CHAPTER 8

Agricultural technology innovation

Summary

How does agricultural technology innovation (ATI) support structural and rural transformations to deliver widely shared benefits in rural areas? How does it contribute to making rural transformation more (or less) inclusive? What are the key strategies, policies and investments that can enable ATI to support inclusive rural transformation while avoiding adverse effects? This chapter tries to provide some answers, initially by arguing that the two transformations hinge on boosting the productivity of the agrifood systems that underpin most rural livelihoods. Productivity growth is an outcome of multiple interacting factors, tied to development, technologies and practices, reliable outlets for generated surpluses, institutions and policies, and investments that strengthen capacities. The key to success is innovation.

The chapter focuses on what drives or impedes innovations in agricultural production technologies. Its analytical framework is based on the concept of an 'agricultural innovation system' – a network of organizations, enterprises and individuals bringing new products, processes, and forms of organization into economic use, with the institutions and policies that affect their behaviour and performance.

ATI is crucial for inclusive rural and structural transformations. With growth linkages, surging agricultural productivity can kick start them, as Asia so dramatically showed in its Green Revolution. Even though framing conditions have changed since, governments seeking to spur rural inclusiveness still need to raise agricultural productivity to support the two transformations.

The most suitable technologies for the pair depend on context-specific conditions, which often change over time. ATI is only inclusive if smallholders can adopt and adapt technologies on a large scale – with challenging physical conditions and pervasive institutional and market failures, inclusivity is far from automatic. Governments and development partners must help create the environment for appropriate incentives for smallholders to do this, and should focus on increasing access to finance, inputs, extension services, and output markets. Once collective institutions like farmers' bodies have strengthened their organizational capacities, they can confer benefits tied to improved access to many of these products and services. Along with rental markets, these bodies can also help make available to their members "lumpy" technologies like tractors and other equipment. Finally, risk management strategies are essential to avoid poverty traps when small farmers adopt new technologies. Special attention must be paid to rural women: there is no such thing as inclusive rural transformation that leaves them behind.

Some agricultural technologies – such as genetically modified (GM) crops – stir up political and social controversy, often driven more by ideology than scientific evidence. But still lacking is an institutional pathway for filling the delivery gap for GM crops for the bulk of the world's smallholder farmers, so that genetic engineering is unlikely soon to be an important source of inclusive ATI in developing countries.

Innovative instruments for developing and disseminating technology, including information and communications technology (ICT), index-based insurance, and "smart" subsidies, may offer new prospects for creating the right environment for smallholders, but the effectiveness of these approaches needs to be carefully evaluated, first. Some experimental studies are promising, but the governance challenges in scaling up these instruments must be reckoned with, as the experience of elite capture in new models of fertilizer subsidies shows. Structural and institutional factors that impede inclusiveness must be addressed if these innovations are to yield their full potential. Viable business models for many of the innovations are yet to be developed.

Countries need to integrate environmental sustainability with their agricultural innovation strategies and develop regulatory mechanisms to mitigate adverse effects. Strategies include investing in farmers' knowledge through, for example, farmers' field schools and ICT, as well as adopting incentive schemes such as payments for environmental services.

To make the best use of technology, evidence-based policymaking should be followed, but it

requires capacity to be developed in agricultural research organizations and ministries' planning units. Participation by farmers, rural women and disadvantaged groups is equally important in crafting policy. Farmers' organizations need their capacity strengthened, an area in which IFAD has played an important role.

Given the wide geographical, economic and institutional range of agricultural innovation systems, political economy and governance challenges are inherent in efforts to promote ATI. The design and implementation of inclusive agricultural research and extension systems are therefore fraught with difficulty. However, with strong political commitment, basic governance problems can be tackled, especially if voice and accountability are expanded through reforms that empower farmers and other stakeholders to demand better services and hold service providers accountable. Development partners can assist governments in identifying, financing and evaluating promising reform strategies.

Truly inclusive solutions are by nature context specific, and "winning" strategies vary by country, but common to all are measures that identify and tackle first-order obstacles that block self-sustaining growth, which should be fuelled by technological advances in agriculture. In much of the developing world, the bulk of these obstacles are found in smallholder agricultural production and trade.

Inclusive innovation

Inclusive ATI features development and dissemination of technologies and practices that boost yields strongly and sustainably, are amenable to adoption by a wide range of farmers of both genders and different localities, and are affordable and easily accessible, ideally through well-functioning markets. Inclusive ATI also features similarly well-functioning markets for farm outputs. The policy instruments and strategies to promote such ATI are therefore well known.

However, countries differ considerably in sustaining ATI. Why? This chapter uses three further questions to tackle this overriding query:

1. How does ATI support processes of structural and rural transformation?

2. How does it contribute to making rural transformation more (or less) inclusive?

3. What are the key strategies, policies and investments that can enable ATI to support inclusive rural transformation while avoiding adverse effects?

A substantial body of knowledge and experience exists for questions 1 and 2, ranging from the classic work of T.W. Schultz (1953, 1964, 1979) to more recent publications, such as the World Development Report (WDR) 2008 (World Bank 2007), the IFAD Rural Poverty Report 2011 (IFAD 2011) and the fast-expanding body of evidence published by the Agricultural Technology Adoption Initiative.[120] This chapter summarizes the central findings from that work, supplemented by new evidence on emerging opportunities and challenges. In some cases, long-held principles are affirmed. In others, new insights are identified.

Evidence to rigorously address question 3 is thin by comparison, yet this is arguably the most important of the three. If the ideas, experience, analyses, policy recommendations and (for the most part) positive effects on growth and inclusion of technology innovation are all well established, why is it that structures and systems needed to jump start and sustain broad-based processes of ATI are still lacking in so many countries?

A key argument is that structural and rural transformations that deliver widely shared benefits in rural areas hinge on boosting the productivity of the agrifood systems that underpin most rural livelihoods. Productivity growth is an outcome of interacting factors including level and speed of development, adoption of improved technologies and practices, reliable outlets for surpluses, institutions that mitigate risk and provide incentives, and investments that strengthen key human, physical and institutional capacities. Key to success is innovation – defined here as a "new product, process, service or management approach that is adopted at a significant scale" (Pyburn and Woodhill 2015, p. 10). Adoption at scale distinguishes an innovation from an invention.

BOX 8.1 Kenya's smallholder dairy commercialization programme

Science and research continue to develop technologies for enhancing livestock productivity. The use of exotic breeds has enabled genetic improvements to accelerate, while biotechnology has led to more cost effective health care. Various additives and supplements have been identified to accelerate weight gain, increase digestibility of feedstuffs or reduce the amount of feed required. Artificial insemination has been supplemented by other techniques for herd improvement, while advances in herd health management have cut medication expenses and increased efficiency. Mechanical technologies allow for electronic monitoring of animal performance, feeding and environment.

Although the use of these and other technologies has upgraded livestock productivity in developed countries, yield gaps between current and potential productivity in developing countries remain high, up to 130 per cent for beef and 430 per cent for milk – considerably greater than yield gaps in crop-based farming systems. Feed deficits mean that many animals only reach 50-70 per cent of their genetic potential. Similarly, animal diseases regularly lower productivity, causing up to 20 per cent of mortality in young animals.

The IFAD-funded Government of Kenya's Smallholder Dairy Commercialization Programme (SDCP) illustrates the opportunities for smallholder farmers to increase livestock productivity through the application of science-based improvements in animal feeding, breeding and health. Traditionally, smallholder dairy producers do not generate adequate quality and quantity to access commercial dairy markets. They are often obliged to sell limited amounts to informal local traders, generating low profits and remaining trapped in a low-input, low-output cycle. Aggravating the relative transaction costs, a SDCP study showed that more than 2.5 million litres of milk were lost per year in the programme area, attributed to poor road networks especially during the rainy season when milk production is at its highest.

Launched in 2006, SDCP promoted Dairy Commercialization Areas (DCAs) and dairy marketing cooperatives to better meet the growing demand for quality milk products. The DCAs, clusters of 800-1,200 dairy farmers, are community-driven organizations that were supported to set development plans for the dairy value chain in the target area. SDCP supports the action planning process with dairy analysis, surveys and value chain mapping. To ensure inclusive benefits, SDCP assisted smallholder dairy groups in developing their Dairy Enterprise Plans, which facilitated the integration of farmers' priority needs in the DCA Action Plans.

