Chapter 2

GLOBAL ISSUES IN AGRICULTURAL DEVELOPMENT

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Chapter 1 reviewed dynamically changing global trends in agricultural development and identified emerging and diverse issues associated with the process of global agricultural development. This chapter reviews the literature on these topics in order to clarify the context under which regional issues (Part II), newly arising critical issues (Part III), and future challenges and opportunities (Part IV) are discussed. More specifically, this chapter addresses the major debates around agricultural development, policies, and technological changes to reduce or eliminate food insecurity and attain sustainable development.[1]

The first section addresses the potential for agricultural growth and structural transformation, including transformation of the rural areas and the dietary transition. The second section discusses markets, food value chains, and international trade, assessing the rapidly changing dynamics of delivering food from the farm to the table. Key topics include the impact of the rise of supermarkets in the developing world, contract farming, and food safety and food quality. The role of international trade and food price stabilization policy is also reviewed. The third section provides an overview of agricultural support policies, including agricultural subsidies, agricultural credit, and crop insurance. The fourth section assesses the potential for sustainable agricultural growth as a foundation for agricultural development by examining the role of technology, including biotechnology, sustainable water and land use, and property rights and climate change. The debate on future sources of sustainable growth is also reviewed.

1 Some sections of this chapter draw upon Rosegrant, M. W. 2014. *Food Security*. Thousand Oaks, CA, US: SAGE. http://ifpri.worldcat.org/title/food-security/oclc/871340599. Used with permission.

Agricultural Development and Transformation

Agricultural Growth and Poverty Reduction

The evolution of agricultural development thinking described in Chapter 1 provides an overview of structural transformation with agriculture-led economic growth, building on the Hayami and Ruttan (1971, 1985) model of structural transformation driven by induced technical change. Scientific progress continues, and the changing nature of technology may drive a new agricultural transformation. In addition to technological change in agriculture, rapid technological change outside of agriculture is creating new potential for technological change in agriculture and for new employment opportunities in rural towns and small cities. New science-based technologies are likely to be strongly laborsaving and can give a big technological advantage to agriculture in developed and middle-income countries. These new technologies are also likely to create economies of scale in agriculture that could create pressures to consolidate land ownership or operational size of farms, particularly in high-performing countries in East Asia. Food value chains will also be fundamentally influenced by these advanced technologies, with the potential for significant reduction in postharvest losses, and fundamental changes in contract farming. How these technologies play out will also influence employment, rural–urban migration, and the future of the structural transformation, as well as poverty reduction. These issues are addressed further in Chapters 3, 9, and 11.

Historically, the major sources of growth in agriculture have been increased input use and productivity growth. In addition to land and labor, increased use and productivity of inputs—including modern inputs such as fertilizer, improved seeds, and water—play a key role for agricultural productivity (Nin Pratt 2015). Other factors have also contributed to agricultural production growth. Craig, Pardey, and Roseboom (1997) demonstrate that improvements in input quality, such as better-educated labor and improved tractors, explain a significant part of the differences in agricultural productivity across countries. They also show that public goods, represented by agricultural research and road density, as well as life expectancy, are important in explaining between-country differences in agricultural productivity.

Productivity growth from technological innovations and institutional changes also contributes to agricultural growth. Key factors affecting agricultural productivity growth include climatic, environmental, technological, institutional, economic, and policy conditions. Measures that increase crop yields include institutional reforms, such as the household responsibility system

in China and Viet Nam (Lin 1991; Rozelle and Swinnen 2004; Jin, Huang, Rozelle 2010). In addition, the development of new varieties, technological diffusion, land improvements, adoption of conservation tillage techniques, denser and earlier planting, irrigation, pest control, and weed control also contribute to enhanced yield. The factors that affect crop yields negatively include land degradation, adverse climate conditions, limited resource conditions, poor farm management, and disincentives like those in the former Soviet Union.

