the needs and demands of both. These two cases offered innovations with multiple benefits for better management, health and market access, and also improved resilience. On the other hand, their complex new practices required significant change in behavior, and their relative success was dependent on the high levels of profitability involved and ability to finance significant technical support and extension services.

Kuroiler Chickens (Uganda) (Foy, 2017) met several of the criteria, such as significant and highly visible benefits in the chickens' increased and rapid meat and egg production compared to indigenous breeds. However, they also had important negatives that impeded successful scaling, most importantly that they required significant changes in animal husbandry practices, e.g., investing in fencing and supplemental feed and vaccinations of chicks that was unnecessary with domestic breeds. Moreover, impact was not robust or stable without strict adherence to these practices. Because they are hybrids they were much less affordable, as new chicks had to be purchased from a breeder. This is an important illustration that these characteristics are not simply a list of which some can be met and others not; in many case just one or two criteria can seriously affect scaling results despite the other characteristics. For any individual innovation, not all characteristics have equal importance or weight.

3.5. Support to Hypothesis 5: Innovations must be packaged with viable funding and implementation models and bundled with systems change

The innovation and scaling literature uses terms like packaging and bundling to refer to elements of an innovation beyond a single core technology or institutional characteristic. While the meanings of packaging and bundling often overlap—so much so that we have deemed it necessary to consider them as parts of the same hypothesis—they refer to two concepts that are important to differentiate.

Packaging refers to the fact that innovations, or combination of innovations, to be scaled or implemented, have to be combined with a viable delivery method and payment/business/funding model to form an innovation package. The delivery method and funding or business model can themselves be innovations, and can often be more important and/or innovative than the innovation itself. Note that this definition differs from what is often called a technical package (which might describe, for example, how Balde Cheio at the technical level packaged feed, animal housing and health).

Bundling refers to the fact that moving a specific innovation or innovation package further along the innovation pathway often requires it to be supported by systems changes and/or institutional innovations (similar to the concept of vertical scaling).[15] These systems changes can range from strengthening or filling in gaps in value chains or market systems, e.g., Sahel Rice, to changes in the public policy and institutional enabling environment, e.g., Trustea, to affecting change in social or cultural norms or mindsets, e.g., Andhra Pradesh Natural Farming (see Woltering et al., 2019; Minh et al., 2021).

The **Mechanization Initiative (Bangladesh)** (Kohl, 2016b) initially assumed that its agro-machinery partners would provide financing, marketing and distribution, but this was not the case until the private partners were sure that there was a large, viable market. When sales to individual farmers proved disappointing because of affordability issues, the business model was shifted to a local service provider model. Even with the new business model affordability remained an issue, however, so that the initiative had to partner with micro-finance institutions to provide financing. Similarly, the project had to bundle the machinery with value chain strengthening, such as arranging for repair services and a reliable supply of (imported) spare parts. This is a good example of how a donor-funded project can absorb the initial costs and function as a leader and intermediary to put in place an innovation package bundled with systems changes and institutional innovations until the private sector is convinced that it is profitable for them to take it forward.