The action plans combined market access issues with application of improved technologies. Based on the latter Action Plans, DCAs negotiated with their county governments the necessary investments in rural roads and dairy cooling facilities. A total of 2,000 km of rural roads were rehabilitated and 10 milk bulking and cooling facilities installed in the programme area.

Reliable access to markets was one important ingredient for inclusive rollout of improved technologies. SDCP also improved the outreach of livestock extension agents, providing more consistent training and advisory services to smallholder farmers, and verifying the quality of private technical services. A number of improved technologies were promoted to support farmers in upgrading dairy production. More productive breeds, better animal husbandry (such as hoof trimming, dehorning/disbudding and castration) and animal housing (such as zero-grazing units), forage and feed management technologies, animal registration and assessment, artificial insemination, vaccinations, rearing of replacement stock, rain water harvesting, cooling and bulking equipment, and use of small labour-saving equipment (feed mixers, biogas units and chaff cutters) all supported dairy farmers to pursue higher productivity and value addition.

Furthermore, community resource persons offered special inclusion-oriented services, such as animal registration, mentoring younger farmers and the application of household methodologies in gender mainstreaming (see Spotlight 5). Finally, knowledge sharing was supported through study visits that were driven by dairy groups' identified needs, covering such areas as the use of sexed semen for faster upgrading of animals, dry matter feeding systems, control of East Coast Fever and use of silage bags for fodder conservation.

Technological improvements reduced the production cost per litre of milk and improved milk hygiene. Diseases dropped by 60 per cent while incidence of vector-borne diseases decreased from 21 per cent to 10 per cent. Labour-saving technologies and micro-processing equipment increased value addition, including in yoghurt, ghee and butter production. Smallholder dairy farmers were thus able to intensify production and improve quality and sales. The area under fodder crops expanded from 11,000 to 30,000 acres and productivity increased from an average of 4 litres per cow per day to 12 litres, while the average production costs dropped by 25 per cent. Almost 100 small-scale feed mills were established by dairy groups and 80 dairy group bulking sites have transitioned into fully commercialized sites that are adding value to crop residues. About 21,000 jobs were created and over 120 million litres of milk marketed, up from 27 million litres. In terms of value, marketed milk increased further, from KES 1.6 million per annum to 25.8 million.

Source: IFAD 2015.

The chapter focuses on innovations in agricultural production technologies, asking what drives or impedes them.[121] The analytical framework is based on the concept of an "agricultural innovation system," defined as a network of organizations, enterprises and individuals focused on bringing new products, processes and forms of organization into economic use, with the institutions and policies that affect their behaviour and performance (World Bank 2006, p. vi-vii).

Applying this concept, the next section examines the most outstanding example of ATI witnessed in recent decades – Asia's Green Revolution – aiming to identify lessons and challenges for current and future efforts. That is followed by an examination of recent trends in agricultural research and development (R&D) investments at national and global levels, along with important developments in the broader agricultural technology industry. The section after that examines how ATI contributes to inclusive structural and rural transformations, or the converse. That section is followed by a review of investment gaps and governance challenges facing the agricultural productivity growth agenda, and by strategies to improve policies and institutions in support of that agenda. Major lessons and conclusions round out the analysis.

ATI and structural transformation: lessons from Asia's Green Revolution

As detailed in the regional chapter on Asia and the Pacific, the Green Revolution in Asia illustrates the role of ATI in setting countries on the path of rapid structural and rural transformations, with fast poverty reduction (Pingali 2012). Initiatives such as the Alliance for a Green Revolution in Africa (AGRA), the Science Agenda for Agriculture in Africa (FARA) and key elements of the narrative justifying Sustainable Development Goal 2 to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture indicate that this "other Asian miracle" remains a source of inspiration.

The Green Revolution was based on a major technological innovation in wheat and rice production: the introduction of short-strawed, high-yielding varieties, alongside the increased application of inorganic fertilizer and agrochemicals for crop protection. The widespread adoption of such technologies by smallholder farmers across Asia led to a remarkable increase in grain production from 313 million tonnes per year in 1970 to 650 million tons in 1995 (Hazell and Ramasamy 1991). The gains were mainly driven by increases in input use rather than in efficiency, as rates of growth of total factor productivity (TFP) were quite modest in the early part of the Green Revolution era in India (Binswanger-Mkhize and d'Souza 2012, p. 193).

The increased productivity on smallholder farms stimulated rural and structural transformations through linkage effects and growth multipliers. Agricultural production generates forward production linkages when agricultural outputs are supplied as inputs to non-agricultural production. Agricultural growth can contribute to expanding agroprocessing and processed food marketing, which provide engines of growth, and in many cases opportunities, to substitute for imports. Agriculture also creates backward production linkages through its demand for intermediate inputs such as fertilizers and marketing services (Johnston and Mellor 1961; Hazell and Haggblade 1991; Hazell and Ramasamy 1991). Both effects were observed in the Green Revolution. The production linkages of agriculture deepen as the transformation proceeds. Backward and forward linkages are both especially strong for the rural non-farm economy, as emphasized by Haggblade et al. (2010).

The Asian Green Revolution offers lessons on the political and institutional dimensions of ATI and rural transformation. In the 1960s, many developing country governments aimed to promote a structural transformation by investing in the industrial sector and by keeping food prices low. In India, this neglect of agriculture led to increasing dependence on foreign food aid, which became a political burden when the United States in the late 1960s started to use food aid as an instrument of foreign policy. This created strong political incentive within the Indian Government to make the country self-sufficient in food production. In other Asian countries, such as Indonesia and the Philippines, food shortages led to food riots, which induced governments to shift their policies towards supporting innovation in agriculture (Djurfeldt and Jirström 2005). As the case of India shows, the governments made major investments in creating an institutional environment that allowed smallholders to adopt the new technologies (Subramaniam 1995).

Although Asia's Green Revolution was inclusive in the regions in which it was adopted (Djurfeldt et al. 2005), it did not reach the poorest farmers or those in semi-arid regions, where poverty rates have remained persistently higher (see the regional chapter on Asia and the Pacific). The Green Revolution helped agricultural labourers and poor food consumers in rural and urban areas via indirect effects of ATI (de Janvry and Sadoulet 2002), especially the greater availability of food and lower prices (Hazell and Ramasamy 1991). However, the Green Revolution also shows that an increase in staple food production does not necessarily translate into nutrition security (see Spotlight 6). Moreover, the Green Revolution has been associated with a wide range of well-documented environmental problems (Ali and Byerlee 2002), which underlines the need to pay specific attention to the environmental effects of ATI.

The yield-enhancing technologies that underpinned the Asian Green Revolution were introduced and promoted in a context of government intervention to support farm output prices and subsidize farm input prices, alongside major public investments in extension systems and rural infrastructure, particularly roads and irrigation. Strong political incentives to achieve food security also made it possible to overcome critical governance challenges involved in promoting technology adoption among smallholders.

Countries seeking to replicate such successes today face a sharply different context. They must operate in a more open economic environment with fewer options to protect their agricultural sectors from international competition. Some analysts have expressed concern that the growth linkages of agriculture in today's open economies are less strong than they were during the Green Revolution, especially in small countries (Hazell et al. 2010). Nonetheless, that revolution's experience remains relevant to the requirements for promoting self-sustaining processes of growth fuelled by technological advances in small-scale agricultural production and trade.

Recent trends and developments in ATI

Broad-based productivity growth in agriculture is crucial for inclusive rural and structural transformations in most contexts, and is often driven by investment in agricultural R&D and related fields.

The idea that investing to enhance agricultural productivity would be essential in reducing poverty and promote structural transformation has long been held in development circles, but studies from the 1990s and since have quantified the effects. Datt and Ravallion (1996) showed how important rural growth had been in India, for instance, and Thirtle et al. (2003) surveyed a much wider set of country experiences around the world. Subsequent syntheses have fleshed out the story (World Bank 2007, chapter 7; Fan et al. 2008; Alston 2010; Mogues et al. 2012; Christiaensen and Todo 2014). The evidence is strong and clear that sustained investment to enhance productivity in agriculture and the broader rural economy has a large impact on both growth and poverty reduction.