While major drivers of productivity growth vary by country and region, there is an extensive literature focused on understanding the determinants of the gains in productivity in agriculture that shows that public and private research and development investments have played a crucial role in realizing productivity growth in the agricultural sector (Hayami and Ruttan 1985; Alston et al. 2000, 2010; Evenson 2001; Fuglie and Schimmelpfennig 2010; Colman 2013). In developing countries, agricultural research and development has been mainly undertaken by public institutions such as government laboratories and universities, as well as nonprofit institutions such as the CGIAR centers, as is discussed by Evenson and Gollin (2003a, 2003b). However, private sector research has been increasing rapidly, particularly in relatively fast-growing countries such as Brazil and India.

Gollin, Hansen, and Wingender (2018) evaluate the impact of adopting high-yielding crop varieties (HYVs) in developing countries, focusing on the Green Revolution period from 1960 to 2000. They estimate that a 10 percentage point increase in HYV adoption increases gross domestic product (GDP) per capita by about 15 percent, by the direct effect on crop yields, factor adjustment, and structural transformation. The study also finds that HYV adoption reduced both fertility and mortality. Hazell (2009) further shows that Green Revolution investments achieved a high rate of economic return. But policies need to address concerns about the sustainability of intensive cultivation, including the possibility of soil degradation, chemical pollution, aquifer depletion, and soil salinity. Pingali and Rosegrant (2000) show that inappropriate management of modern inputs was the primary cause of these Green Revolution problems, driven mainly by inadequate extension and training, ineffective regulation of water quality, and input pricing and subsidy policies that made modern inputs too cheap and encouraged excessive use.

However, the Green Revolution has had limited impacts in Africa. Reasons for this include the lack of a dominant farming system (such as rice and wheat); predominance of rainfed rather than irrigated agriculture; lack of an effective extension system; poor soil fertility; underinvestment in agricultural research and development and rural infrastructure; lack of competitive

markets and conducive enabling environments; the negative impact of poor human health on agriculture; minimal mechanization; and the predominance of customary land tenure (InterAcademy Council 2004). Recent literature focuses on the role of farmer-to-farmer extension, which is complementary to conventional public-sector extension, and discusses how to select and incentivize the farmer-trainers (see Takahashi, Muraoka, and Otsuka 2020 for a review). Prior to the implementation of structural adjustment programs, macro, trade, and taxation policies heavily penalized the agricultural sector, resulting in high costs and limited access to inputs and low output prices for farmers. Implementation of structural adjustment programs and agricultural market liberalization programs in the 1990s started reducing these penalties (Hazell 2009).

Agricultural growth can be a key driver of poverty reduction, more so than nonagricultural growth in some instances. Since poverty is largely a rural phenomenon and since many of the poor depend, directly or indirectly, on the farm sector for their incomes, growth that raises agricultural productivity and the incomes of small-scale farmers and landless laborers is particularly important in reducing poverty and improving food security (Rosegrant and Hazell 2000; Diao et al. 2014; Christiaensen and Martin 2018). In addition to driving agricultural development and transformation, productivity growth has far-reaching impacts beyond agricultural growth. Recent studies confirm the significant impact of agricultural growth on poverty reduction. Growth in agriculture is shown for many countries to be generally more effective at reducing poverty, in comparison to nonagricultural growth, by two or three times, and this advantage is more defined for the poorest populations (Thirtle, Lin, Piesse 2003; Christianesen and Martin 2018). Yet, Dercon and Gollin (2014) note that heterogeneity in the agricultural sector at all levels—in countries, subnational regions, villages/communities, individuals—affects potential pathways for agricultural development and impact on poverty reduction. Heterogeneity can be found in many factors, including climate and soils, policies, institutions, access to markets, and more, which is discussed further in Giller et al. (2011). Further, the authors indicate there is room for improvement in the empirical studies on agricultural growth considering agriculture's impact on poverty reduction. For example, more rigorous assessment of the costs and the opportunity costs of boosting growth in agriculture is needed. Studies should account for the relative cost-effectiveness of obtaining growth in agriculture compared with obtaining growth in other sectors and avoid assuming a straightforward path from investment to agricultural growth to poverty reduction. Overall balance is another important factor noted by the

authors, as agricultural growth will not come in isolation but rather from its interaction with the rest of the economy.