Another is **Sahel Rice (Senegal)**, Kohl (2016c) which followed up on the 1990s introduction of improved varieties of rice in the Senegal River Valley, where most farmers never came close to realizing the new varieties' productive potential. Sahel Rice's long list of systems changes included a certified seed system, rehabilitating rice milling, reviving links with urban market, encouraging entrepreneurs to provide machinery services, and restoring and repairing irrigation infrastructure. The success of all was preconditioned on a highly supportive policy enabling environment (systems change), which the government put in place following the world food crisis of 2008/09. Supportive policies included a variety of price supports, subsidies and regulatory controls along with an implicit guarantee that reduced risk for investors and donors. The systems changes have endured and rice productivity has begun to realize its genetic potential, but the "commercial" system remains heavily reliant on government support and intervention. Still, it compares favorably to **Drought Tolerant Maize for Africa/Hybrid Maize (Zambia)**, Kohl (2016a) another "commercial" business and delivery model. While the seed varieties were produced, marketed and distributed by mostly commercial seed companies, their progress to scale was predicated on a major institutional innovation—a donor-funded national seed certification system. This systems was foundational not only for the widespread adoption of hybrid maize but for the country becoming a major exporter of maize seed for Southern and Eastern Africa. Other countries and markets found they could depend on the quality and reliability of these imported seeds. In Zambia, scaling was heavily dependent on massive public sector subsidies for the purchase of seeds and fertilizer and a guaranteed market for hybrid (not specifically drought tolerant) maize. These subsidies were similar to those present in Sahel Rice, but not in size or impact. In Zambia, the subsidies were so large as to fuel excessive production and created severe distortions that virtually eliminated commercial buyers. As a result, they eventually become fiscally unsustainable. These two cases make the case for the importance of institutional and systems change and especially public policy, even within commercial innovation pathways, but also illustrates the careful balance that between adequate support, perverse incentives and fiscal sustainability that needs to be achieved when governments provide support to private markets.

P1+2 (Brazil) (Chiodi Bachion et al., 2022) was able to reach over 200,000 families between 2007 and 2020 under two successive Workers' Party governments. The implementation model was done by contracting under the Brazilian Tenders Law (8.666/1990) and the federal government's agreement model. When these two structures became an obstacle to implementation, the government effected changes in the legal framework that were critical for the functioning and expansion of the program.[16] These changes allowed scaling to continue and even accelerate, a perfect example of combining iteration and adaptation with bundling. However, when political parties and leadership shifted in 2016, funding

15 This is in the context of horizontal, vertical and functional scaling up (also referred to as scaling out, scaling up or scaling deep). This is used by many authors; Hartmann and Linn (2007) define vertical scaling up as "creating the organizational and political framework needed to permit going to a larger scale," and horizontal scaling up as "the expansion of coverage of a project, program, or policy across more people and greater space."

16 Specifically, the changes in the legal framework "made it possible to formalize contracts by means of bidding waivers with private non-profit entities previously accredited by the [Ministry for Social Development] and conferred agility in accountability by shifting the focus from services to the final product (delivered technology)" (Chiodi Bachion et al., 2022, p. 26).

evaporated. Thus the reliance on federal funding as the business model, i.e., packaging, appears to have been both a blessing and a curse in terms of long-term financial sustainability.

While packaging and bundling are often necessary for successive scaling, the particular choices that are made can often either limit the scale and impact achieved, or confine it to certain, usually more well-off, demographic. This is particularly true when the business model or funding mechanism is significantly commercially driven, i.e., the innovation user or adopter pays, even when that may be partly subsidized. Two of the Brazil cases illustrate this point. In the case of **ILPF (Brazil)** (Chiodi Bachion et al., 2022), public and private partners cover the costs of developing and improving the technology package and of technical referral units, but most of the cost is borne as individual investment by (mostly large- and medium-scale) farmers. The model also included the creation of specific credit and financing lines in the context of a sectoral plan for agriculture—systems changes in policy and financing mechanisms. This business model was actually a blend of packaging and bundling, and has proven more sustainable than P1+2's politically dependent funding, at least for those adopters who can afford it.[17] Likewise, the scaling of **Aqua Digital Irrigation Monitoring System (Brazil)** (Chiodi Bachion et al., 2022) was packaged with a funding model that relied mostly on private financing sources and customer fees, making it impervious to political vicissitudes, but like ILPF, limiting scale. As a wholly private social enterprise, furthermore, it was not bundled with any systems changes. While successful commercial pathways cases do occur where there is little or no involvement of the public sector, there are so many counter-examples that the presumption should remain that public sector support is usually necessary, especially at larger scales such as the national,[18] as it is in many developed countries where supportive agricultural policies and subsidies are ubiquitous.[19]