Investment in agricultural R&D

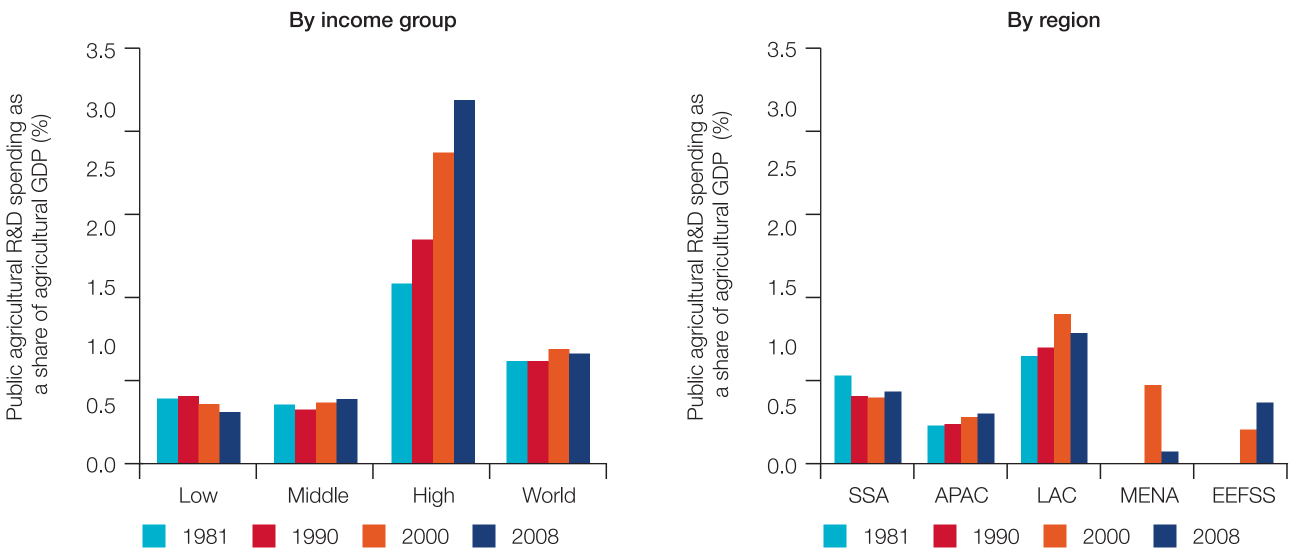
An essential precondition for ATI is investment in agricultural R&D. This section reviews recent trends of public and private investment in agricultural R&D.

National public investment

Agricultural research intensity (spending on agricultural R&D as a share of agricultural gross domestic product [GDP]) in Asia and the Pacific is well below 1 per cent (figure 8.1), often considered a target.[122] In sub-Saharan Africa (SSA), Swaziland, Kenya and Malawi are among the dozen or so countries that exceed this threshold. Benin, Mali, Tanzania and Côte d'Ivoire are among the next dozen countries spending more than 0.5 per cent. Agricultural R&D funding in SSA is more dependent on contributions by development partners than that in other developing regions, and – linked to this – funding is also more volatile (Beintema and Stads 2014).

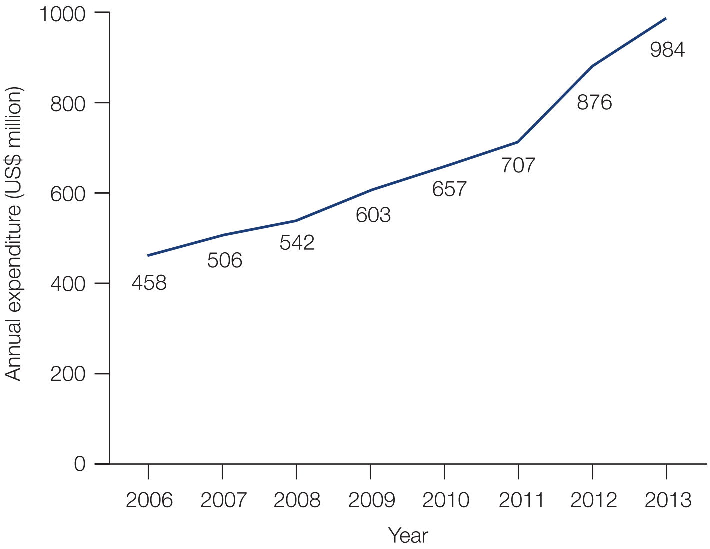
Efforts to collect data on other components of the agricultural innovation system, especially agricultural extension and education, are less

FIGURE 8.1 **Agricultural research intensities by country income and region, 1981-2008**



Note: SSA = Sub-Saharan Africa; APAC = Asia-Pacific countries; LAC = Latin America and the Caribbean; MENA = Middle East and North Africa; EEFSS = Eastern Europe and former Soviet States.
Source: Beintema et al. 2012, p. 10.

FIGURE 8.2 **Annual expenditure of CGIAR centres, 2006-2013**



Source: Ufer and Birner 2015, based on audited CGIAR financial reports of 2006-2013.

frequent and systematic than for agricultural research. The Asian Green Revolution countries seem to have maintained quite large public extension systems, while few countries in Africa, such as Ethiopia, Kenya and Rwanda, have made major efforts to increase the number of their public agricultural extension agents (Swanson and Davis 2014).

International public investment

Since the start of the Asian Green Revolution, the international development community has invested heavily in agricultural R&D, most notably by funding the now 15 international agricultural research centres, known as CGIAR. The re-emergence of agriculture and food security on the global development agenda during the 2000s led to a substantial increase in funding to the CGIAR centres (figure 8.2).

The CGIAR centres more than doubled their spending between 2006 and 2013. More than half of CGIAR funding is spent on SSA. This increase in funding was associated with a major institutional reform of the CGIAR system that started in 2009, partly aimed to improve coordination among the centres.

The CGIAR is mainly financed through grants provided by bilateral and multilateral development agencies. IFAD, for example, provided almost US$100 million over 2004-2013 to support agricultural research conducted by the CGIAR, focusing on technologies for smallholder farmers (IFAD 2014, p.15).

Private investment

The private sector can play a major role in areas of research that are not in themselves subject to market failures, such as seed multiplication and distribution, agrochemicals and agricultural machinery (Byerlee and Haggblade 2014). Globally, its contribution has been climbing fast in recent years, by more than 40 per cent during 1997-2010, according to a survey of seven agricultural input industries. By far the largest share went into crop seeds and biotechnology (Fuglie et al. 2012a). Although private investment is still concentrated in industrialized countries, developing countries can benefit from it, especially if they create a business environment that assists agribusinesses.

Private agricultural R&D tends to focus, however, on specific types of commodities for which returns are easily appropriable, and many of those are not essential to smallholder livelihoods. Moreover, these investments persistently overlook the crops, traits and technologies that are vital to the livelihoods of the poor. While many market and institutional factors explain the low rates of private investment, incentive mechanisms could stimulate private investment better, such as push-and-pull mechanisms that stimulate both demand for and supply of private R&D – if carefully designed, adequately funded and politically backed. Further research is needed to isolate which measures are the most effective, in which circumstances, and especially their impact on private investment in pro-poor agricultural R&D (Naseem et al. 2010). (The implications of private investment in R&D for the inclusiveness of transformation in developing countries are discussed in "Strategies for boosting investments and improving governance" below.)

Technology adoption and crop yields

Data on the adoption of agricultural technologies, such as improved seeds, are only available for all developing regions until 2000 (table 8.1). For Africa, more recent data are in Walker et al. (2015). Adoption rates in SSA have increased significantly since 2000 for all crops except rice (table 8.2, which also reveals the importance of CGIAR contributions to progress), with wide variations across countries. Moreover, except for soybeans, which are not a traditional crop in Africa, adoption rates are still below 50 per cent in most countries, thus lagging behind the rates reached in other developing regions two or three decades earlier (see table 8.1).

The adoption of improved varieties is a major factor in promoting increases in crop yields, with the adoption of complementary technologies such as fertilizers and crop protection. The yields of cereal crops have been rising in all regions of the word except SSA, even though the rate of increase has been slowing (figure 8.3).

Analysts such as Alston and Pardey (2014) report similar results. Fuglie (2012, p. 357) finds significant slowdowns for wheat and rice yields, although maize has made good progress since 1990. These trends seem less alarming when the acceleration of TFP growth is taken into account.

The slow rate of growth of the crop yields in SSA is somewhat surprising, since adoption rates of improved varieties have increased. This result may be due to minimal adoption of complementary technologies, such as fertilizer. Moreover, while not reflected in average yields, the increased use of improved varieties may still have contributed to increased efficiency in using factors of production.

