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Food and agricultural innovation pathways for prosperity

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ABSTRACT

This introduction to the special issue deploys a framework, inspired by realist synthesis and introduced in Section 1, that aims to untangle the contexts, mechanisms, and outcomes associated with investments that link poverty reduction and rural prosperity within a broad agri-food systems perspective. Section 2 considers changes in contexts: Where are agricultural research investments most likely to be an engine of poverty reduction? Over the past 25 years, there have been profound changes in the development context of most countries, necessitating an update on strategic insights for research investment priorities relevant for the economic, political, social, environmental, and structural realities of the early 21st Century. Section 2 briefly surveys changes in these structural aspects of poverty and development processes in low-income countries, with particular attention to new drivers (e.g., urbanization, climate change) that will be of increasing salience in the coming decades. In Section 3, we turn to mechanisms: What are the plausible impact pathways and what evidence exists to test their plausibility? Poor farmers in the developing world are often the stated focus of public sector agricultural research. However, farmers are not the only potential beneficiaries of agricultural research; rural landless laborers, stakeholders along food value chains, and the urban poor can also be major beneficiaries of such research. Thus, there are multiple, interacting pathways through which agricultural research can contribute to reductions in poverty and associated livelihood vulnerabilities. This paper introduces an *ex ante* set of 18 plausible impact pathways from agricultural research to rural prosperity outcomes, employing bibliometric methods to assess the evidence underpinning causal links. In Section 4, we revisit the concept of desired impacts: When we seek poverty reduction, what does that mean and what measures are needed to demonstrate impact? The papers in this special issue are intended to yield insights to inform improvements in agricultural research that seeks to reduce poverty. History indicates that equity of distribution of gains matters hugely, and thus the questions of "who wins?" and "who loses?" must be addressed. Moreover, our understanding(s) of "poverty" and the intended outcomes of development investments have become much richer over the past 25 years, incorporating more nuance regarding gender, community differences, and fundamental reconsideration of the meaning of poverty and prosperity that are not captured by simple head count income or even living standard measures.

1. Introduction

The last three decades have seen significant progress in reducing poverty and boosting prosperity. Nevertheless, approximately 800 million people continue to live in extreme poverty (World Bank, 2017). Moreover regional progress has been uneven, with Sub-Saharan Africa accounting for half of the world's extreme poor. Therefore, much remains to be done in terms of international efforts to reach the target for 2030 as articulated under Sustainable Development Goal 1 (SDG 1), i.e. eradicate extreme poverty.

Poverty is a multidimensional concept and poverty reduction is achieved through many routes (Alkire and Foster, 2011). No country – putting aside city states – has achieved prosperity without growth in productivity in multiple sectors (agriculture, industry, services) and for

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many countries this growth process has been mutually reinforcing. However, agriculture can and does play a central role in reducing poverty, since the majority of the world's poor are still rural people who depend upon agriculture for their livelihoods (Webb and Block, 2012). Fostering agricultural growth can serve as a critical entry point for designing effective strategies to transform the rural economy and meet SDG 1 (Christiaensen et al., 2010), and investments in agricultural research for development (AR4D) are key to agricultural growth (Fuglie, 2017). A considerable amount of publicly-funded agricultural research has taken place in the CGIAR, a worldwide partnership addressing AR4D. The CGIAR has three System Level Outcomes (SLOs) aligned with the SDGs and under SLO 1 aims to assist 100 million people, of whom 50% are women, to exit poverty by 2030.[1]

Evidence to date suggests that investment in AR4D provides high economic returns (Hurley et al., 2016), and has been an effective tool to combat poverty (Adato and Meizen-Dick, 2007; Renkow and Byerlee, 2010; Pray et al., 2017). Results from a recent simulation study have revealed that investment in agricultural research reduces poverty more than irrigation, water holding capacity, or infrastructure investments and is even more beneficial when coupled with these other investments (Rosegrant et al., 2017). Nonetheless relationships between AR4D strategies and investment priorities for poverty reduction continue to be debated. Apparent lack of consensus concerning the key links between AR4D and its impact on poverty reduction is a barrier to clarity and effectiveness in development strategy as well as weakening the case for public investment.

Consensus has been elusive (in part) because these multiple links involve:

- systems of numerous components, in which major interactions can be non-linear, complex, and interdependent;
- interventions aimed at affecting components and outcomes also are numerous, complex, and interdependent;
- implementation of interventions requires partnership and concerted cooperation across multifarious organizations and scales;
- key phenomena (e.g., both socioeconomic and ecological processes) display emergent properties, meaning that there may be no clear "line of sight" linking intervention points (say in fields, farms, or firms) with desired impacts (viz, poverty reduction); and,
- prospects for desired impacts are context dependent.

The compendium of papers in this special issue grew out of the 2016 CGIAR Independent Science and Partnership Council (ISPC) Science Forum (SF16) that was held from 12 to 14 April 2016 in Addis Ababa on "Agricultural research for rural prosperity: rethinking the pathways[2]". This set of papers does not constitute the proceedings of the Forum. Rather, insights from the Forum were used to identify strategic gaps, constraints and opportunities in this broad field and to frame a coherent and comprehensive collection of research papers from a systems perspective. Each assesses the evidence for the key causal connections linking AR4D to poverty reduction for their focal pathway(s) and suggests priority research questions, implications for research methods and design, and for necessary AR4D partnerships.

Realist research (Dieleman et al., 2012; Rycroft-Malone et al., 2012) is an emerging method developed to address complex system interventions with the characteristics faced in the particular case of AR4D. The structure of this paper (context in part 2, mechanisms in part 3, and impacts[3] in part 4) is directly inspired by the realist research literature. As with that body of work, our objectives with this special issue are "identifying underlying causal mechanisms and exploring how they work under what conditions" (Rycroft-Malone et al., 2012). And, like those authors, our basic task is to determine "what works, for whom, in what circumstance …" (Rycroft-Malone et al., 2012). In contrast to the structured rigor of "realist synthesis" (sensu R. Pawson), this paper is a more modest effort to characterize concisely the vast inter-related literature on AR4D context, mechanisms, and impacts as a framework and foundation for the expert assessments of specific mechanisms in the subsequent papers in this collection.

2. Context: where are agricultural research investments most likely to be an engine of poverty reduction?

Among the five bullets listed in Section 1 above, most concern systems properties within the scope of AR4D that will be addressed in various ways in the other papers in this special issue. The exception is the last point on context, which is the focus of this section. Context has long been recognized as a key consideration in agricultural development (e.g., Lewis, 1954; Johnston and Kilby, 1975; Timmer, 1988; Tomich et al., 1995). Specifically, similar mechanisms may have different prospects for success depending on context, and these contextual matters conditioning success can shift over time. For example, the recent review by Pray et al. (2017, p. 4) concluded that the notion that AR4D investments were associated with poverty reduction now holds "for Asia and Africa but not in the Americas." This section considers relevant long term changes of four main types: structural transformation, agrarian differentiation, urbanization of human populations, and climate destabilization. It concludes with a note on some other factors and emerging sources of uncertainty.

2.1. Structural transformation

Economic growth involves patterns of change in economic structure across many sectors; these patterns have been a mainstay of development economics for decades. Two variables receive particular emphasis in this structural transformation literature: agriculture's share of gross domestic product (GDP, as a measure of aggregate income) and of the economically active population (as a measure of labor); both measures tend to fall as GDP rises. Because of the centrality of labor productivity and employment in poverty reduction, Tomich et al. (1995) argued that priority for agricultural development investments should go to those countries with more than 50% of their economically active population primarily dependent on agriculture.[4] In 1990, there were 58 of these "countries with abundant rural labor". Fig. 1 shows how agriculture's share of GDP changed for the 37 of 58 countries for which data are available to compare GDP shares over approximately 25 years (1990 to 2015); sequenced from lowest to highest by their GDP per capita in 1990 (Tomich et al., 1995, Table 1.1, p. 11). Of the 37, four of the five that had significant increases in agriculture's share of GDP (Chad, Sierra Leone, Burkina Faso, and Togo) also experienced civil war or active insurgencies, as did two of the three for which this measure stayed essentially unchanged (Pakistan and Sudan). The other 29 all have seen significant declines in the share of agriculture in GDP.

While these long term comparisons of GDP shares face important difficulties, the challenges of comparing changes in agriculture's share of the labor force are even more daunting. Indeed, for the 37 countries in Fig. 1, comparable data on agriculture's labor force share spanning this period are only available for a few. Johnston and Kilby (1975, p. 194) present data on the contrasting cases of structural transformation in the United States (1820 to 1970) and Japan (1885 to 1970). To be sure, there can be setbacks to the decline of agriculture's share of the

[1] http://www.cgiar.org/our-strategy/.

[2] http://www.scienceforum2016.org/.

[3] Much of the AR4D literature distinguishes intermediate "outcomes" from ultimate "impacts." While realist synthesis uses "outcomes," the term "impact" is more accurate for our purposes and is used in this paper.

[4] Tomich et al. (1995) was an effort to distill lessons that had "withstood the test of time" from the publications of the 1960s, 1970s, and 1980s, including the vast literature on what came to be known as the Green Revolution. Tomich et al. cite hundreds of scientific publications from that era; a few of the subsequent noteworthy publications include Lipton and Longhurst (1989), Hazell and Haddad (2001), and Gollin et al. (2016a).