Many other examples illustrate the trade-offs found in scaling numbers, reach and demographics depending on the packaging or bundling chosen. **Water Harvesting (Kenya)** (Mati et al., 2022) was characterized by an *ad-hoc* mix of partial donor, NGO, public and end-user financing, and estimate that by 2021, 10,000 farm ponds had been excavated in the three counties studied, reaching at least 100,000 people. While this was an important achievement for those people, the rural population of the three counties was ∼2.1 million, suggesting that scale was a fraction of potential demand. Meanwhile, **Solar Powered Irrigation (Kenya)** (Mati et al., 2022) illustrated what happens when the challenge of a viable business and delivery model is only partially addressed. It did have a viable private sector delivery model and there was a small and growing market in the one county studied, and probably elsewhere in the country. However, Mati et al. (2022) conclude that sustainable impact would have been much greater if some actor had invested in increasing market awareness, achieving lower prices through economies of scale and subsidizing or otherwise lowering financing costs. The packaging was good but the bundling with public goods was inadequate.

Some successful cases were themselves examples of systems change *as* the innovation. **Safe Harvest (India)** (Khandelwal et al., 2022) was one, providing pesticide-free agricultural products to urban markets through value chain linkages. **Trustea (India)** (Khandelwal et al., 2022) achieved something similar through its tea certification standard and traceable chain of custody. The **Upper Tana–Nairobi Water Fund (Kenya)** (Mati et al., 2022) was a system-changing institutional innovation, and included a viable funding model through a donor-financed trust fund, as well as an implementation model through its secretariat, electricity, water and sanitation companies and local NGOs. The completeness of this package seems to explain much of its success and sustainability.

Lastly, **PICS Bags (Kenya)** (Foy and Wafula, 2016) were again the outlier among technological innovations. They went to large scale, sustainably, based solely on an end-user-pays model with no elements of packaging or bundling. The project identified a domestic plastics manufacturer for production and then leveraged existing delivery mechanisms, both traditional agro-dealers and independent distributors on bicycles and motorcycles. Central to this was the very low unit cost and high returns for end users, such that it was affordable for them while allowing producers and distributors to make a good return.

3.6. Support to Hypothesis 6: Partnerships are critical for innovation, scaling and systems change

Partnerships are both critical on their own and often combined with bundling of systems change and participation and inclusion in recommendations regarding good practice in moving forward along innovation pathways. This is in large part because participation and partnership are interdependent and mutually reinforcing. In terms of achieving impact at large scale, partnerships are seen as critical because often no one actor has the necessary resources, be they financial, operational or political, to succeed on their own. This is particularly true when innovators are researchers and lack those resources (or the mandate or ability to act as intermediaries), or when the innovation itself is institutional or a form of systems change, bundled with such changes, or packaged with financing models. In commercial innovation pathways, as demonstrated in the previous section, partnerships or at least some involvement of the public sector is required to ensure a supportive policy enabling environment, if not to provide specific types of public support.

Partnerships for innovation vs. for scaling tend to have their own separate literatures. For that reason, we cover partnerships in innovation under participation and inclusion, and focus on partnerships in scaling or systems change in this section. Partnerships were, indeed, found in most of the case studies and

17 Chiodi Bachion et al. (2022) conclude that the scale achieved is still low compared to its potential precisely because it was packaged with a quite restrictive financing model.

18 See in Lesson #9 in Kohl and Linn (2021), which states: "Public and private actors—consider and address the appropriate role for the government/public sector in a predominantly private scaling pathway, and the role of the private sector in public scaling pathways."