Changes in factor productivity

Adoption of new technologies and improvements in the efficiency of known technologies lead to increased productivity of the production factors of land, labour and capital. This is why factor productivity is a widely used indicator to measure innovation in agriculture. The adoption rates of agricultural technologies shown in the previous section help to explain recent patterns in land and labour productivity (figure 8.4). Japan, Western Europe and North America have been on vastly different paths on these two indicators, with labour productivity rising faster in all regions. China, Latin America, the Middle East and North Africa, and Asia have made impressive gains on both measures of productivity, with China having the most balanced increases. Compared with other regions, SSA has seen very little growth in labour

TABLE 8.1 **Area planted to modern varieties, 1960-2000 (% of total area harvested)**

	Year	Sub-Saharan Africa	East and South-East Asia and Pacific	South Asia	Middle East and North Africa	Latin America and the Caribbean
Rice	1960	0.0	0.0	0.0	0.0	0.0
	1970	0.0	9.7	10.2	0.0	4.7
	1980	3.1	40.9	36.3	2.2	16.2
	1990	12.3	63.5	52.6	4.3	27.8
	2000	31.0	80.5	71.0	10.4	32.3
Wheat	1960	0.0	0.0	0.0	0.0	0.0
	1970	0.4	0.0	39.6	7.6	11.4
	1980	4.1	27.5	78.2	33.8	61.3
	1990	6.3	58.7	87.3	43.8	79.3
	2000	47.4	89.1	94.5	69.1	93.2
Maize	1960	0.0	0.0	0.0	n.a.	0.0
	1970	0.0	16.2	17.1	n.a.	1.6
	1980	0.4	61.7	34.4	n.a.	11.2
	1990	7.5	73.0	47.1	n.a.	27.0
	2000	16.8	89.6	53.5	n.a.	56.5

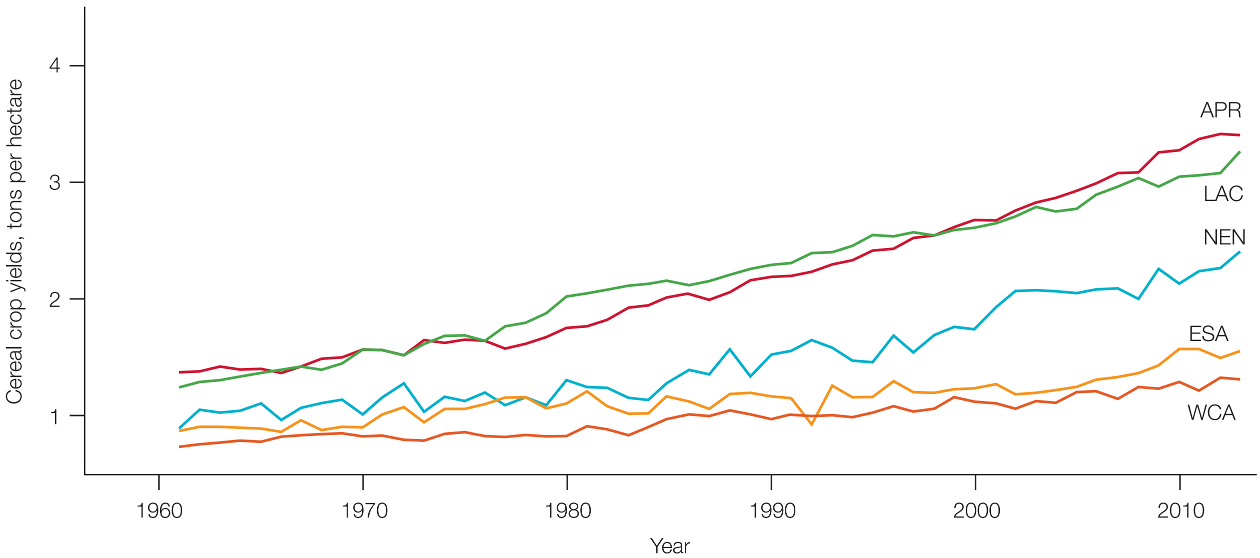
Source: Gollin et al. 2005, p. 1313, based on data shared by Robert E. Evenson

TABLE 8.2 **Adoption of modern crop varieties (MV) in Africa and the contribution of CGIAR, circa 2010**

	Total area (million ha)	MV area (million ha)	% MV of total area (%)	MV area CGIAR related (%)
Maize	24.67	13.03	53	55
Sorghum	17.97	4.93	27	78
Cassava	11.04	4.38	40	83
Rice	6.79	2.58	38	51
Pearl millet	14.09	2.55	18	87
Groundnut	6.36	1.85	29	86
Yam	4.67	1.41	30	50
Soybean	1.19	1.04	87	63
Wheat	1.45	0.85	59	65
Bean	2.50	0.72	29	81
Other crops[a]	16.99	4.63	27	61
Total	107.72	37.97	35	66

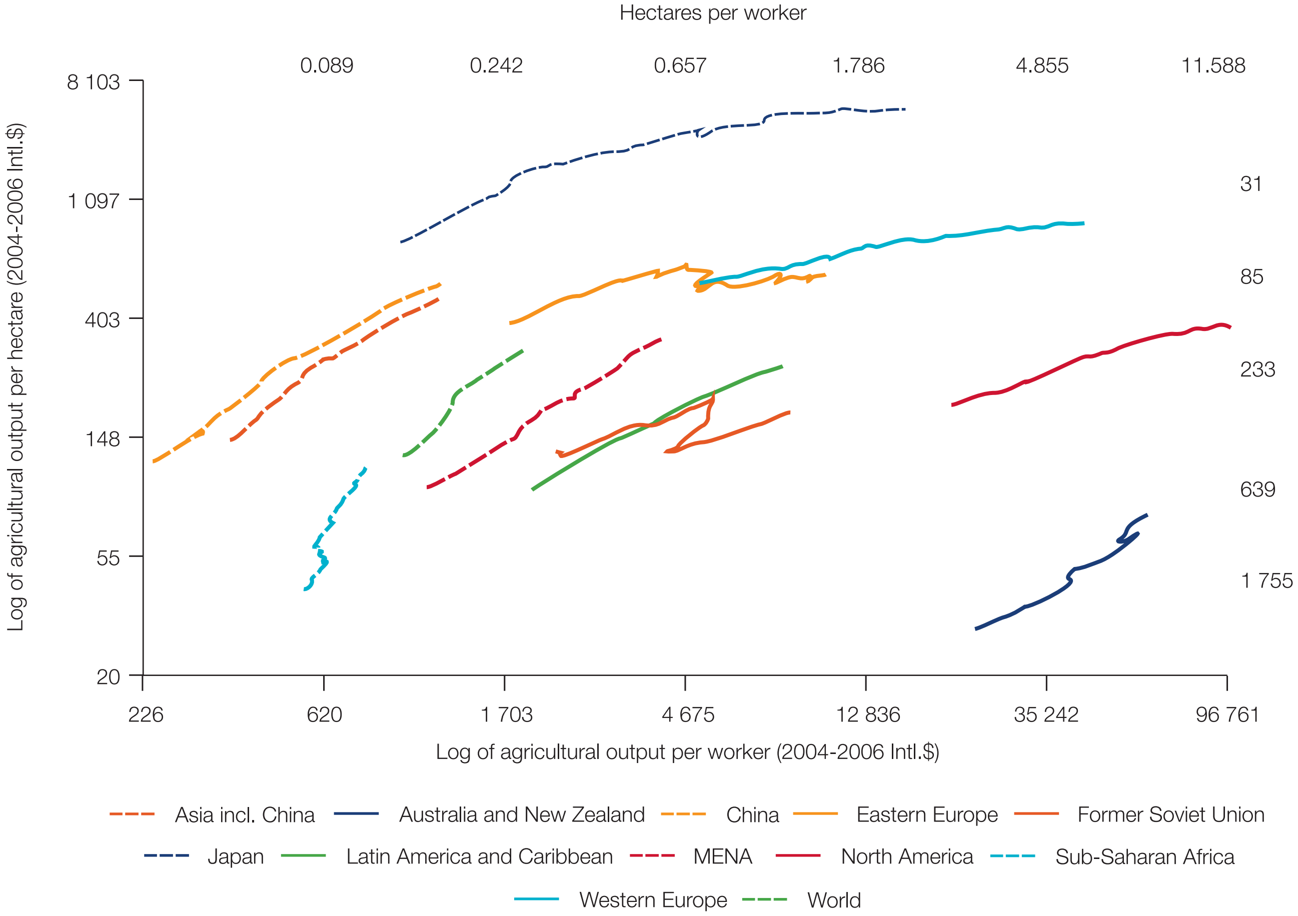
[a] Includes pigeonpea, potato, barley, chickpea, fababean, lentil, sweet potato and field pea, all with less than 0.5 million hectares of MV adoption.
Source: Walker et al. 2015, chapter 19, with selections made by Derek Byerlee for this tabulation.