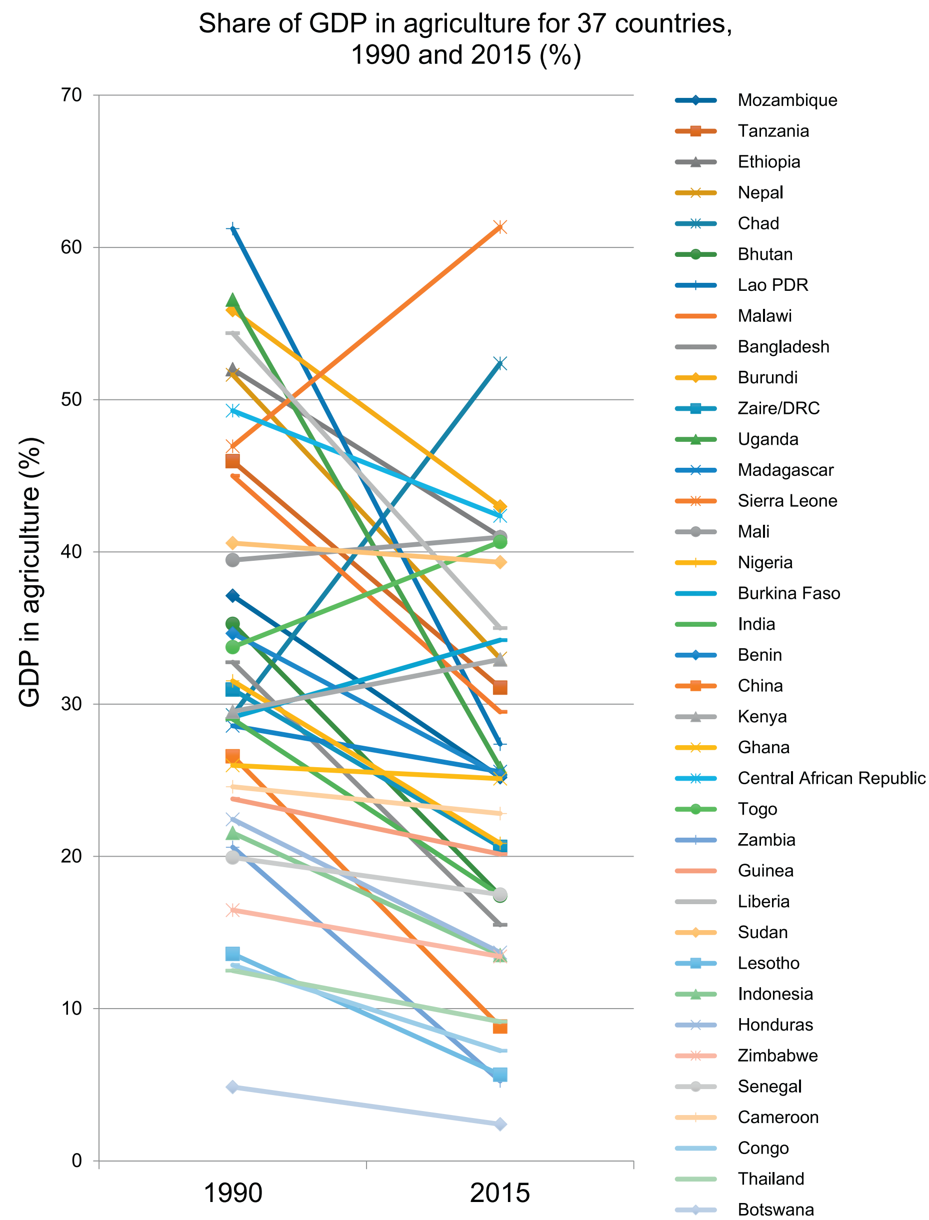

Fig. 1. Shares of GDP in agriculture for 37 countries, 1990 and 2015 (in 2010 constant US$).
Source: The World Bank. 2017. "Agriculture, value added (% of GDP)." World Development Indicators, World Bank Databank. URL: http://databank.worldbank.org/data/reports.aspx?source=2&series=NV.AGR.TOTL.ZS&country=#

labor force, as occurred in Japan right after World War II; but the long term patterns are the same in each case. While agricultural labor force may continue to grow in absolute size in the earlier decades, non-agricultural labor grows faster. This decline in the relative size of agriculture in the labor force accelerates after the absolute size of the agricultural labor force peaked in the US after World War I and in Japan after World War II. Overall, the relative size of the agricultural labor force declines for each country from over 75% in the 19th century to well below 5% for each country in the 21st Century (Tomich et al., 1995, pp. 67–69; World Bank, "World Development Indicators", Table 2.3). Another perspective can be gained from the related (but not identical) distinction between rural and urban population.[5] Jayne et al. (2014) use UN data to show that total rural population already had peaked in China before 2000 and has declined dramatically in absolute numbers. Of the remaining developing regions in Asia and Africa, total rural population is projected to peak almost everywhere before 2050. The exception is sub-Saharan Africa, where rural (and urban) populations are projected to continue to increase significantly until at least 2050 (Fig. 2).

One corollary of this general pattern of GDP shares falling faster than labor force shares is known as the "agricultural productivity gap" (Gollin et al., 2014): measures of productivity per worker in agriculture fall behind other sectors throughout much of the process of structural transformation. Barrett et al. (2017, p. 6) emphasize that for sub-Saharan Africa, this disparity may arise more from high unemployment than low productivity per hour worked. Whether this gap arises from gaps in productivity, or employment, or both, shortage of opportunities for productive work is an important contributor to mass poverty. As

[5] This avoids some of the challenges in partitioning labor by economic sector, but adds the new issue of differences across countries in their statistical definitions of "urban" and "rural".

Table 1
Pathways linking Agricultural Research for Development (AR4D) to Poverty Reduction.
Source: Authors.

	Impact pathway	R for D activity	Output	Uptake	Outcome	Impact at agroecological zone/national scale
1	Innovations to increase productivity	Breeding	Higher yielding cultivars and varieties, improved livestock and fisheries	Adoption by poor farm households	Increased farm productivity	Increased farm incomes (in cash and kind) for the poor; increased employment opportunities in agricultural markets; increased demand for farm and non-farm labor
2	Innovations to increase productivity	Farming practices	Productivity-enhancing farming practices	Adoption by poor farm households	Increased farm productivity	Increased farm incomes (in cash and kind) for the poor; increased employment opportunities in agricultural markets; increased demand for farm and non-farm labor
3	Innovations to minimize production risks	Breeding	Resilient/resistant cultivars and varieties, improved livestock and fisheries	Adoption by poor farm households	Reduced farm-level production risk uncertainty; investment incentives	Reduced vulnerability for poor farmers; more stable demand for farm and non-farm labor
4	Innovations to minimize production risks	Farming practices	Resilient/resistant farming practices	Adoption by poor farm households	Reduced farm-level production risk uncertainty; investment incentives	Reduced vulnerability for poor farmers; more stable demand for farm and non-farm labor
5	Market imperfections and failures	Input systems (seeds and other genetic material, nutrients, agrochemicals, etc.)	Analysis of market functions, market infrastructure and related policies	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations	Greater access, better quality, lower prices and adoption of agricultural inputs	Reduced production costs for poor farmers; increased employment on-farm and through backward linkages to input supply
6	Market imperfections and failures	Value chains	Analysis of value chains, market functions, market infrastructure and related policies	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations	Greater market access, higher farmgate prices for poor farmers	Increased revenue for poor farmers; increased employment on-farm and through forward linkages through value chains
7	Agricultural diversification	Farming systems, breeding, agricultural practices, input systems and value chains	Cultivars and varieties, improved livestock and fisheries, and practices appropriate to the diversified farming system and market opportunities	Awareness of problems and opportunities for poor farmers, private sector, civil society organizations and policy makers	Expansion of profitable agricultural production options, including poor farmers	Increased income for poor farmers; increased employment opportunities in agricultural markets
8	Natural resource management	NRM technologies, institutions and policies	NRM innovations	Awareness and adoption of a) innovative techniques by poor farmers; b) institutional innovations by communities; and c) institutional reforms and appropriate policies by policy-makers	More sustainable natural resource management; increased certainty of returns for poor farmers; strengthened capacities to cope with risks, including climate change	Reduced vulnerability for communities and poor farmers; more stable demand for farm and non-farm labor
9	Natural resource governance, property rights and livelihoods	NR institutions and policies	Analysis of NR challenges, institutions and policies	Awareness and understanding of indigenous institutions and institutional innovations by communities, and supportive institutional reforms and appropriate policies by policy-makers	More equitable distribution of land and other resources; security of tenure and improved access to resources/assets; enhanced governance and communal rights to exploitation and management of the local commons	Improved distribution of wealth, benefitting poor people; rural poor empowered and their livelihoods improved
10	Human nutrition	Farming systems, breeding, agricultural practices, input systems and value chains	Analysis and development of associated value chains, market functions and related policies; cultivars and varieties, improved livestock and fisheries, and practices that enhance nutritional value	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations; adoption by poor households	Diversified income and employment opportunities both within and outside agriculture	Increased revenue for poor farmers; increased employment on-farm and through forward linkages through value chains
11	Human health - food consumers	Farming systems, breeding, agricultural practices, input systems and value chains	Risk assessment and interventions in associated value chains, market functions and related policies; cultivars and varieties, improved livestock and fisheries, and practices that improve food safety and address antimicrobial resistance	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations; adoption from “farm to fork”	Policy-makers, private sector and civil society organizations develop capacity and act to ensure safe foods in markets; adoption by poor households (cultivars and practices), traders and processors (practices)	Increased income from higher labor productivity and higher labor force participation by poor people