19 Cf. OECD (2022), which shows that public support "in 2019–21, representing 17% of gross farm receipts in OECD countries" had experienced a 2.4× increase since 2000.

we can say with some confidence that partnerships in most cases facilitate success. The more interesting questions revolve around what constitutes a *good* partnership and how to create or sustain one. Drawing on several sources (notably Barrett et al., 2020), the literature suggests certain characteristics of good partnerships:

- A shared commitment to a common vision and alignment of that collective vision with individual incentives and interests.
- Mechanisms to ensure effective coordination of individual actions.
- Clear definition of individual roles and sharing of responsibilities and risks.
- Effective accountability mechanisms based on monitoring of mutually agreed key performance measures and enforcement of agreed actions.
- Sufficient financial and other resources, management and governance structures to operate effectively and sustainably.

The **Upper Tana–Nairobi Water Fund (Kenya)** is a strong example of partnerships in multiple dimensions, in this case across a water supply chain. The partnership between upstream farmers in the catchment area and downstream users was initially organized and facilitated by The Nature Conservancy, and then was transformed into a fully incorporated trust including public, private and development actors and communities. This succeeded despite the interests of upstream and downstream users not being clearly pre-aligned, illustrating the need for leadership to align disparate incentives. It was run by a Board of Management under a Board of Trustees, the latter representing diverse stakeholders that ranged from water, sewage and electricity parastatals to NGOs and community organizations. Management included a thorough monitoring system for financial and environmental outcomes. As such the innovation was both a financing and governance mechanism; the funding was initially endowed by donor partners and downstream users and replenished in payment for improved water quality.

Despite the fact that **Balde Cheio (Brazil)** (Chiodi Bachion et al., 2022) was driven by the government, partnerships were essential, especially between different levels of public actors within Brazil's decentralized federal government. These included technical assistance and rural extension agencies, linked to State and Municipal Agriculture Secretariats, and teaching and research institutions; private partnerships brought in cooperatives, dairy product companies, associations and agricultural federations. A strong governance mechanism was also important after Embrapa decided to transform the informal partnerships into a formal relationship and strengthen administration—a good illustration of the benefits of organizational over individual leadership in a partnership context. Partnerships were core to this innovation, and scaling would not have occurred at all or been very limited without them. These improvements in governance allowed for additional scaling to 50% more states and a 25% increase in both the number of technicians trained and in local partnerships.

P1+2 (Brazil) (Chiodi Bachion et al., 2022) benefited from an existing alignment of interests between the Workers' Party government and grassroots entities. It was *de facto* a public–private partnership between the Ministry of Social Development and a grassroots coalition ASA, "the result of a long process of institutional maturation … and the recognition of the importance of civil society's participation in implementing public policies" (Chiodi Bachion et al., 2022). On the other hand, **ILPF (Brazil)** (Chiodi Bachion et al., 2022) primarily partnered with commercial actors like Syngenta and John Deere. Here the Worker's Party government role was less about aligning interests, and more about public-private funding mechanisms and providing the leadership (by Embrapa) to manage the partnerships. Technologies were packaged with various forms of training and extension support supplied by partners.

Andhra Pradesh Natural Farming (India) (Khandelwal et al., 2022) was a partnership between a non-profit corporation spun off by the state government as a farmers' association, and the state government itself. It was implemented in partnership with local governments and women's self-help groups, the latter also being a source of financing for farmers. The state government provided funds for the association to manage these partnerships effectively. Local partnerships were co-creative and scaling largely horizontal and farmer-to-farmer.[20] The creation of this partnership, too, required an alignment between the values of natural farming and the politics of the state government at that time.

The other Indian cases are also partnership-driven. **Trustea (India)** (Khandelwal et al., 2022) began as a partnership between corporate tea processors and the Sustainable Trade Initiative, a Dutch organization comprising private companies, NGOs, trade unions and the Dutch Government. This then expanded to work with NGOs with standards and verification expertise, and eventually took the form of a multistakeholder governing council that also included the government regulatory agency. Despite the lack of pre-aligned interests between corporate processors and NGOs, the case validates the importance of a shared vision, clear mechanisms and governance structures in bringing such diverse and potentially oppositional interests together. It also supports the importance for successful partnerships of monitoring of key performance measures (standards compliance), integration with government systems, clearly defined complementary roles, and formalized relationships.