FIGURE 8.3 **Trends in cereal crop yields, by region**



Note: APR = Asia and the Pacific, ESA = East and Southern Africa, WCA = West and Central Africa, LAC = Latin America and the Caribbean, NEN = Near East, North Africa, Europe and Central Asia.
Source: IFAD, based on FAOSTAT.

FIGURE 8.4 **Land and labour productivity by region, 1961-2013**



Note: Uses double logarithmic depiction introduced by Hayami and Ruttan 1971, 1985; updated in Pardey 2015.
Source: Pardey 2015.

productivity and only modest growth in land productivity.

The most informative indicator of technology innovation is TFP, which is a broad measure encompassing an appropriately weighted average of productivity of all inputs: land, labour, capital and materials employed in production. In addition to growth of cereal yields, TFP includes productivity increases in other crops, and from shifts in the cropping patterns towards higher-value products. Despite the global slowdown in growth of cereal yields, there does not seem to be a slowdown in sector-wide global agricultural productivity growth (table 8.3). Indeed, TFP has accelerated largely because of the rapid productivity gains achieved in several large developing countries, notably Brazil and China. At the global level, increases in TFP (indicating more efficient use of resources) have replaced land expansion and increased use of inputs as major drivers of growth in agricultural output, and so observers may be more relaxed about supply in agriculture meeting the rising demand from worldwide population and income growth.

However, many countries have been unable to sustain productivity growth in agriculture. The largest group of countries in this low-growth category is in SSA, although several are in Latin America and the Caribbean (LAC) and Asia and the Pacific (APR). Fuglie and Rada (2012) document in some detail the rather disappointing growth of TFP in SSA. Nin-Pratt and Yu (2012) found broadly similar results on TFP using different analytical methods. They identified more favourable agricultural policies (Anderson and Masters 2009) and lower political instability over recent decades as factors that contributed to a "remarkable recovery" in the performance of SSA's agriculture in the mid-1980s and later, after a long period of poor performance and decline. These authors judge the performance of some nine countries to be "good," namely Angola, Cameroon, Ethiopia, Ghana, Guinea, Mali, Mozambique, Nigeria and Zambia, although for Angola and Mozambique, it was largely catch-up of earlier losses during periods of conflict. It is not mere coincidence that, as reported in the chapter on SSA, five of these countries (Cameroon, Ethiopia, Ghana, Mali and Mozambique) have also been most successful in cutting rural poverty in recent decades.

Technologies to promote sustainable productivity growth

The new Sustainable Development Goal 2.4 envisages, "By 2030 ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality."

Agricultural innovation strategies need to take this sustainability goal into account. As the Green Revolution showed, agricultural intensification has been associated with negative effects, such as overuse of agrochemicals and irrigation water. Areas not affected by that revolution suffer from different types of environmental problems, such as degradation of soil and pasture land, and loss of forests and wetlands due to the expansion of the agricultural frontier (WDR 2011, chapter 8). These experiences have led to increasing investment in developing and promoting environmentally sustainable agricultural production technologies and natural resource management practices.

TABLE 8.3 **Average growth in agricultural total factor productivity (TFP) by region**

Region	Average TFP growth rate (% per year)				
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2009
All developing countries	0.69	0.93	1.12	2.22	2.21
Sub-Saharan Africa	0.17	-0.05	0.76	0.99	0.51
Latin America and the Caribbean	0.84	1.21	0.99	2.30	2.74
Brazil	0.25	0.60	3.02	2.62	4.03
Asia (except West Asia)	0.91	1.17	1.42	2.73	2.78
China	0.94	0.67	1.71	4.10	3.05
West Asia and North Africa	1.40	1.66	1.63	1.74	1.88
All developed countries	0.99	1.64	1.36	2.23	2.44
United States and Canada	1.25	1.67	1.31	2.18	2.24
West and Central Europe	0.58	1.44	1.43	1.25	1.98
Transition countries (former USSR and Eastern Europe)	0.57	-0.11	0.58	0.78	2.28
World	0.18	0.60	0.62	1.65	1.84

Source: Fuglie and Wang 2012, p. 4, based on Fuglie et al. 2012.

As seen in the chapter on land and natural resources, many initiatives are under way to improve sustainability, some of which are spreading rapidly and widely. Some include developing high-potential varieties for crop and livestock production, such as drought-tolerant maize, varieties of "New Rice for Africa" (NERICA) suited to upland conditions and drought-tolerant Napier grass and Rhodes grass. Other promising moves feature combinations of technical improvements with institutional innovations, often aiming to build robustness into technologies through integrated systems. For example, in pest control, soil management, agroforestry and crop-livestock interactions, novel "management platforms" that bundle together soil improvement, new crop and livestock varieties, intensified input use and farmers' collective action, are showing strong potential for increased incomes, improved sustainability of farming systems and adaptation to a range of farming systems and agroecologies.

Conservation agriculture, which has permanent soil cover combined with appropriate crop rotation, has been adopted on 125 million hectares of land across the world, opening scope for sustainable growth in agricultural productivity even under the inevitable effects of climate change andvariability.

Integrated soil fertility management, featuring combined use of mineral fertilizers and local soil amendments, such as lime and phosphate rock, and organic matter such as crop residues, compost and green manure, improves soil quality and the efficiency of fertilizers and of other improved inputs. It also promotes improved germplasm, agroforestry and the use of crop rotation and intercropping with fertility-enhancing legumes (Place et al. 2003).

Integrated pest management promotes agroecological principles as a basis to reduce use of agrochemicals. Although it requires heavy investment in farmers' knowledge, adoption is encouraging. The push-pull technology developed by the International Centre of Insect Physiology and Ecology (ICIPE) and partners for managing maize stem borer pests involves selection, placement and sequencing of plants that allow use of behaviour-modifying stimuli to manipulate the distribution and abundance of stem borers and beneficial insects (Hassanali et al. 2008).

The "farmer field school" approach brings together concepts and methods from agroecology, experiential education and community development to lower the use of pesticides and improve sustainability of crop yields. Its effectiveness in improving farmers' knowledge of integrated pest management principles has been shown in numerous studies (e.g. Godtland et al. 2004), although questions of cost-effectiveness and scalability remain (e.g. Ricker-Gilbert et al. 2008).

Innovation entails expanded uptake and use of technologies and practices such as these, while opening scope for new ones to take hold.

Contested technologies

Quantitative field-based research has yielded basic tools with which preferred traits can be identified, quantified and exploited for crops (and livestock). However, these conventional field-based approaches to selection and breeding are lengthy and at times inaccurate. Recent advances in biotechnology have opened the way for rapid progress in understanding desirable traits in more direct and precise ways. In particular, marker-assisted selection of target genes within preferred crop varieties (and animal breeds), and marker-assisted introgression of target genes from superior to inferior crop varieties (and animal breeds) are major thrusts in molecular genetics research. In just two or three decades, these methods of modern biotechnology have moved from being theoretical concepts to basic practice – commonplace, uncontroversial and widely embraced.

That cannot be said for genetic engineering that yields genetically modified organisms (GMOs). Information flows on GMOs are often poor, however (IFAD 2011, p. 152). Little space has been given to the voices of small farmers in authorizing GM crops. As IFAD (2011) pointed out, this needs to change for countries to be able to more effectively access the potential benefits of GMOs for increased productivity, reduction of risk faced by smallholders and contribution to poverty reduction, while being aware of emerging understanding of the potential environmental and health risks that may be associated with their use. It is up to countries to make their own decisions, based on their assessment of potential risks and expected benefits.

Controversies over GMOs revolve around three broad concerns: potential environmental and health hazards, increasing dependence on a small number of multinational companies and potential negative effects on smallholder farmers.

Hazards in the first group vary according to the type of organism being modified and its intended application. The environmental impacts of introduced GMOs can be ecological or genetic, and may include:[123]

- Unintended effects on the dynamics of populations in the receiving environment owing to impacts on non-target species, which may occur directly by predation or competition, or indirectly by changes in land use or farming practices.
- Unintended effects on biogeochemistry, especially through impacts on soil microbial populations that regulate the flow of nitrogen, phosphorus and other essential elements.
- The transfer of inserted genetic material to other domesticated or native populations, generally known as gene flow, through pollination, mixed matings, dispersal or microbial transfer.