(*continued on next page*)

Table 1 (*continued*)

	Impact pathway	R for D activity	Output	Uptake	Outcome	Impact at agroecological zone/national scale
12	Human health - farmers and farm workers	Farming systems, agricultural practices and input systems	Risk assessment of farming systems and development of practices and policies that reduce exposure of farmers and farm workers to agriculture associated diseases (AAD: zoonoses and emerging infectious diseases, water-associated diseases, occupational hazards and diseases)	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations; adoption across the agriculture sector	Policy-makers, private sector and civil society organizations develop capacity and act to ensure health and safety of farmers and farm workers; adoption of practices (cultivars) by farms	Increased income from higher labor productivity and higher labor force participation by poor people
13	Education (agricultural skills)	Program design and development, assessment	Organizational models	Awareness of strengths and weaknesses of alternative models by policy-makers, private sector and civil society organizations; participation by poor people	Policy-makers, private sector and civil society organizations develop capacity for cost-effective programs; enhanced skills and capabilities of poor people, including poor farmers	Increased income from higher labor productivity, higher labor force participation and entrepreneurship by poor people; rural poor empowered and their livelihoods improved through greater access to information and strengthened organizational capacities
14	Food supply	Food policy analysis, markets and value chains, farming systems, breeding and agricultural practices	Analysis of value chains, market functions, market infrastructure and related policies; policy options; higher yielding cultivars and varieties, improved livestock and fisheries; productivity-enhancing agricultural practices	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations; adoption by farmers	Greater supply of food and lower food prices for consumers in both rural and urban areas	Increased income in real terms, especially for the poor because food prices are lower (and the poor spend a large proportion of their income on food)
15	Food waste	Food policy analysis, markets and value chains, farming systems, breeding and agricultural practices	Analysis of value chains, market functions, market infrastructure and related policies; policy options; cultivars and varieties that reduce waste; livestock and fisheries practices that reduce waste	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations; adoption from “farm to fork”	Greater supply of food and lower food prices for consumers in both rural and urban areas; income, employment and entrepreneurial opportunities from food and agricultural waste management, (reduction, reuse and recycling)	Increased income in real terms, especially for the poor because food prices are lower (and the poor spend a large proportion of their income on food); potential for increased income for poor farmers; expanded employment and income opportunities for poor households in both rural and urban areas
16	Food safety nets	Food policy analysis, markets and value chains, farming systems, breeding and agricultural practices	Analysis and design of mechanisms to support purchasing power and smooth food consumption	Awareness of problems and opportunities for policy-makers, private sector and civil society organizations; adoption by farmers	Policy-makers, private sector and civil society organizations develop capacity to create and manage “food safety net” programs; adoption by poor households	Food consumption levels for the poor supported in rural and urban areas; reduced vulnerability for poor rural and urban communities and poor people; decreased vulnerability of the poor to climate change and other shocks; more stable demand for food
17	National agricultural R & D	Research on national agricultural research and extension systems and strategies	Comparative analyses of NARES systems, strategies, capacities and effectiveness	Awareness of problems and opportunities for agricultural R & D as part of national development strategy for policy-makers, leaders of R & D institutions and funders	Policy-makers, leaders of R & D institutions and funders develop capacity to strengthen NARES	Enhanced national capacity for poverty alleviation through agricultural R & D
18	National food and agricultural policy	Food policy analysis, political economy of food policy	Comparative analyses of food policy and political economy	Awareness of problems and opportunities for food and agricultural policy as part of national development strategy for policy-makers, leaders of R & D institutions, and funders	Policy-makers, leaders of R & D institutions, think-tanks, civil society organizations and funders increase awareness, develop capacity to undertake and use food and agricultural policy analysis, and create policy analysis institutions	Enhanced national capacity for poverty alleviation through improved food and agricultural policy

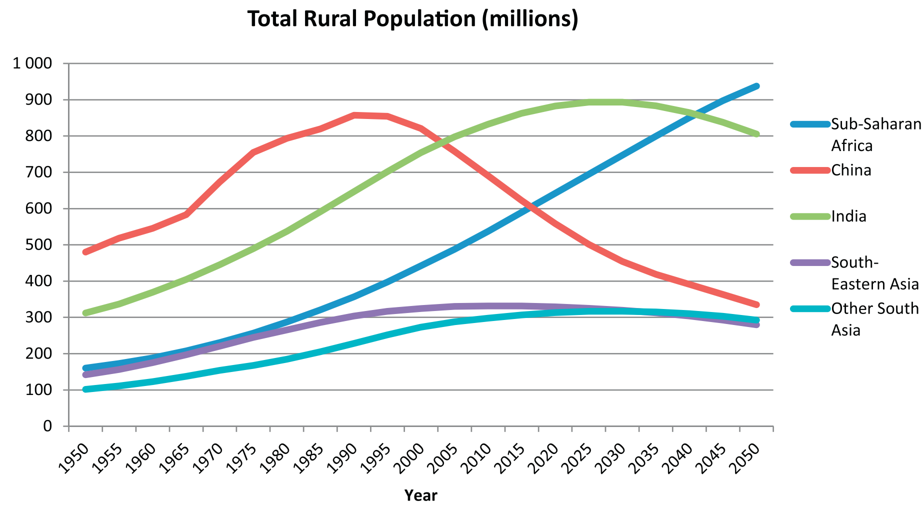

Fig. 2. Total rural population (millions), 1950 to 2050.
Source: United Nations, Department of Economic and Social Affairs, Population Division. 2014. World Urbanization Prospects: The 2014 Revision, custom data acquired via website.

Pray et al. (2017, p.7) observe, since a central aspect of AR4D investments' effectiveness in poverty reduction rests on these structural patterns and related labor force differences, "This leverage eventually disappears as countries become richer, because a smaller fraction of the workforce remains in agriculture …".

2.2. Agrarian differentiation

In their effort to synthesize strategic insights from agricultural and rural development experiences of the 1960s–1980s, Tomich et al. (1995) built a case for the feasibility and desirability of a broad-based agricultural development strategy aiming for a "unimodal" agrarian structure (the distribution of farms by size). Recognizing differences across farms and within households, the point nevertheless was that a single agricultural strategy could raise productivity on the vast majority of farms in a country (including especially the majority of farms that were small- and medium-scale operations, but also some large farms), entrain economy-wide growth multipliers, including growth in income and employment in the rural non-farm economy, and thereby create a growth dynamic that tightened labor demand and dramatically reduced poverty.[6]

Looking ahead to prospects for 2050 and based on 21st Century experience, Hazell (forthcoming) foresees growing differentiation within the agricultural sectors of developing countries, with small farms becoming smaller and more numerous; more part-time farmers, particularly among smallholders, for whom agriculture is a modest and diminishing share of household income; and growing bifurcation between large and small farms, commercial and non-commercial farms, young and elderly farmers, and geographically well-situated regions (both rural and urban) versus isolated, marginal rural areas. In contrast to the Tomich et al. strategic view for the late 20th Century, Hazell makes the case that contemporary conditions require that AR4D strategies aimed at poverty reduction must consider a typology of different smallholder types with very different resources, connections to markets, and hence economic prospects and AR4D needs.[7] To these categories, we must also add important differences in household structure and intra-household differences across farms, even within the same communities, and the culturally-mediated roles of gender and marital status in access to education and health services and to land, irrigation water, forests, and other resources as well as proscriptions on social interaction, affecting both labor market participation and wages, and which systematically disadvantage women and girls and make them more likely to experience poverty (Sen, 2001).[8]

2.3. Urbanization

Our species passed an historic turning point with the new millennium: we now are predominantly an urban species for the first time. According to the World Bank ("World Development Indicators"), world population was 54% urban in 2015 compared to 43% as recently as 1990. Urban population shares are positively related to GDP per capita, but most low and middle income countries also have seen significant increases in urbanization over the past 25 years. For the 60 countries in Fig. 3 – the 58 from Tomich et al. (1995) plus the two newest, South Sudan and Timor L'este – 48 saw their urban share grow by more than 5 percentage points and only 5 experienced a decline in the share of urban residents from 1990 to 2015. During this period India's urban share increased from 26% to 33% while China's increased even more dramatically, from 26% urban in 1990 to 56% in 2015.

D'Amour et al. (2016) project that expansion of cities through 2030 will continue to occur on some of the world's most productive croplands, as has been the case through much of human history, with the vast majority of this cropland loss from forthcoming urban expansion in Asia and Africa. They also project that cropland lost to urbanization globally by 2030 will account for 3–4% of crop production in 2000. This is a noteworthy number to be sure, but to understand the most important implications of urbanization for AR4D, one must consider two other phenomena: dietary transformation and shifts in non-farm economic activities related to food and agriculture. One important driver of these dietary patterns is the decline in starchy staples and rising consumption of dairy, livestock, and seafood products, edible oils, and fruits and vegetables that accompanies rising household income and food expenditure, known as Bennett's Law. For example, a recent study of shifting food demand in the 15 West African countries by Zhou and Staatz (2016) suggests that while there may be ongoing shortfalls in production of rice and wheat, the focus of food policy needs

[6] There are many elements to this analysis, but one empirical pattern that underpins the case that there is no tradeoff between production efficiency and social equity while wages are low is the empirical evidence pointing to an inverse relationship between farm size and productivity (often proxied by crop yields). Initially drawn mainly from research in Latin America and South Asia (Berry and Cline, 1979), other evidence indicates a strong inverse relationship persists in sub-Saharan Africa (Barrett et al., 2017).