In all of the USAID cases, the USAID projects or USAID-funded innovators themselves played the partnership managing role. This worked better in some cases than others. **Sahel Rice (Senegal)** (Kohl, 2016c) featured partnerships with rice breeding research institutions, farmers' organizations, government agencies, and perhaps most importantly, informal coordination with other donors. The USAID project's lead role allowed for collective action and coordination of donor efforts and a multiplier effect on financial resources. The value-chain strengthening efforts by multiple donors were able to reach a much larger number of farmers than any one organization could have done on its own. Farmers' organizations, rice millers and other value chain actors

20 This however needs to be seen in light of the large organizations and significant money involved in rapidly scaling the "co-creation" and priming it as an investment opportunity, which has raised some potential contradictions with its horizontal partnership approach, not to mention its "zero-input" basis (Saldanha, 2019).

were key partners, as well as government parastatal banks and insurance companies.

The **Kuroiler Chickens (Uganda)** (Foy, 2017) case provides an example where the partnership approach was not initially successful because the initial partner didn't have the right complementary skills, in this case intermediary skills. Arizona State University's initial partner was a government research agency and enthusiastic supporter, but they were not capable of creating a supply chain of chick breeders and incubators and provide sufficient extension. This omission was eventually addressed by engaging a private partner, i.e. a partner with the right skills, the initial and prolonged delay caused a shortage of chicks for several years and nor the needed extension support. The national agricultural research system, in Zambia, was also the partner in developing **Drought Tolerant Maize for Africa/Hybrid Maize (Zambia)** (Kohl, 2016a), and this too fell short for similar reasons. Once the genetic material was made available, CIMMYT did not engage in partnerships to promote adoption, market development or demonstration, and drought tolerant maize reached very limited scale compared with hybrid maize generally.

4. Discussion

Here we make recommendations to the numerous actors working toward sustainable impact in SAI.

4.1. Innovation pathways must be participatory and inclusive

This was perhaps the hypothesis where the evidence was most ambiguous. On the positive side, there is clear evidence that consulting with and/or involving farmers in developing, testing, refining and scaling of innovations produces better results in two senses. They are more likely to be sustainably adopted and have greater impact because they are aligned with farmers' actual felt needs, existing practices, and constraints, e.g., financing and affordability, and they are more likely to scale because participation creates ownership and buy-in (the characteristics of hypothesis 4). Participation is important not just for farmers but other parts of the market system; it ensures production, marketing and delivery are profitable and therefore there will be a reliable, accessible supply, including to the last mile.

On the negative side, the extent of involvement must be weighed against significant costs of organizing, convening and aligning interests and vision. Scaling is almost always a multi-stakeholder process, but requires balancing the benefits of breadth and depth of participation necessary for success, as well as equity considerations, with the costs. Also, in the few cases where both the development and supply of technology packages and access to markets were provided by private actors for commercial markets rather than own consumption or local markets, participation was less important. Greater comparative or controlled research is needed on how the extent of participation affects outcomes in terms of improvements in productivity and incomes.

4.2. Leaders, intermediaries and champions are key to innovation pathways

In most of the cases, leadership played an important role at some stage. While more research is needed on the roles of leaders and other actors in innovation pathways, one of our major findings is that the need for leadership must be extended beyond the innovation phase to include intermediaries: organizations who facilitate scaling and/or systems change. Cases where one actor can lead the whole innovation process to the end of the pathway—large scale—are notably rare. It is unusual that all of the resources and capacities, and often motivation, of both leading innovation and facilitating scaling (intermediation) are to be found in one actor, especially when the innovator is a research organization. Leadership needs to be disaggregated by the stages or phases of innovation pathways, and specify the different skills and resources needed depending on the phase, type of innovation package, extent of bundling with systems changes, and current level of scale.