These potential effects have been intensively studied over the past decade. A recent review of the literature, which included a thorough review of the evidence on different types of gene flow, concluded that "the scientific research conducted so far has not detected any significant hazards directly connected with the use of GE [genetically engineered] crops" (Nicolia et al. 2014).

There is also evidence of potential positive effects of GMOs on the environment. To the extent that GMO adoption leads to higher yields, the pressure to convert additional land into agricultural use is reduced. Moreover, herbicide-tolerant GM crops have aided the shift to conservation agriculture practices, which also has positive environmental effects (Carpenter 2011). Less pesticide use is a potential benefit for the environment and for human health, and several studies have found that the adoption of GM crops lowered pesticide use (Hossain et al. 2004; Bennett et al. 2006). There is also, however, evidence from China that the absence of enabling institutions and lack of farmers' knowledge can limit such benefits of Bt cotton for small farmers, which points to the need for advisory services on crop protection and for quality control to ensure appropriate Bt concentration of the seed material (Pemsl et al. 2005).

For food safety, the potential implications of GM crops have also been thoroughly assessed in recent years, even if a review of this literature by Domingo and Bordonaba (2011) notes that the topic remains subject to controversy. The review by Nicolia et al. (2014, p. 8) examined potential health hazards, such as safety of the inserted transgenic genetic material and safety of the intended and unintended changes of crop compositions, and as with the environmental effects, found no significant health hazards directly connected with the use of GM crops.

On the second broad concern – dependence on a small number of multinational companies – there is clear evidence that concentration in the seed sector, in particular the GM seed sector, is very high and likely to increase further (World Bank 2007; Bonny 2014). This possibility certainly requires regulatory attention.

Regarding the third broad concern, suitability for small farmers, it is noteworthy that GM crops are widely grown by small farmers in countries where they have been authorized – as in the case of Bt cotton, in Burkina Faso, China and India. A recent meta-analysis of the economic impacts of GM crops concluded that the average agronomic and economic benefits of growing GM crops were large and significant. Yield gains and pesticide reductions were larger for insect-resistant crops than for herbicide-tolerant crops. Moreover, yields and farmers' profit gains were higher in developing than developed countries (Klümper and Quaim 2014).

There is no escaping the conclusion that, beyond the use of biotechnology methods in molecular genetics research described above, thus far the biotechnology revolution has been a narrow one. GM crops feature the same two traits (herbicide resistance and insect resistance) that were introduced in 1996. Nor is there a clear institutional pathway for filling the delivery gap for GM food crops. Obstacles to multinational corporations' entry to developing countries' food-crop seed markets persist: small market sizes, regulatory expense, inability to protect intellectual property from seed piracy, lack of political incentives for governments and overall public opprobrium for the GM industry. The persistent and widespread weakness of conventional seed-delivery systems reduces prospects for delivery of GMOs outside of the multinational pathway.

Emerging digital solutions

ICT is a promising set of technologies increasingly used in developing countries. Over the past two decades, ICT use has exploded in virtually every facet of life. The number of people with mobile phones has increased from virtually none in 1980 to around a billion in 2000, and to an estimated 4.5 billion unique subscribers and nearly 7 billion subscriptions in 2013. Internet use has also grown at a torrid pace, via computers and more recently smartphones: in 1995, only 16 million users worldwide accessed the Internet. Today some 2.5 billion do. The past five years has seen a doubling of the Internet population.

With this technological explosion, employing ICT tools for development has become a focus of national and international organizations, governments and corporations (Belden and Birner 2011). The agricultural innovation system offers many opportunities to use ICTs (e.g. in research and extension), as do the various segments of agricultural value chains. A rapidly expanding array of tools attempts to enhance yields, improve quality, reduce post-harvest losses, remove intermediaries and disseminate knowledge about best practices. Through websites, smartphone applications and SMS text messages, farmers can gather information on a huge range of topics, such as plant diagnostics, planting reminders and advice, fertilizer and pesticide application assistance, weed identification, GPS-enabled field notes and yield improvement.

A major focus of these applications – mostly developed by private companies but often with public support – is to remedy the asymmetry of information between buyers and sellers of agricultural commodities. In particular, ICT gives farmers tools to find out market prices, empowering them in interactions with traders and other service providers. In some places, farmers can use their mobile phones to send SMS text messages to a centralized data centre and receive price information. Older ICT technologies still play a role, too: radio has long been the best way to reach millions of rural residents and remains an important tool. Internet also plays a role, particularly for larger buyers and sellers. Market information is continually posted on websites in countries and regionally, allowing buyers and sellers to match up.

Another focus of digital innovation is agricultural extension. In the Indian state of Madhya Pradesh, Kisan Call Centres, which are run by the Ministry of Agriculture, handled more than 200,000 farmers' queries from 50 districts in their first year of operation. Queries related to topics such as crop diseases or marketing issues (FAO 2013, p. 7). Government commitment is required to make such call centres work, since they rely on a skilled team of motivated experts who need to be on hand to reply to the queries.

International development agencies and networks are also contributing, both in the development and rollout of initiatives, and in assessing their efficacy and impact. IFAD supported the Indigenous Maasai Cultural Centre to establish a radio-based system to collect observations and weather predictions from Maasai herders scattered across thousands of hectares, to document and verify these observations, and to map them with geographic information systems. This information helped the Council of the Maasai Elders make key decisions on communities' and livestock movements, based on where rainfall is expected.[124] An evaluation by the Agricultural Technology Adoption Initiative of a mobile-phone-based agricultural advisory service called

"Avaaj Otalo" in India found that the investment promoted a shift to more effective and less hazardous pesticides in cotton production (Cole and Fernando 2012).

The promise of digital solutions is immense – even though they are helping to disseminate global knowledge, they are not necessarily democratizing it. Benefits from improved access to knowledge disproportionately accrue to the wealthier, the better educated and the well-connected (World Bank 2016).

ATI: adoption, inclusion and exclusion

A technology is inclusive if a broad base of farmers, especially smallholders and women, can adopt it, and if it brings in geographically or culturally disadvantaged groups. This section examines evidence on factors that influence the inclusiveness of agricultural technology adoption. It reviews potential implications for inclusion (or exclusion) under the following four headings.

Properties of technologies

The properties of the technology (in particular, divisibility and other factors influencing scale effects) and the state's capacity to protect intellectual property rights largely determine how inclusive ATI can be.

Divisible technologies such as seeds and fertilizer are, in principle, scale neutral and should not cause problems for inclusiveness if they do not require complementary technologies that are not scale neutral. Still, farmers need to purchase such inputs, and market failures in agricultural finance and insurance are pervasive in the early phases of agricultural development (Binswanger and McIntire 1987; Byerlee and Haggblade 2014), so that smallholders may find it hard to access innovations.

Although rural financial services have improved with the microcredit revolution, these types are usually more suitable for non-farm activities, as they are not geared towards agricultural production in their payment structure and risk management (World Bank 2007; see also chapter 7).

Even if farmers can access technology, required inputs and credit, they may face other constraints, including paucity of complementary technologies. For example, they may be able to buy improved seeds for tomatoes, but if they lack irrigation facilities then they may still be excluded from the technology. Many innovations require clusters of technologies. They may also face similar problems in accessing product markets, eroding their incentive to innovate because of the risk of not being able to turn a profit.

An enduring quandary for policymakers and analysts is persistent low fertilizer use, which restricts agricultural productivity and contributes to soil degradation. Because fertilizer use is scale neutral, it is still a contested question as to why adoption rates among smallholders in Africa especially remain low, whereas smallholders in other countries have adopted this technology on a large scale.

Randomized controlled trials (RCTs) have been conducted on this topic. Based on field experiments in Kenya, Duflo et al. (2008) showed that micro-dosing of fertilizer can have high returns, while conventional application, including official recommendations of the Ministry of Agriculture, were unprofitable for the farmers studied.

A study by Carter et al. (2014) on the use of fertilizer and seed vouchers in Mozambique found that a voucher led to a large, persistent increase in agricultural production and market sales, a result that the authors attribute to "learning." Other studies have identified low yield response rates to fertilizer as a major problem, which points to the need to invest in complementary inputs and management practices, such as addressing soil acidity problems (Jayne and Rashid 2013; Sheahan et al. 2013). Further, the benefits of "smart" fertilizer subsidy programmes in Kenya, Malawi and Zambia have been affected by diversion of subsidized fertilizers before they even reach the farm and the crowding out, by subsidized fertilizers, of fertilizer purchases on the open market (Jayne and Rashid 2013). Future programmes need to resolve these two problems to make such subsidies an attractive use of state resources.