[7] Over the past 10–15 years, advances in remote sensing and spatial analysis methods have greatly increased possibilities for analysis of the geography of smallholder agriculture; compare Dixon et al. (2001) to Samberg et al. (2016) and Herrero et al. (2017).

[8] For overviews of rigorous modeling approaches see Strauss and Thomas (1995) and Haddad et al. (1997).

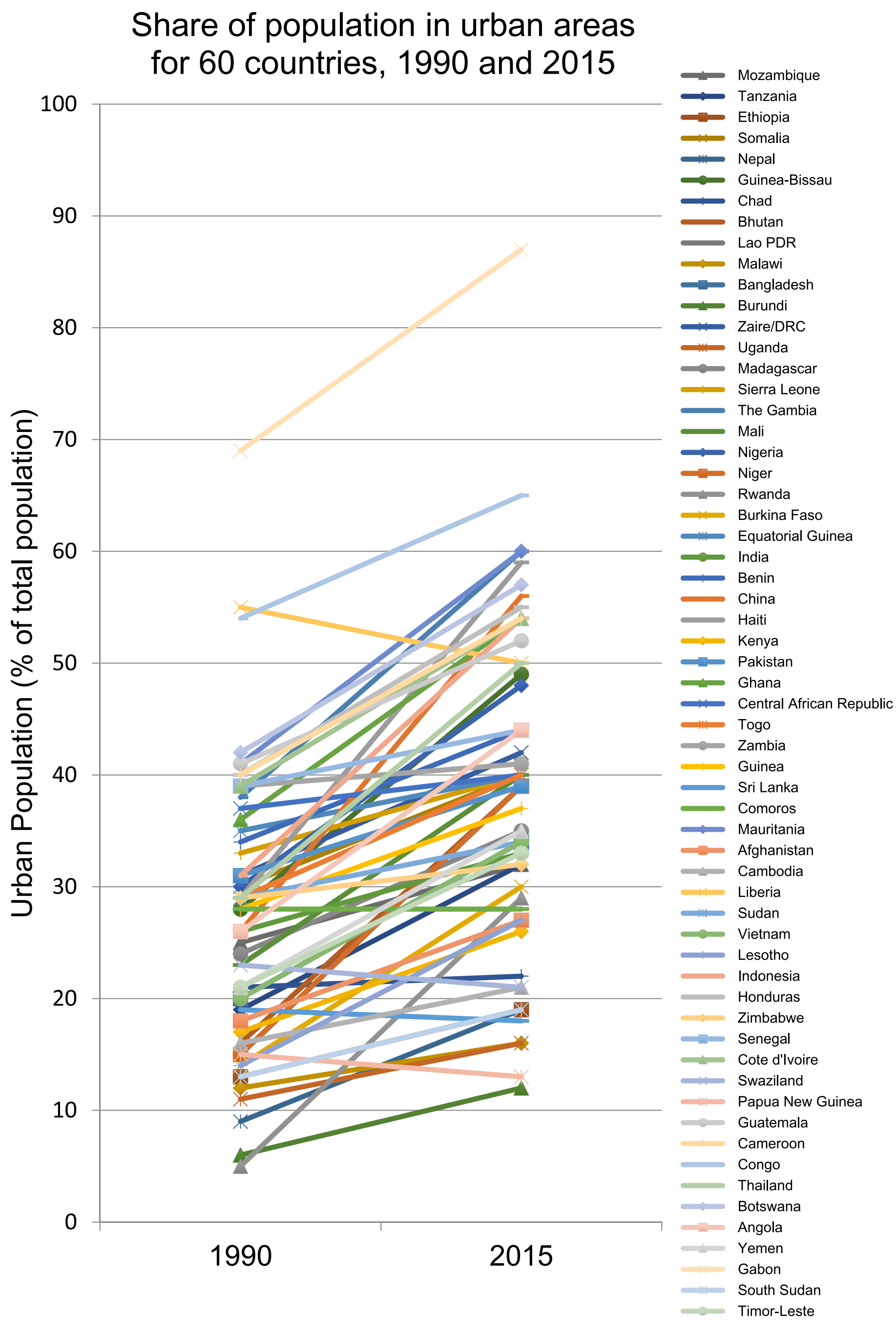

Fig. 3. Share of total population in urban areas for 60 countries, 1990 and 2015.
Source: The World Bank. 2017. "Table 3.12 World Development Indicators: Urbanization." Data Catalog. URL: http://wdi.worldbank.org/table/3.12.

to broaden to include foods for which demand will increase more quickly, in line with Bennett's Law.

But urbanization also is associated with significant changes in human diets above and beyond the effects of prices and income, typically shifting food consumption toward sources that are more convenient, including supermarket shopping and meals away from home, and often toward greater reliance on more processed foods (Hawkes et al., 2017; Minten et al., 2017). In Africa, an extreme version of these phenomena is expressed in "consumption cities," a term coined by Gollin et al. (2016b) to describe urbanization involving high import shares, including relatively high reliance on food imports, and a large share of employment in non-tradable services rather than manufactured goods. Barrett et al. (2017, pp. 2–3) associate these "consumption cities" with "greater slum formation, higher urban poverty, larger rural-urban income gaps, and more inequality …".

All of the contextual factors covered in this section so far – structural transformation, agrarian differentiation, and especially urbanization – lead to growth in transportation distances, grading, aggregation, storage, and other marketing functions plus processing and manufacturing; wholesale and retail food sales, including food hawkers and stalls, cafés and restaurants; and even agrotourism; as well as natural resource flows, recycling, and waste management at each step. Each of these depends on agriculture, but none counts within the agricultural sector in the accounting conventions that produce GDP estimates. Put simply, the development process brings a big shift from farm-level production to myriad services and manufacturing. Reardon et al. (2018, in this issue) present data on the scale and significance of these activities in contemporary developing countries, illustrating the particular importance of labor-intensive service sector growth related to food and agriculture.

This is why Barrett et al. (2017, p. 14) call for the strategic focus to be … "as much on the post-harvest value chain and the rural non-farm economy as on farm-level production". Those authors make that argument for sub-Saharan Africa, but it applies with growing force across the developing world. Indeed, we argue in our review of impact pathways and mechanisms in Section 3 of this paper that this "food systems perspective" (Fig. 3) holds important insights on opportunities for growth in income and employment, and hence poverty reduction and rural prosperity, through AR4D. This food systems perspective, which provides the overarching conceptual framework for the next section of this paper and this special issue, includes a "value chain" running from agricultural inputs all the way through human wellbeing as its backbone, supported by the natural resource base and also encompassing wastes from these value chain activities, which can be recycled or reclaimed into resource flows in some cases. Fig. 3 also portrays the food system as a quintessential example of a coupled ecological and social system, spanning both landscapes and "lifescapes".

2.4. Climate destabilization

Evidence has mounted since the 1990s that there has been a "great acceleration" of changes in "the state and functioning of the Earth System" since the mid-20th Century (Steffen et al., 2015). In particular, the set of assessment reports of the fifth assessment of the Intergovernmental Panel on Climate Change (IPCC AR5) concluded that "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia" (IPCC, 2013, p. 4). This warming is projected to increase variability in climate and weather (Thornton et al., 2014, p. 3313). Risks from extreme weather and climatic uncertainty always have been challenges for farmers, pastoralists, and fisher folk, but some of the changes that already have been seen are unprecedented in human history and uncertainties ahead may conceal significant vulnerabilities across our food system.

Among key risks of climate change that have been identified with "high confidence," the IPCC included "… breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations …" and "loss of rural livelihoods and income due to insufficient access to drinking water and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions" (IPCC, 2014, p. 13). Effects of climate extremes on agricultural production are expressed through sensitivity of crop yields to extreme daytime temperatures,[9] elevated ozone levels, spread and competition from invasive weeds, drought and flooding, with greatest negative effects for food and agriculture projected to occur in the tropical and subtropical developing countries (IPCC, 2014; Thornton et al., 2014). Although the strongest effects of climate change are likely to be at the agricultural production stage, and most research has focused on crop yield impacts, climate destabilization also threatens other aspects of the food system, including food safety (Vermeulen et al., 2012) and destruction or disruption of critical food system infrastructure, such as roads, bridges, ports, storage and processing facilities, or the power grid (Reardon and Zilberman, 2018). Prospects for sea level rise from global warming have changed markedly across the various IPCC assessment cycles and remain highly uncertain; estimates incorporating new ice sheet models and data after IPCC AR5 suggest that global mean sea level rise "could exceed 2 m by 2100" (Oppenheimer and Alley, 2016, p. 1375); compounding uncertainties regarding inundation of low-lying cropland and coastal cities, including many of the Earth's great metropolises, and inducing migration by huge numbers of people.