Investors in SAI innovation pathways can take one of three approaches to the leadership question:

- Identify and support existing innovation leaders with the capacity and skills to take end-to-end innovation pathways to scale and/or affect the necessary systems changes.
- Ensure that innovators who lack intermediary skills are partnered with appropriate public or private actors from the beginning who can take innovations to scale, e.g., commercial partners.
- Support intermediaries that function in between innovators and large-scale Doers and Payers.[21]

While partnerships, hand-off and exit strategies between researchers/innovators and intermediaries or large-scale partners make sense in principle, the very creation, organization and implementation of these strategies itself requires leadership or intermediary skills—and the commitment of all the organizational resources implied. Some of these functions that pertain to intermediaries are also difficult to achieve, given limited actual experience. Ethiopia's Agricultural Transformation Agency, a parastatal, is a well-regarded and widely-used example (see FAO, 2020) precisely because it is rare.[22] Although donor projects can function as intermediaries, they are rarely designed for the purpose. Accelerators, with whom there is substantial experience, can play this role to a limited extent, as the support they provide generally covers only the earliest stages of scaling or systems change. Much more applied research and many more case studies on these critical points are needed.

21 Payers are those actors who provide sustainable funding for an innovation or systems change at scale; Doers are the actors who have the capacity and skills to sustainably implement or operationalize an innovation or systems change at scale.

22 Chivasa et al. (2022) detail the successful updating of maize varieties in Ethiopia without describing the institutions that made it possible.

4.3. Innovation pathways should be iterative, adaptive and flexible

Many development efforts take the form of projects with rigid sets of activities, workplans and targets. By contrast, an adaptive approach starts with the premise that innovation pathways are ultimately involved in transformation of agri-food systems, and therefore are inherently complex and dynamic. To be effective, that systems transformation or innovation pathway process needs to adapt to this emergent process by constantly reexamining its assumptions based on actual experience and monitoring, and revising its vision, strategy, activities and tactics accordingly (see Woltering et al., 2019; Kohl and Linn, 2021; Minh et al., 2021). This is particularly true because necessary systems changes only become apparent as scale increases.

The evidence for an adaptive, iterative approach to developing innovations was almost universal, and these adaptive approaches need to apply even more so to scaling and systems change as context and relevant systems change at different levels of scale and scope.

Innovation pathways should therefore include multiple and continuous feedback loops and evidence generation to support these activities, building on monitoring and evaluation (M&E) with adaptation and learning (MEAL). Evidence generation does not stop with proof of concept at a pilot stage, and in fact even that needs to be revisited, as noted above, when scale increases and contexts multiply. Funders need to balance accountability for the overall goals and mission with flexibility in terms of specific crops, activities, pathways and strategies.

4.4. Innovation should strive to have characteristics that facilitate progress along innovation pathways and achieving large-scale SAI

A large literature suggests that innovations with specific characteristics have greater potential for achieving SAI (e.g., Cooley and Kohl, 2005; Jacobs et al., 2018; Kohl, 2018). Our cases also reinforced that technical innovations of products and services should be designed and developed to align with characteristics that facilitate scalability, including:

- **Relevance** to an important and subjectively felt need (demand).
- **Tangible** and easily observable impact.
- **Relative simplicity** with few components, so that the benefits are realized even when adoption is imperfect or incomplete (in terms of components of an innovation bundle), i.e. robustness.
- **Affordability** given wealth and income constraints, and adopter's aversion to putting their working capital at risk.
- **Benefits offered** along multiple tangible and intangible dimensions.
- **Alignment** with constraints to adoption and existing norms, practices, tools and equipment, minimizing the behavior change or additional investment(s) required.
- **Superior effectiveness** relative to current and emerging alternatives.
- **Reduced risk** and increased resilience, not just or only increased returns.

Nevertheless, we found that for innovations that didn't have these, bundling with systems changes, capacity building or strengthening Doers and Payers, or developing alternative business or delivery models that when innovation lacked these criteria did allow for scaling and advancement along innovation pathways—at a generally higher cost. Innovators, funders and implementers should make explicit choices about whether the benefits justify devoting the additional time, effort and resources required.