The inclusiveness of a technology can also be promoted by improving characteristics particularly relevant for disadvantaged farmers. One example is the submergence-tolerant rice variety Swarna-Sub1. A study based on an RCT in Orissa by Dar et al. (2013) found that low-caste groups benefited most from this technology, as their land is predominantly in areas liable to flooding. Another is NERICA rice varieties, which are particularly suitable for disadvantaged upland rice farmers given characteristics such as short growing duration, drought tolerance and weed competitiveness. Kijima et al. (2006) concluded that NERICA varieties had "revolutionary" yield potential and, if supported properly, could lead to a quicker increase in upland rice yields than Asia achieved during the Green Revolution.

The complexity of a technology also influences its inclusiveness, because disadvantaged groups with little education may have problems in acquiring the knowledge needed. For such technologies, learning in social networks can help, though empirical results are mixed (Jack 2013). In an RCT study in Malawi, Beaman et al. (2015) found that for complex technologies, strategic targeting of an intervention within a social network can be critical to reach the threshold of adoption required for a technology to spread. In another RCT study in India, Emerick (2014) found that promoting a new technology through door-to-door sales was more effective than using social networks, given social barriers between farmers belonging to different castes.

The inclusiveness of a technology is further influenced by intellectual property rights. For hybrid seeds, private companies have a good chance of protecting their rights, which has increased private sector investment in R&D in recent years. If credit-market constraints can be overcome, therefore, smallholder farmers are not excluded from adopting the technologies that the private sector provides. However, the increasing market concentration in agricultural input industries could reduce competition, ultimately slowing the rate of innovation and raising the prices at which farmers can access the technologies.

Technologies that are not divisible, such as tractors and other agricultural machinery, are not scale neutral. The same is true for many schemes for product or process certification. However, these innovations do not need to be less inclusive than scale-neutral technologies, because this effect can be mitigated by institutions such as rental markets or forms of collective action that allow for the joint use of machinery (Binswanger 1986) or for group certification (see chapter 6).

Agrarian structure – especially the distribution of farm sizes – is another important aspect of the institutional environment that influences inclusiveness of technology adoption. Concerns are growing that new dualistic farm structures in land-abundant countries – where few large farms using landless hired labourers coexist with multiple smallholder farmers – are being formed by huge foreign and domestic land acquisitions that create large farms (Deininger and Byerlee 2011, 2012).

Properties of smallholders' physical and socioeconomic environments

Almost 30 years ago, Binswanger and Rosenzweig (1986) wrote powerfully of the "behavioural and material" determinants of production relations in developing countries. They argued that spatial dispersion, high transport costs, seasonality, limited physical infrastructure, and yield and market-price risks for smallholders impose deep challenges not only for smallholders themselves, but also for efforts to create conditions in which large numbers of smallholders have strong incentives to adopt and use improved technologies.

Their insights are still highly relevant, and the literature continues to stress that risk is a major obstacle to technology adoption by smallholder farmers (Dercon and Hurley 2010; Christiaensen 2011; Hardaker et al. 2015). These include the weather, prices (paid and received), health (family members, crops and livestock), social and political turbulence, and corruption of public officials. Most people will try to avoid risk, based on their perceptions of it, especially those on adopting technologies.

Smallholder farming remains a physically dispersed activity facing high transport and other transaction costs, and seasonal weather patterns are increasingly unpredictable with global climate change. Physical infrastructure in areas most in need of productivity boosts currently stand at levels well below those in place in pre-Green Revolution India. The highly diversified, low-input, low-output farming and livelihood systems actually adopted by smallholder farmers reflect these realities (Hazell 2012). These systems generate multiple context-specific benefits for smallholders. Paradoxically, the drivers of these benefits represent the principal barriers to be overcome in promoting inclusive ATI.

Poverty traps

Poverty traps form one set of mechanisms excluding people from agricultural development, and are tied to risk. They stem from the interactive impacts of household and individual skills, the levels and changes in their asset holdings, and a range of external factors such as the available production technology and the structure and functioning of factor markets. Households change their asset accumulation and production choices in response to risk assessments and to actual shocks, sometimes eliciting disaccumulation of assets along with pursuit of low-risk, but low-return, production practices, which together drive households below poverty thresholds from which there are no natural dynamics supporting escape – hence the term "poverty trap" (Barrett and Carter 2013; Carter and Barrett 2006). Actual outcomes depend on household characteristics, with asset holdings, skills and capabilities, and associated livelihood options being key.

Especially relevant for ATI are poverty traps relating to the size and quality of the land resources controlled by smallholders. For instance, although the average returns to fertilizer use are considerable for small-scale maize farmers in western Kenya, fertilizer application does not pay for the poorest one-third of farmers, who mainly cultivate lower quality soils (Marenya and Barrett 2009; Barrett and Carter 2013). These farmers quite rationally fail to invest in what otherwise appears an attractive input. Thus long-term soil fertility decline can generate asset thresholds that trap some households in poverty and food insecurity. On the positive side, other farmers in the same region of western Kenya who were offered discounts on fertilizer just after harvesting increased their fertilizer use if they saw a potential profit. This may help them escape the poverty trap (Duflo et al. 2009). Poverty traps are not necessarily permanent.

Gender relations

Most rural women have less access than men to productive resources and services such as agricultural extension, greatly limiting their ability to adopt ATI. Yet there is ample evidence that productivity could be increased substantially if women's access to resources were increased, including to land and agricultural services. Closing the gender gap in agriculture would generate hefty gains for the sector and for society. Gender-linked differences in adoption of improved crop varieties were long ago rigorously attributed to parallel differences in access to key inputs and factors (Doss and Morris Doss 1999). If women had the same access to productive resources as men, they could increase yields on their farms by 20-30 per cent, possibly raising agricultural output in developing countries by 2.5-4 per cent (SOFA 2011).

ATI interacts with gender relations in many ways, however, and some innovations worsen gender inequalities by, for example, placing a further labour burden on female household members or by changing the intra-household income distribution (World Bank, FAO and IFAD 2008). However, many are gender neutral, benefitting individual women just as much as individual men.

To the extent that ATI is inclusive, it is driven not just by technological advances but also by the institutional arrangements that allow women to participate and benefit at scale – arrangements which are not, however, always present.

Investment gaps and governance challenges

Countries differ considerably in effort and success in sustaining inclusive ATI. Why? Two major obstacles are low investment in agriculture (often derived from inadequate political will) and governance weaknesses that undermine investment effectiveness.

Investment gaps and paucity of political will

The public sector plays a critical role in ATI. Key among the factors contributing to the major differences across regions and countries in ATI are the differences in political will to prioritize investment. Political will is "the extent of committed support among key decision makers for a particular policy solution to a particular problem" (Post et al. 2010, p. 659). A range of indicators can be used to measure the political will to support productivity-increasing investment in agriculture.

A powerful and readily available first measure is the level of investment in agricultural research and extension (hereafter "R&D"), expressed as a share of agricultural GDP (see "Investment in agricultural R&D"). Such investments are typically well below accepted benchmarks (Alston and Pardey 2014).

Another indicator is the share of the national budget dedicated to agriculture, even though composition and effectiveness of such spending matters. Under the Comprehensive Africa Agricultural Development Programme (CAADP), African countries committed themselves in 2003 to a minimum of 10 per cent by this metric. According to official budget data, progress against this target has been slow (Benin 2015).

A third indicator of political will is support to, or discrimination against, agriculture. This indicator reflects the effect of all policies. The number of countries that lack such political will has declined in recent decades, as most developing countries have stopped taxing their agricultural sector and started to subsidize it, although this trend has been less pronounced in Africa than in other continents (Anderson and Masters 2009).

These empirical findings beg the question as to why there are differences (over time and among countries) in political support for agricultural development.[125] Recent studies indicate that democratization has been important in the shift from taxing to subsidizing agriculture (Olper and Raimondi 2010; Bates and Block 2013). It reduced the "urban bias" that previously dominated agricultural policies in developing countries (Lipton 1977; Bates 1981). However, such quantitative political economy models have generally neglected factors on which few data are available, such as the roles of emerging farmers' organizations, of the private sector and international development agencies, and of policy tenets (Binswanger and Deininger 1997; Birner and Resnick 2010; Mockshell and Birner 2015).