2.5. Other factors and sources of uncertainty

Climate destabilization is but one of several important factors underlying the new reality of non-stationarity in key life support systems.[10] Integrated ecosystem assessment practice provides some guidelines on underlying economic, demographic, sociopolitical, cultural (and religious), and technological drivers to be considered in assessing dynamics of change in Earth systems (Tomich et al., 2010, p. 88).[11] Some of these economic and demographic drivers have been discussed above in Sections 2.1–2.3, though these are not exhaustive by any means. For example: aging of the human population, particularly in rural areas, brings its own sweeping implications.

Trade policy is one of the most important sociopolitical drivers of the food system, particularly the durability of an always-elusive "consensus" on free trade that has been advocated since the mid-19th Century. Despite significant progress on reducing trade barriers since WWII, history shows that this is easily reversible. "Liberal" trade in food commodities is particularly problematic politically and socially. Moreover, mounting problems of invasive pests and novel diseases accompanying global change also may add pressure on trading regimes. Emerging cultural shifts with implications for the food system include concerns with the welfare of livestock and their international manifestation in vegetarian, vegan, and animal rights movements.

Any contemporary consideration of possible disruption of the food system (for good or ill) through technological change would have to include the displacement of the public sector role by private investment as the leader in agricultural R&D; CRISPR-Cas9 biotechnology; and other separate prospects for applications of modern genetics to the ecologies of entire biomes (e.g., soil, plant, and gut biomes of humans and livestock). The sensor revolution, including wearable devices, spans scales from the individual person or small patches within fields to entire regions and the whole planet; these in turn may enable rapid development of food system informatics with its own potential for disruption of food business models. Included in this is the emerging commercial viability of synthetic substitutes for red meat and potential for invertebrate sources of animal protein (e.g., arthropods) for humans, pets, and livestock.

Each of these possibilities encompasses complex economic, social, and technological changes. Many other sources of uncertainty are less obvious because they span sectors. Consider the possible reaction and implications for concentrated animal feeding operations of a plausible historic disruption of the human health system linked to non-therapeutic use of antibiotics in livestock. Food and energy interactions are another potent source of feedbacks (Pelletier et al., 2011), including biosphere-scale tradeoffs between food versus biofuel (Rosegrant and Msangi, 2014) and biomaterials.

3. Mechanisms and pathways to prosperity

While often listed as the primary intended beneficiaries of AR4D, poor smallholder farmers are not the only potential winners, nor is a

[9] In temperate regions, "chilling hours" necessary for production of some deciduous fruit trees may not be met because of warming of winter nights.

[10] Non-stationarity is the term for uncertainty in key model parameters, the Earth System modelers' version of the financial sector adage "past performance is no guarantee of future results." This creates an imperative for greater investment in foresight efforts by our scientific leaders, national policymakers, international organizations, funders, and others who shape AR4D policies and priorities (Pingali and Serraj, 2018).

[11] Though true foresight lies beyond human capabilities, there are proven methods for improving consistency and rigor in dealing with uncertainty in Earth's life support systems, including the food system. One practical step is the consistent assessment of qualitative uncertainty, developed for the Intergovernmental Panel on Climate Change (IPCC) by Moss and Schneider (2000); also see Mastrandrea et al. (2011); contributors to this special issue have been encouraged to employ this approach.

Table 2
Bibliometric search strings and number of publications ("hits") for our 18 impact pathways.
Source: Data from Elsevier Scopus. URL: http://scopus.com.

	Pathway	Search term string	Hits[a]
	All[b]	*("poverty reduc*" OR "poverty alleviat*" OR "poverty impact")*	
1	Innovations to increase productivity – Breeding	*AND ((increase OR improve) AND (productivi* OR yield)) AND ("plant breeding" OR animal OR livestock OR genetic* OR crop OR fish OR poultry)*	2271
2	Innovations to increase productivity – Agricultural practices	*AND (((increase OR improve) AND (productivi* OR yield)) AND agricult* AND practic*) OR "sustainable intensification"*	1960
3	Innovations to minimize production risks – Breeding	*AND (mitigat* OR minimiz* OR reduc*) AND risk AND (breeding OR "genetic improvement") AND (crop OR livestock OR fish OR poultry OR animal)*	388
4	Innovations to minimize production risks – Agricultural practices	*AND (mitigat* OR minimiz* OR reduc*) AND risk AND agricult* AND practic* OR climate*	4182
5	Market imperfections and failures – input systems	*AND agricult* AND input AND market**	1455
6	Market imperfections and failures – Value chains	*AND agricult* AND ("value chain" OR market*)*	10,697
7	Agricultural diversification	*("poverty reduc*" OR "poverty alleviat*" OR "poverty impact") AND ((agricult* AND diversi*) OR agrobiodiversity) AND (practic* OR market* OR system*)*	5317
8	Natural resource management	*AND ("natural resource management" OR "land restoration" OR "soil fertility management" OR water OR watershed OR forest* OR tree* OR agroforestry) AND agricult**	9808
9	Natural resource governance, property rights, and livelihoods	*("poverty reduc*" OR "poverty alleviat*" OR "poverty impact") AND "natural resource*" AND (governance OR institution OR polic*) OR property OR livelihood**	7828
10	Human nutrition	*AND nutrition* AND ("farm system" OR breeding OR practic* OR input OR "value chain")*	3407
11	Human health – food consumers	*AND (health* OR safe*) AND food AND ("value chain" OR "input")*	1247
12	Human health – farmers and farm workers	*AND health AND (farm* OR (worker OR laborer)) AND (disease OR zoono* OR infect* OR hazard*)*	2523
13	Education (agricultural skills)	*AND educat* AND (agricult* OR farm*) AND (skill* OR income OR labor)*	4210
14	Food supply	*AND "food supply"*	1161
15	Food waste	*AND "food waste"*	68
16	Food safety nets	*AND food AND (secur* OR consum*) AND ("purchasing power" OR vulnerability OR demand OR policy)*	8957
17	National agricultural R & D	*AND agricult* AND ("research and development" OR "R&D" OR extension)*	5845
18	National food and agricultural policy	*AND national AND (food OR agricult*) AND (policy OR "political economy")*	10,560

[a] Searches run on Elsevier Scopus during the period 1 December 2016–19 May 2017, on article title, abstract, and keywords. Results restricted to publication dates in the range 1990–2015.
[b] All searches prefixed with a string to include poverty reduction, poverty alleviation, or poverty impact and all truncations of these terms.

positive outcome guaranteed. Indeed, poor farmers can lose out in the innovation process. In addition, it is important to recognize that rural landless laborers, traders and entrepreneurs, and food consumers (including the urban poor) also are among the groups who can benefit (or lose). As a starting point, which will be elaborated and qualified in the balance of this paper (see Section 4 below), there are at least four important and complementary mechanisms out of poverty for rural people in developing countries: (1) increased farm income; (2) decreased food prices; (3) greater employment opportunities and higher wages (in real purchasing power) due to tightening demand for rural labor, including farm labor; and (4) rural to urban migration (World Bank, 2008). In practice, there are multiple, complex impact pathways through which AR4D could contribute to reductions in poverty.

In this section, we consider both the direct ways AR4D can increase farm income and the equally important indirect effects of AR4D, operating through agricultural labor demand and multiplier effects that expand employment in the non-farm labor market (both rural and urban), and complementary innovations in institutions and policies. In addition to short-term income effects on poverty, investments in assets, including both natural and human capital, provide the basis for long-term poverty reduction. Moreover, effects on poverty (for good or ill) often depend on additional complementary activities and investments both within and beyond agriculture. And, as discussed in the previous section, the likelihood of success overall is shaped (often decisively) by the broader context. However, it also is important to note that the important topics of rural – urban migration and international migration as pathways out of poverty are beyond the scope of this special issue. Here too, the results can be mixed. In Nepal and parts of India, for example, men are migrating or pursuing non-agricultural livelihoods (Sunam, 2017), leaving women with greater responsibilities in agriculture ("feminization of farming"), without necessarily the resources to meet those responsibilities.

Impact pathway analysis (Springer-Heinze et al., 2003) is a widely-accepted technique in international development practice for systematic analysis of causal relationships linking development investments (e.g., AR4D) through to impacts (e.g., poverty reduction).[12] The primary purposes of this section are to present an *ex ante* set of 18 plausible poverty impact pathways (Table 1) and to introduce the collection of papers in this special issue, which have been invited to clarify causal hypotheses underlying these pathways, assess the empirical evidence linking AR4D investments to poverty impacts, and to consider potential trade-offs; for example, situations in which innovations may be detrimental to groups of poor people or increase income inequality. Many of the papers in this special issue address more than one of our 18 impact pathways; in this section we bring up each paper in turn regarding its respective focal pathway.

Following the terminology of "outcome mapping" (Smutylo, 2001), Table 1 is organized to show relationships spanning AR4D activities, their outputs, uptake, outcomes, and poverty impacts for our 18 *ex ante* pathways. Building on an initial list of eight pathways linking AR4D with poverty reduction, approximately 200 expert participants at the ISPC's Science Forum 2016 made further suggestions in semi-structured sessions. These suggestions were compiled into 18 *ex ante* pathways in a results-based management format (Table 1).

Standard bibliometric tools were used to describe the scope and time trends in publications from 1990 to 2015 for each pathway as a measure of adequacy and currency of data on key cause-effect relationships. A string of search terms was developed for each pathway (Table 2) and queried in Elsevier Scopus, Web of Science, and Ovid. Keywords and Boolean combinations were iteratively tested and adjusted in order to reduce the numbers of irrelevant results. Scopus returned significantly more publications for all pathways than Web of Science or Ovid, with a high rate of overlapping results; because of this, Scopus was used as the primarily bibliometric tool.