4.5. Innovations must be packaged with viable funding and implementation models and often bundled with systems change

Packaging comes out clearly in the case studies, and bundling a bit less so. Many innovations fail to scale not because the innovation combination doesn't produce value for end users, but because it isn't packaged with a viable business, funding or delivery model. One of our findings is that the meaning of packaging tends to differ between commercial and public sector innovation pathways. For innovations scaling through commercial pathways, it implies that all actors in the value chain are able to make money from the innovation. In public sector pathways, a multitude of political economy considerations are relevant beyond alignment with stated policy objectives, as many innovators and their funders have discovered to their chagrin.

The evidence was also supportive, though less strong, for the importance of bundling with systems analysis and change; sustainable scale can sometimes be achieved without it, but bundling increases the likelihood of success and can often take it much further than would otherwise be the case. Several CoSAI cases were in fact institutional changes bundled with technology packages and technical assistance, while the most successful USAID cases involved major efforts at strengthening value chains or were combined with extensive support and changes in the public sector enabling environment. The importance of bundling seems to depend heavily on the type of innovation, choice of scaling pathway (public, private, NGO, or some mixed approach), and alignment with the relevant systems implied by that scaling pathway.

Developers of an innovation need to identify from the beginning whether the innovation is already aligned with existing systems constraints or whether it needs to be bundled with systems change. If the latter, what time and resources are required, and who could lead that effort effectively? For systems changes and institutional innovations, do these require additional adjustments such as changes in social norms? Mapping and analysis of systems and the ambition of systems change—while important in a world of complexity and multiple, interrelated goals—need to be a careful balancing act with a practical assessment of the feasibility of organizational change and a realistic assessment of incentives and political will as well as costs and benefits.

4.6. Partnerships are critical for innovation, scaling and systems change

The evidence confirming the critical role of partnerships was very strong, though it also underlined how much work these involve to organize, operate and sustain. Successful partnerships reinforce and interact with some of the other recommendations, particularly the role of a lead actor or organizations in being willing to absorb the costs and compromise on some of its own interests for the greater good and to create public goods, even by private actors. They are also essential as the diverse political, financial and implementation resources needed at scale that are rarely found in one actor. Even when a single Payer or Doer is feasible, partnerships have significant advantages for sustainable impact at large scale by creating shared buy-in and ownership.

An overlooked part of partnerships that needs support, again interacting with other findings, is the issue of intertemporal roles, sequencing and complementarity. Funders, donors and the public sector are well placed to absorb initial risks and engage in risk mitigation. This can then allow the private sector to invest and assume the role of Doers and Payers.

Yet partnerships also take substantial time, effort and resources to create, manage and sustain, and require aligning a shared vision and creating trust. This is nowhere more true than in the public–private examples—where the work is also highly political. Different kinds of government administrations partner more successfully with NGOs to reduce poverty, or with commercial interests to boost growth and resource use. Vision and trust fundamentally define all of these partnerships and are no small considerations.

4.7. Conclusion

The case studies reviewed in this paper all achieved sustainable impact, though at widely varying degrees of scale. Some achieved relatively large scale, while others achieved more limited scale; all were successful in advancing adoption and implementation to some degree. The uneven success and limited scale achieved doesn't allow us to conclude that following these hypotheses ensures sustainable impact at large scale. The cases reviewed, and particularly the variance in outcomes among them, does allow us to conclude that NOT following these principles is likely to at best impede progress toward this goal, if not severely limit success.