Governance challenges

Even if countries develop the political processes to support ATI in smallholder agriculture, they must still overcome governance issues, on which the literature is limited. Again, definitional, measurement and explanatory issues arise. Fulginiti et al. (2004) found that good governance in the form of higher levels of political rights and civil liberties was associated with higher levels of agricultural productivity. Lio and Hu (2009) found that the governance indicators that mattered for agricultural productivity are rule of law and control of corruption.

Conceptually, two types of governance challenges in promoting ATI may be distinguished:

(1) Choice of appropriate ATI strategies and policy instruments, some of which are contested.

(2) A pervasive lack of transparency and accountability, leading to elite capture, corruption and absenteeism of service staff, preventing effective implementation.

The two problems are linked. The capacity to implement different instruments influences their choice.

On the first, a major controversy has focused on the role that the state should play vis-à-vis the private sector and the "third sector" (e.g. farmers' associations, cooperatives and non-governmental organizations) in promoting

ATI. Domestic policymakers tend to favour state support for technology adoption by, for example, promoting input subsidies, whereas development partners consider these policies problematic, highlighting governance problems like political capture and poor targeting, and technical challenges (Banful 2011; Jayne and Rashid 2013; Mockshell and Birner 2015). Some efforts seek a middle ground, including the concept of "market-smart subsidies" (Morris et al. 2007). Overall, however, this controversy has hindered collaborative efforts in, among other areas, determining how to sustainably implement input subsidy programmes that avoid leakages and that are targeted to farmers who would not use the inputs otherwise. Likewise, ideological debates about contested technologies, such as GM crops or conservation agriculture, have not brought about a more pragmatic approach (Sumberg and Thompson 2012). The full potential of many technologies thus remains unseized.

Among the governance problems in implementing policy (table 8.4), promoting irrigation typically requires infrastructural investment, either in large irrigation schemes or in small reservoirs. These investments seem particularly prone to irregular public procurement and broader corruption, which are, however, less prevalent in agricultural extension services if the extension agents do not distribute inputs. Extension services often suffer from absenteeism, a problem linked to the difficulty of supervising large numbers of staff dispersed throughout the country. Addressing this governance challenge is particularly difficult if

TABLE 8.4 **Agricultural technological innovation (ATI) governance challenges**

Government function	Examples	Governance challenges
Policymaking		
Formulating policies and strategies	■ Priorities and strategies for ATI	■ Building capacity for innovation policy analysis and priority setting ■ Ensuring participation and using evidence ■ Overcoming ideological debates o contested technologies
Policy implementation		
Addressing market failures in ATI	■ Public agricultural research (with a focus on non-excludable technologies) ■ Publicly funded agricultural extension services for smallholders	■ Retaining highly qualified researchers in national research organizations ■ Avoiding staff absenteeism and elite capture in extension services ■ Making research, extension and education gender sensitive
Investing in infrastructure	■ Large-scale irrigation systems	■ Avoiding political interference in public procurement and corruption ■ Preventing embezzlement of funds
Providing input subsidies to promote adoption of new technologies	■ Price subsidies for agricultural inputs or targeted input voucher programmes	■ Larger farmers capturing benefits ■ Politically motivated targeting ■ Leakages of subsidized fertilizer to the open market
Adopting regulations to address externalities in technologies	■ Regulation for biosafety, food safety, pesticides, veterinary drugs and seed certification	■ Finding a balance between over- and under-regulation ■ Reducing regulatory costs ■ Promoting sound implementation

Source: Authors.

communities are not involved in the evaluation of extension service providers (Birner and Anderson 2007).

Agricultural research involves fewer people than extension. The governance challenge there is to retain highly qualified staff and block any brain drain. Regulation involves its own governance challenges. Approval processes for inputs provided by the private sector, such as seeds or agrochemicals, are often slowed by unnecessary bureaucratic procedures and may involve requests for bribes (AGRA 2014). Regulatory procedures to ensure quality of inputs are often not functional, sometimes because there are too few inspectors.

Strategies for boosting investments and improving governance

Largely following the distinction between policy choices and policy implementation, this section identifies strategies to overcome the obstacles identified above.

Promoting evidence-based policymaking

The past decade or so has seen an increasing focus on participatory and evidence-based policymaking in agriculture (Resnick and Birner 2010). This approach requires the development of capacity in research organizations and planning units of ministries to use appropriate tools and analysis. They need to be able to identify the technology options that are most relevant and beneficial for target groups, depending on the phase of the rural and structural transformations. Examples include the International Food Policy Research Institute (IFPRI) DREAM model (Dynamic Research Evaluation for Management) for priority setting in agricultural research, and decision support systems such as ReSAKSS (Regional Strategic Analysis and Knowledge Support System). Both were central to the evidence-based process led by the African Union Commission and the New Partnership for Africa's Development Agency to develop more than 40 CAADP Compacts and translate the majority of them into comprehensive and coherent national agricultural investment plans (AU/NEPAD 2014). Ethiopia's Agricultural Transformation Agency, and to a lesser extent Kenya's Agricultural Sector Coordination Unit, are examples of national efforts to design and implement agricultural development strategies with an evidence base. A critical assessment of a country's agricultural innovation system (World Bank 2012) is also extremely useful.

Enhancing voice, accountability and delivery capacity

Participation of stakeholders in policymaking can be important in developing buy-in and consensus on ATI policies. However, such participatory policy processes have to be organized carefully to avoid bias and unrealistic expectations among participants (Resnick and Birner 2010). It is important that representatives of farmers' organizations have a voice. Building capacity among these bodies and among rural women's organizations can help to make such participatory policy processes more inclusive. IFAD plays an important role through support to networks of farmers' organizations and multistakeholder policy dialogues at regional and national levels. One example is its support to the Commission on Family Farming in MERCOSUR, which helped to attract attention to policy changes favouring smallholder farmers (IFAD 2014).

To address implementation problems, one can distinguish between demand- and supply-side strategies (World Bank 2007). As shown in figure 8.5, supply-side strategies aim at improving the incentives and capacity of the organizations that supply services in support of ATI, such as agricultural research and extension organizations. For example, public sector management reforms can strengthen incentives and performance of agricultural researchers and extension agents – through merit-based promotion opportunities and appropriate salary scales.

In view of the limited success with supply-side reforms, demand-side approaches have attracted increasing attention in recent years. These strategies strengthen the capacity of farmers to demand better services and hold service providers accountable. Examples in agricultural research include the introduction of participatory technology development

FIGURE 8.5 **Demand- and supply-side strategies to improve governance**

Source: Authors, adapted from World Bank 2007.

approaches, and inclusion of farmers' and women's representatives in the governing bodies of agricultural research organizations, as in the case of Uganda's National Agricultural Research Organization.

In agricultural extension, a variety of reform approaches have been implemented in recent years. These approaches often combine supply- and demand-side reform elements in different ways (Birner et al. 2009; Feder et al. 2011). There are two major trends: (1) decentralization of agricultural extension by shifting the responsibility for service provision either to decentralized offices of agricultural line ministries, or to locally elected government bodies (a supply-side strategy); and (2) formation of farmers' groups who are supposed to make the farmers' voice heard and hold extension providers accountable (a demand-side strategy). Decentralized demand-driven provision of agricultural extension services has been highly successful in China (Hu et al. 2010). Uganda's National Agricultural Advisory Services (NAADS) programme is an example with both features. Responsibility for extension was decentralized to the sub-county level. In addition, Uganda experimented with the outsourcing of extension services to private service providers. Farmer-based organizations had the right to decide on the contracts, depending on the performance of the extension agents. Despite a promising start, the reform was ultimately not successful. Reasons included governance problems, such as procurement problems in the contracting of the service providers, and a range of unanticipated political hurdles. Analysis suggests that since the reform effort was driven largely by donor agencies, incentives to overcome these political problems were limited (Rwamigisa et al. 2013).

Nevertheless, the Uganda experience has informed investment elsewhere in Africa and in other regions. For instance, AGRA has invested in national and regional Soil Health Consortia to bring together scientists, industry actors and policymakers to jointly identify and address cross-cutting constraints to expanded adoption of integrated soil fertility management technologies and practices (AGRA 2015). IFAD has supported multistakeholder Country Fora (CF) that provide professional platforms for harmonization and improvement of agricultural advisory services. The CFs have stimulated interest among stakeholders for learning and sharing of knowledge, along with participation in policy formulation (IFAD 2015). These networks and platforms are complex to design and challenging to implement and sustain, but returns in relevance and impact potential appear to justify the costs.

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