[12] This is similar to the idea of "logical framework" analysis used widely by operational organizations when designing and assessing program implementation.

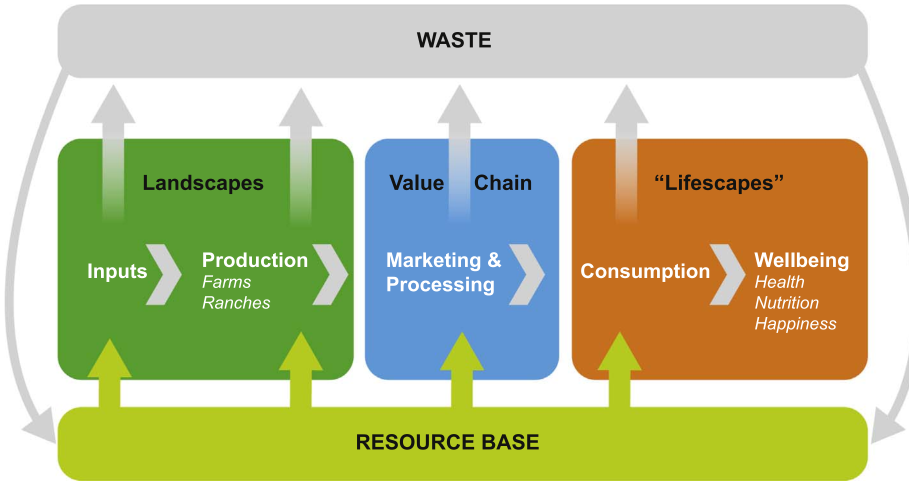

Fig. 4. Food systems perspective.
Adapted from a figure by Michele Grant, World Food System Center, ETH Zurich.

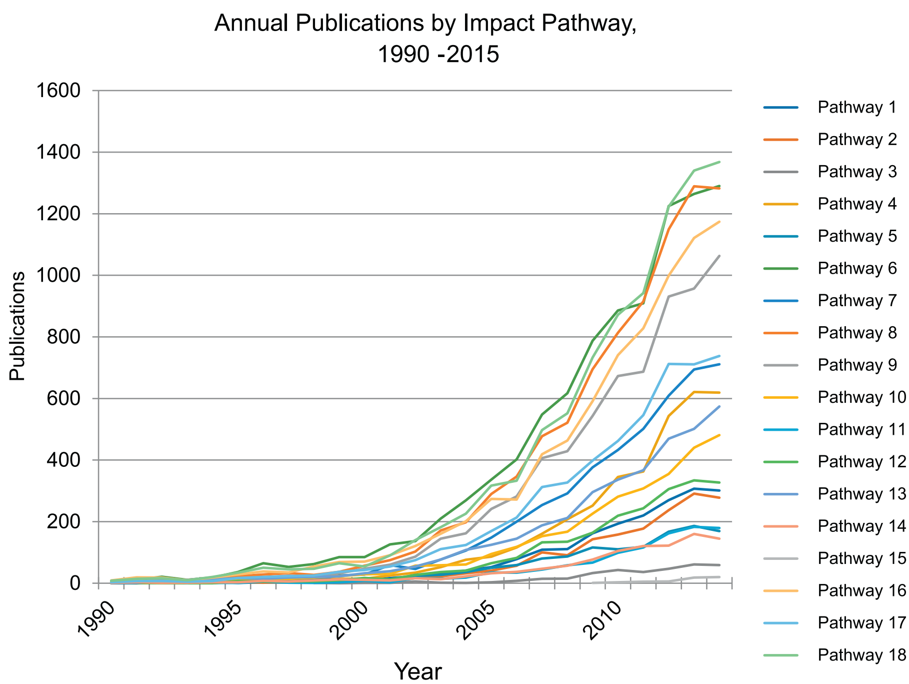

Fig. 5. Publications by impact pathway, annually, 1990–2015.
Source: Data from Elsevier Scopus. URL: http://www.scopus.com.

As can be seen in Table 2, the number of publications per poverty impact pathway during that time period varies by three orders of magnitude, from a low of 68 for food waste (**pathway 15**) to more than 10,000 publications each for value chains (**pathway 6**) and national food and agricultural policies (**pathway 18**). At least for publications indexed in Elsevier's Scopus database, publications meeting the search criteria in Table 2 appear to be increasing with time for each of the poverty impact pathways (Fig. 5); it is no surprise that one of the newest areas of research, food waste (**pathway 15**), also has the fewest publications.

Investment to increase agricultural productivity through breeding of new varieties of crops, livestock, poultry, and fish (**pathway 1**) combined with improved management practices (**pathway 2**) has been fundamental to the case for AR4D investment since at least the 1960s. Hayami and Ruttan (1971, 1985) used evidence from an international cross section of countries to link agricultural productivity growth to increased incomes (in cash and kind) for poor farmers; increased employment opportunities in agricultural markets even for landless rural laborers; and, higher wages overall because of increased demand for farm and non-farm labor. These potential poverty-reducing effects are focused within the "landscapes box" (including input supply and farm-level production) of Fig. 4; as we will see below, these innovations entrain effects across the value chain, with potentially large benefits for urban workers and food consumers as well.

Widening application of low-cost modern genetic testing ("genetic fingerprinting") and other increasingly rigorous impact assessment methods have raised some questions and qualifications regarding the scope of adoption of some major staple crop varieties (Ilukor et al., 2017; Walker and Alwang, 2015). Alwang et al. (2017, this issue) employ meta-analysis to critically examine the links between AR4D investments to increase staple crop productivity and poverty reduction. (Unfortunately, it was not possible to secure a comparable paper regarding investments intended to increase productivity in livestock or aquaculture).

As noted by Krishna (2010), to reduce poverty overall, it is not enough for the poor to increase their incomes; it is also important to reduce the likelihood of people becoming poor. This is particularly true for rural households. Thus, in addition to concerns with "average" productivity trends over time, all farmers face numerous challenges, risks, and vulnerabilities, including climate variability and extremes (droughts and floods), pests and diseases, adverse price changes, institutional failures and political upheaval, to name a few, that can devastate farm production and hence income. Uncertainties raised by climate change (Section 2.4) greatly accentuate all of these potential risks and uncertainties.[13] Innovations to minimize production risks and uncertainties through breeding (**pathway 3**) and risk-mitigating agricultural practices and other risk management mechanisms (**pathway 4**) for crops, livestock, poultry, and fisheries can reduce vulnerability for poor farmers; and, as a consequence, create more stable demand for farm and non-farm labor (**pathways 3 and 4**).

Even more than **pathways 1 and 2**, AR4D investments for **pathways 3 and 4** have focused on the "landscape box" in Fig. 4. Hansen et al. (2018, this issue) consider the role of AR4D investments in mitigation of risks and uncertainty, with emphasis on approaches to uncertainty resulting from climate destabilization (Section 2.3), as a means of reducing poverty. Our bibliometric analysis (Table 2) suggests a surprising imbalance here between the poverty impact pathway for breeding aimed to reduce production risk (**pathway 3** with only 388 hits) versus agricultural practices to reduce production risks (**pathway 4** with 4182 hits). Hansen et al. (2018, this issue) also consider how climate shocks can propagate uncertainties and vulnerabilities across food supply chains and promising measures on how food supply chain actors might mitigate shocks through, for example, diversification of agricultural investments, including rigorous development of evidence to guide these investments to greater resilience (Global Panel, 2015a).

Underpinning all this is the existence of necessary input supply chains for plant and animal germplasm, nutrients, and other agricultural inputs (**pathway 5**). Our bibliometric analysis suggests this is only a moderately well-studied impact pathway (1455 hits in Table 2), which is a bit of a riddle given the centrality of input supply, to the "seed-fertilizer revolution" that was central to the so-called "Green Revolution" (Tomich et al., 1995).

In contrast to the relative paucity of attention to input supply (**pathway 5**) in Table 2, Scopus bibliometric analysis indicates that publications on output market opportunities and "value chains" is one of the two poverty impact pathways for which publications are most numerous (10,697 "hits" for **pathway 6** in Table 2). Reardon et al. (2018, this issue) explicitly address the entire value chain (spanning from "landscapes" to "lifescapes" and also consider food waste streams (**pathway 15**) in Fig. 4; their analysis makes a strong case for broadening and extending consideration of AR4D priorities to a food systems perspective, especially in light of the contextual changes discussed above (Section 2).

Diversification of crops from starchy staples (grains, roots, and tubers) to livestock, poultry, and fish; pulses and oil seeds; vegetables and fruit; livestock feed and fodder; biofuel and other products (often from agroforestry and forest trees) and extending beyond commodities to services such as ecotourism, can increase income for poor farmers and rural workers (**pathway 7**). Diversification toward profitable agricultural production options such as livestock, poultry, fish, edible oils, fruits and vegetables has received a significant amount of AR4D research emphasis (e.g., 5317 "hits" for **pathway 7** in Fig. 4). There is little doubt that in the right context – viz., the demand patterns predicted by Bennett's Law when a country reaches "middle income" status – shifting to production of commodities and services with positive income elasticities holds profitable opportunities for farmers, including small-scale farmers (Siegel et al., 2014).