Of the various hypotheses considered in this paper, perhaps the most significant failing traditional approaches to advancing along SAI innovation pathways is that many actors focus on *innovations* rather than *innovation pathways*. As such, they don't incorporate scaling as an integral component that needs to be taken into account at every step of the process. For example, by minimizing participation, they neglect demand in favor of need as determined by technical experts. By ignoring constraints at scale, they design innovations that are incompatible with those constraints—and either fail to identify viable implementation and funding models, Doers and Payers, or to anticipate the partnerships, systems change and institutional innovations needed, and the resources and leadership necessary to create these. They assume that proof of concept is sufficient and some never-clearly-specified Doers and Payers will magically materialize; perhaps the national government will do it, even in the absence of resources, implementation capacity and political incentives.

Furthermore, donor projects use a definition of scale which is often too limited i.e. simply getting to a large number of adopters in a fixed period of time. They ignore issues like the sustainability of incentives, production, delivery and implementation, and financing and other resources. By doing so, they overlook the need for investing in packaging and bundling with institutional innovations and systems and systems change. Even when they do so, they do this after progress along the innovation pathway is relatively well advanced, requiring retrofitting which can be expensive and time-consuming, rather than integrating these considerations into the innovation process itself.

Pursuing a broader approach to innovation pathways, and therefore leadership, increases the chance of achieving sustainable impact at large scale and the much-discussed but rarely achieved game-changing disruptive change. To do this requires a number of changes in approach, such as more participation, adaptiveness and flexibility, and usually partnerships. It also requires wholly different skills, capacity and resources, including a broader definition and role of leadership to include the intermediary role in particular than is found in traditional innovation and scaling approaches.

Importantly, then, the six hypotheses we have investigated here are very closely intertwined. Their synergies and interactions mean that none can be easily discarded. It is essential to consider them together as aspects of the same difficult pathways to a sustainable future.

Serious systems change, bundling and packaging, participation and partnership, iteration and adaptation: these all take additional time, money and effort. They mean recognizing a far higher level of complexity; the dynamic, emergent and unpredictable nature of the process; and, because they involve people and their organizations and enrolling their engagement and support, the inherently political nature of innovation pathways and especially their scaling components. Admittedly, this brings the rarely acknowledged political aspects back into innovation—a field that is attractive to so many precisely because it appears technocratic and politically frictionless.

Therefore, taking scaling seriously requires both a willingness to commit greater resources (or focus on a smaller number of big bets) and an increased appetite for risk. Rather than playing to the expectation that most projects will succeed in meeting their time-limited, numerically-specific targets (as when the World Bank and International Fund for Agricultural Development report that 70%−80% of their agricultural projects are at least moderately successful), innovation pathways that seek to have *sustainable* impact at *large* scale (commensurate with the size of the problem) will often fail to meet that much more ambitious target.

Yet if we are to achieve the Sustainable Development Goals by 2030, we must embrace that risk by adopting a portfolio

approach often found in venture philanthropy. In this approach an expectation of a relatively large number of failures is offset by a few transformative successes which then change the lives of hundreds of millions, if not billions.[23] Current approaches are doing something very different: ensuring, with a high probability of success, time-limited impact in numbers that are overshadowed by the scale of need. In contrast, private venture capital has changed the world based on an acceptance—even a rule of thumb—that three out of four start-ups will fail (Gage, 2012). While the evidence and recommendations presented here are only a start and more evidence, examples and detailed guidance are needed, there are many lessons we have already learned well. Development actors who apply these to SAI innovation pathways will be more likely to successfully change the world's agri-food systems and achieve global goals for rural livelihoods, food security, resilience and climate change.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://wle.cgiar.org/cosai/pathways-for-innovation.

Author contributions

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23 According to one representative source SoPact, characteristics of venture philanthropy include "targeting systemic change through collaboration (e.g. partnerships); a focus on scaled or scaling interventions at a sector level (systems change), use of a multi-stakeholder focus (participation and inclusion), long-term engagement … in alignment with a systems change mindset, and agile M&E [for] swift adaptation of interventions as needed based on outcomes." To give but one example, the Draper Richard Kaplans Foundation (2022) claimed that out of their 168 investments totaling $70 million, 18 were having a significant impact on millions of people.

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