However, we would argue that too much of the "diversification" literature focuses on the production side to the neglect of the crucial role of prosperity-driven demand patterns in shaping profitable production opportunities (the "landscapes box" in contrast to the "lifescapes box" in Fig. 4). Barrett et al. (2017, p.5), for example, argue that "diversification is too often thought of as just a risk mitigation strategy … The rural non-farm sector thus provides a crucial bridge between commodity–based agriculture and livelihoods earned in the modern industrial and service sectors in urban centers …," foreshadowing the argument developed in Reardon et al. (2018, this issue) and spanning the entire backbone of the food system, from inputs and farm level production to marketing and processing, and ultimately to consumption and food waste management (Fig. 4). Moreover, each of these steps is potentially highly labor-intensive, which is a positive attribute in creating labor demand and higher wages for workers at the bottom rungs of the socioeconomic ladder in the poorest countries, whether they are rural or urban.

A separate pair of pathways concern the resource base underpinning every aspect of our food systems (Fig. 4). More effective natural resource management (NRM) through AR4D investment to improve and develop new practices and technologies, combined with AR4D research on institutions and policies, can contribute to increased incomes for the poor through innovations in natural resource governance, property rights, and rural livelihoods, thereby reducing vulnerability for rural communities and poor farmers; more stable demand for farm and non-farm labor; improved distribution of wealth, benefitting poor people; improved environmental health, and empowerment of the rural poor to improve their livelihoods (**pathway 8**).

As discussed by van Noordwijk (2017, this issue), NRM policy research and institutional innovations can also build security of tenure and access to resources (i.e. land, fisheries, grazing, forests, freshwater for domestic use and for irrigation) and thereby have sweeping implications for reduction of poverty and vulnerability to external threats, both biophysical and anthropomorphic. Even more recalcitrant cultural, social, political, and economic injustices in access to these resources can perpetuate the intergenerational transmission of chronic poverty despite all these other AR4D investments. Since the ability to feed and educate children adequately determines so much of their prospects (as discussed immediately below), ingrained social, cultural, political, and economic factors that differentiate opportunities of men from women and boys from girls (see Section 4) are directly implicated in the persistence of poverty (**pathway 9**). Meinzen-Dick et al. (2017, this issue) conduct a comprehensive survey of the literature on the links between women's land rights and rural poverty, including through the effects on consumption and investments that affect intergenerational transfers.

It may appear obvious that AR4D investments that support improvements in human nutrition and health are important for poverty reduction (**pathways 10, 11, and 12**). Increased labor productivity and greater labor force participation to increase wages for laborers and incomes for poor farming households underpin all pathways from AR4D to prosperity.

Although it is widely argued that incorporating nutrition objectives into AR4D can produce improvements in dietary quality, and hence on nutrition for the poor (Gillespie and van den Bold, 2017; Pingali and Sunder, 2017), rigorous empirical evidence linking these results on to reduction of poverty has been elusive.[14] Part of the challenge in marshalling evidence for AR4D impact pathways linked to health and nutrition arises from potential confounding factors, such as access to

[13] Knight (1921) distinguishes "risk", for which probability distributions are knowable (based on the notion of stationarity of system parameters; viz., the past is a reliable guide to the future) from "uncertainty", for which probability distributions are unknown *ex ante*. As we argued in Sections 2.3 and 2.4 above, this pure uncertainty in Knight's sense is increasingly important in our food systems and other key life support systems on our planet.

[14] Hoddinott et al., 2013, is one of the relatively few examples.

health services, child feeding practices, water, sanitation and hygiene, education, consumer preferences and food handling practices. At the same time, a mother and child's adequate, high quality and diverse diet acts on poverty reduction and rural prosperity through multiple long-term (intergenerational) pathways; these include reduced childhood morbidity (which carries mortality risks and treatment costs), appropriate school attendance and higher educational attainment, lifetime physiological and cognitive development, and total income earned via adult labor productivity (Alderman et al., 2017). Empirically tracing such long-chain results – from investments in agriculture through pregnancy and childhood diets all the way to adult wages – represents a major research challenge. Few longitudinal panel and prospective birth cohort surveys have been able to meet the numerous costs and challenges involved in following individuals from pregnancy to adulthood and into the subsequent generation (Morrow and Dornan, 2017). The few that have achieved this, at least in part, have generally documented the positive value of meeting dietary needs on early child growth and development, leading to much improved health, education and physiological status (Prendergast and Humphrey, 2014; Ramirez-Zea et al., 2010). However, much more needs to be understood regarding key determinants and mechanisms along this longest of pathways.

In light of evidence that illness is one of the major reasons that people fall into poverty (Krishna, 2010), it is a point of particular concern that human health effects of food safety (**pathway 11**) have received relatively limited attention in the AR4D literature, including innovations in field practices, post-harvest management and food storage, processing, and distribution, plus creating enabling policy and institutional environments to reduce contamination and food-borne pathogens for consumers. Unsafe food is a significant cause of disease and death, with the global burden of food-borne diseases estimated at 33 million Disability-Adjusted Life Years (DALYs),[15] and the uncertainties accompanying climate change and emerging science on naturally-occurring food-borne toxins and on the gut microbiome (Sections 2.3 and 2.4) increase the importance of these issues. Separately, and more directly, occupational health of farmers and farm workers (**pathway 12**) is affected by exposure to pesticides and other agri-chemicals, risk of injury (both acute and chronic) associated with agricultural production practices, alteration of ecosystems due to agricultural practices that contribute to water and vector-borne diseases, and prospects for emergent zoonotic diseases associated with intensive animal husbandry (e.g., virulent flu virus strains and antibiotic-resistant strains of bacteria). Underinvestment in research on these topics is not limited to the developing world; it is almost universal.

Some opportunities for significant gains in human wellbeing rest with familiar practices such as integrated pest management to reduce pesticide use and lie squarely within the "landscape box" of Fig. 4; however, even more worrying threats to food systems and health systems may require heretofore unprecedented integration of R&D strategies across our food systems and crossing boundaries between our food and health systems, including only partially-understood potential risks from widespread (mis)use of pesticides and other agrichemicals, growth hormones, endocrine disruptors, and antibiotics in our food systems as well as environmental pollution from other pharmaceuticals and personal care products entering our food system through contaminated water.

The effectiveness of educational investments to build agricultural skills as well as basic literacy and numeracy (**pathway 13**) is well studied (4210 hits in Table 2). Such investments have been a well-established development priority for a long time (Tomich et al., 1995, Chapter 8). Although not typically grouped within AR4D, reasonable people may disagree whether this topic (and indeed others) was a priority for this special issue. Since these basic educational investments do not seem controversial in their impact on poverty; they have intrinsic value in and of themselves (Schultz, 1975; Sen, 1981 and 1989) particularly as means to deal with uncertain prospects like those discussed in Sections 2.3 and 2.4; and because they tend to be politically popular, a paper on **pathway 13** was not sought for this special issue.

Agricultural productivity growth also tends to lower food prices, which benefits the poor who are net purchasers of food, and spend a large proportion of their incomes on food (**pathway 14**). This whole food system effect – emphasized by Reardon et al. (2018, this issue) – with productivity-boosting innovations in rural landscapes producing poverty reduction in distant "lifescapes" (Fig. 4) is one of the greatest benefits of the "Green Revolution" and also produced some of the seminal work on AR4D impact assessment (Scobie and Posada, 1978).

Food waste has received more attention in recent years in relation to the environmental "footprint" of food systems (Chen et al., 2017). At the same time, food waste management has received little attention in the context of poverty reduction (**pathway 15**); our bibliometric study found only 68 citations on this topic in Scopus (Table 2). Nevertheless, if food waste is a significant problem in developing countries, there may be expanded employment, entrepreneurial, and income opportunities for poor households in both rural and urban areas through expansion of labor-intensive recycling enterprises and other initiatives to reduce food system waste and convert waste into commercially-valuable resources; yet another possibility that emerges from a whole-food-system perspective (Fig. 4). Reardon et al. (2018, this issue) consider food waste (**pathway 15**) within the broader scope of food and agricultural markets and value chains (**pathways 5, 6, and 14**); the results of their analysis of the limited evidence that is available are provocative, to say the least.

The scope and limits of "food safety net" programs to reduce poverty (**pathway 16**) has received a great deal of study since they became common during World War II and persisted through the post-colonial period in many developing countries. Because of their continued prevalence, potential fiscal burdens, and opportunity costs entailed vis-à-vis AR4D and other development investments, these programs have been the subject of continuing research, including major studies led by the International Food Policy Research Institute (IFPRI). From 1990 to 2015 alone, we found 8957 hits in Scopus for **pathway 16** (Table 2). Many of these have generated influential policy-relevant findings on, for example, food subsidy programs (as in Egypt), conditional cash transfers tied to health and nutrition (Mexico), labor-intensive public works supporting food transfer (India, Niger), rural finance for consumption smoothing (Mali, Madagascar) and food transfers in the context of famine or other humanitarian crises (Ethiopia, Sudan) (Hazell and Slade, 2015). Such work has recently focused more narrowly on cost-effectiveness, distributional impacts by income level and gender, and potential for cash or vouchers in lieu of food transfers (IFPRI, 2015). While many large national programs transferring income or food in poorly targeted and cost-inefficient ways have received much criticism, the continuing potential for effective public procurement and food transfers to achieve nutrition aims remains on the policy agenda of many low income countries – in part because of the opportunities presented to simulate domestic food production, marketing, and processing (Global Panel, 2015b).

Research and institutional development for national AR4D capacity – by this we mean research on national agricultural research and extension systems and strategies – and to build capacity for national food and agricultural policy (food policy analysis, political economy of food policy) can enhance national capacity for poverty alleviation (**pathways 17 and 18**). India is a very important case for any consideration of AR4D policy because of its size, its diversity, its complex challenges mixed with remarkable recent progress and, perhaps especially, because India is the world's largest democracy. Dey et al. (2018, this issue) present a case analysis from a long-term study of the interplay between a national non-governmental organization, the Honey Bee Network, and Indian AR4D priorities. Finally, Benfica et al. (2018, this issue) use

[15] http://www.who.int/mediacentre/news/releases/2015/foodborne-disease-estimates/en/.

a mix of methods and data for Mozambique to explore one of the most strategic questions regarding AR4D: given a range of possible investments – e.g., irrigation infrastructure, extension advice, or improved seeds and chemical fertilizers – what should be the top priorities for development investment and how can we know?

The links across some of the posited pathways remain poorly understood and evidence of effects is stronger for some pathways than for others. Moreover, as argued in Section 2 above, the strength and effectiveness of each depends greatly on structural and contextual elements that extend beyond the agricultural sector. Taken together the papers in this special issue seek to offer insights to inform improvements in the design of AR4D which seeks to reduce poverty. Owing to this heterogeneity and the agrarian differentiation discussed in Section 2.2, pathways to reduction of poverty may be very different for different groups of poor people, requiring different strategies and policies. Thus, it is important to distinguish different categories and characteristics of the rural poor; we turn to that topic in Section 4.

4. Impacts: reducing poverty, increasing resilience, and promoting rural prosperity

By conventional measures (e.g., the gap between income and some designated "poverty line"), the World Bank (Olinto et al., 2013, p. 1) reckoned for 2010 that "more than three quarters of those living in extreme poverty are in rural areas and nearly two thirds of the extremely poor earn a living from agriculture." Despite significant advances in the developing world overall since 1980, progress has been slowest in the lowest income countries (Olinto et al., 2013, p. 6).

Since at least the 1980s, development institutions have recognized that these conventional income- and head-count based poverty concepts convey only part of the story, especially for chronic poverty. The Multidimensional Poverty Index (MDPI), developed for the UNDP Human Development Report since 2010, measures 10 indicators of deprivation in the dimensions of health, education, and standard of living (see Alkire and Robles, 2017; UNDP, 2016). As Hulme and Shepherd (2003, p. 406) concluded, "… it is now widely accepted by analysts and policy makers that poverty is deprivation in terms of a range of capabilities in addition to income – education, health, human and civil rights – and that these capabilities are significant in their own right and in terms of their contribution to economic growth and income enhancement …".

The seminal work on this "entitlement" or "capability" approach is Sen's study of famines (1981): "In understanding the proneness to starvation, we have to view them not as members of the huge army of the 'poor,' but as members of particular classes, belonging to particular occupational groups, having different endowments, being governed by rather different entitlement relations." Sen shifted the focus of assessment of poverty or prosperity from measurement of "commodities or incomes" (which in his view confuses means with ends) to "evaluating the importance of various functionings in human life" (Sen, 1981, p. 44), These include states of being (nutrition, health, and other aspects of individual well-being) and also the capabilities for active pursuit of a full and satisfying life: access to education and productive resources, economic self-determination, cultural and social connections, and political voice to fulfill one's own potential.

Sen's perspective of "poverty as capability deprivation" (Sen, 1999) underpins the "sustainable livelihoods" approach now widely employed in development thinking and practice, including AR4D (Adato and Meizen-Dick, 2002, 2007). This approach expands conventional AR4D considerations to encompass gender bias and institutional mechanisms for greater equity in resource access, property rights, and redistribution of assets as means to address poverty, as well as basic human rights. Gender equity is particularly important in this regard, not only because of the strong gender gaps in resource access and capabilities, but also because of the importance of improving the status of women and girls for ending the intergenerational transmission of poverty.

While income or consumption-based measures and even the multidimensional poverty index are standardized, participatory poverty assessments draw on localized definitions of poverty, which may include other aspects, including social exclusion. Krishna (2010) used participatory poverty assessments to examine poverty dynamics over time, including factors affecting the likelihood of falling into poverty. Such approaches can be aligned with emerging notions of building resilience, which means "helping people, communities, countries and global institutions prevent, anticipate, prepare for, cope with, and recover from shocks and not only bounce back to where they were before the shocks occurred, but become even better off" (Fan et al., 2014, p. 4). Emphasizing the dynamics and uncertainty characteristic of these systems, Barrett and Headey (2014, p. 188) ask "… what does good measurement mean in the context of … resilience: risk, vulnerability, chronic and transient poverty, and food insecurity; and complex interactions between shocks and stressors at various scales and between households and their social, economic, and biophysical environments?"

Although poverty generally is measured at the household level, and most AR4D interventions take place at field, landscape, or watershed scales or within the agricultural sector as a whole, poverty, resilience, and prosperity manifest at individual (intra-household), household, community, regional, and national scales. As stressed by Hoddinott (2014, p. 25), measurements of impact for individual units is insufficient and a systems perspective is indispensable, with special importance to human capital formation (health, schooling, nutrition) as a means of building sustainable resilience … Barrett and Swallow (2006) note that constraints at various scales within these systems can lead to "fractal poverty traps", which require concerted action to overcome.

This cross-scale aspect of these complex casual relationships among AR4D investments, interventions, outcomes, and impacts presents significant challenges for monitoring, evaluation, learning, and impact assessment, and consequently for attribution of results.[16] Poverty, resilience, and prosperity each is an emergent property of the agri-food systems that AR4D is intended to affect, which materially complicates learning and impact assessment. Impact assessment methodology is well beyond the scope of this introduction to the special issue. Linking poverty impacts to A4RD is difficult, even for relatively well-researched pathways such as breeding to improve crops and livestock (**pathway 1**). Even in this case, unless AR4D products (crop varieties, livestock breeds, agronomic practices, or other innovations) are specifically introduced in a setting where poverty impacts can be observed against a clear counterfactual, the inference problem is severe. Farmers who adopt technologies typically are different from those who do not, and the corresponding selection bias makes it problematic to interpret differences between the groups as resulting from the technology. In cases where research products can be introduced in some randomized fashion, with an appropriate research design, poverty impact can in principle be inferred – but only if observations continue over a sufficiently long time horizon. A key lesson is that poverty impacts are almost impossible to measure reliably unless the initial research design is structured around this goal. Without thoughtful research design at the early stages, there is no statistical technique that can provide convincing evidence after the fact.

Moreover, the strategic challenge is not confined to the development of metrics for M&E and methods for impact assessment. Clark and coauthors (Clark et al., 2016; Anadon et al., 2016) argue that AR4D and other forms of innovation so often fail to work for sustainable development "because impoverished, marginalized, and unborn populations too often lack the economic and political power to shape innovation systems to meet their needs" (Anadon et al., 2016, p. 1). This is particularly applicable to women, who generally have less voice in AR4D systems. The implications of these challenges for metrics and indicators as well as partnerships, governance, transparency, and mutual

[16] See for example Duffy et al., 2017 for an effort to develop national level indicators.

accountability, are topics to which we return in the concluding paper of this special issue.

5. Conclusions

This paper approaches prospects for AR4D to contribute to poverty reduction as a systems problem, requiring consideration of shifting contexts, interconnected mechanisms, and complex outcomes and impacts. In the concluding paper in this special issue, we revisit these considerations and their implications for impact pathways, partnerships, and priorities. Changes in the context of these efforts in the developing world over the past three decades have fundamental implications for AR4D priorities. Structural transformation has significantly reduced the number of countries in which agriculture plays the dominant role in the economy, either in terms of GDP or employment. At the national level, the conditions that underpin the most compelling case for AR4D will largely be confined to sub-Saharan Africa in the decades ahead.[17] At the same time, a combination of structural change, better methods, and more nuanced understanding of chronic poverty has revealed the need for a more multifaceted approach to AR4D that targets the needs, constraints, and opportunities of specific groups, including women farmers and laborers. In light of these changes, plus the urbanization of the human population, it is necessary to embrace a food systems perspective well beyond farms and fields, the traditional foci of AR4D, to longer and increasingly complex food chains encompassing myriad activities off-farm and extending all the way to urban areas. Finally, mounting sources of uncertainty, vulnerability, and potential disruption in these food systems (for better or worse – and from a host of drivers, not just climate change) suggest that flexibility, adaptability, and resilience are important considerations in AR4D strategy.

The food systems perspective reveals a large number (indeed an unmanageably large number) of plausible pathways, from the conventional AR4D investments in breeding and livestock improvement to food waste recycling and food policy research. We now turn to our collection of papers that explore these implications for specific poverty pathways, with consideration of causal relationships across each pathway in light of changing context and understanding gained from decades of AR4D experience.

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[17] One aspect that is not considered here, but deserves to be mentioned, concerns the regional differences within some large middle income countries (e.g., Brazil, China) where poverty headcounts still are big and agriculture might still hold important opportunities for growth in aggregate income and employment. If so, this raises the additional question of whether these merit international efforts or if these development tasks are best left to national programs.

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