Research-led technological change in agriculture in Africa and Asia has substantially reduced poverty, whereas productivity growth in industry and services has had a relatively modest impact except in East Asia (that is, Northeast and Southeast Asia) (Thirtle, Lin, and Piesse 2003). Fan et al. (2000) investigate the causes of the decline in rural poverty in India and the role that government investments have played. They show that government expenditures have both direct and indirect effects on poverty reduction. Such expenditures directly generate income through employment generation. Much larger indirect benefits are due to investments generating long-term agricultural and nonagricultural growth. Investments in roads and agricultural research and development have the largest impacts on poverty reduction and growth in agricultural productivity, followed by government spending on education, which may generate benefits over extended periods.

Nevertheless, nonagricultural growth also plays an important role in poverty reduction, including through the reallocation of labor from agriculture to nonagricultural sectors, which are often more skills intensive and labor-productivity enhancing. Nonagricultural growth can also be poverty reducing by contributing to agriculture. While the degrees of impact depend on the national subsectors involved, growth in some sectors, such as transport services and manufacturing (especially agro-processing) in Africa, can be as effective as growth in agriculture (Dorosh and Thurlow 2018). Increased efficiency of trade and transport also saw reduced transaction costs for all marketed products, particularly those with high cost margins, such as agriculture and food (Christiaensen and Martin 2018).

Masters (2005) assesses trends in poverty and undernutrition in Africa; the availability of food, rural population, and demography; farm output and input use; and determinants of input use and agricultural research effort. He points out that African farmers have adopted profitable new varieties when they have been available but that research and seed delivery systems have often not effectively developed suitable varieties. A Green Revolution in Africa will require the introduction of agronomic and other innovations for many crops and many environments, supported by investments to develop and spread new seed varieties. More appropriate and better-targeted research and development and effective extension systems for agriculture are essential for the economic future of the African continent (Otsuka and Larson 2013, 2016). Sources of agricultural growth will be further analyzed in five regional chapters in Part II (Chapters 3 to 7).

Meanwhile, the potential impact of the decreasing share of the agricultural sector on poverty reduction and other development outcomes should be taken into account when considering future investment priorities. Human capital investment that drives long-term development is also fundamentally influenced by agricultural growth and access to food. Alderman, Hoddinott, and Kinsey (2006) show that even short-term shocks such as drought and war early in life can have long-term negative effects on individuals' nutritional status. When such events generate reductions in consumption because households are unable to protect against the shock, they lead to long-term reductions in height and schooling achievement. Improvements in preschool nutrition and health—and prevention of losses in preschool nutritional and health status due to shocks—not only have immediate benefits, but also have long-term benefits in improved height and educational attainment.

The Dietary Transition

The structural transformation literature emphasizes the importance of agricultural growth as a means of reducing poverty and increasing food security through greater availability of food and lowering food prices. In his classic writing in the early 1980s, Amartya Sen introduced the *entitlement* approach, which contrasts with the more usual food availability approach, concentrating instead on the ability of the people to afford food through use of production possibilities, income, trade opportunities, and entitlements with respect to the state (Sen 1981). This shift in focus from food supply to individual access to food highlighted the important role of demand failure due to unemployment, adverse movement in the terms of trade, production failure, termination of transfers, or other forms of entitlement failure (Barrett, Carter, Timmer 2010). The past paradigm of agricultural development focused on growth, productivity, and poverty reduction. However, the current global context warrants a broader perspective toward agriculture, namely its contribution to improved nutrition, health, and human well-being (Fan and Pandya-Lorch 2012). In this regard, diets are key in our approach to modern agrifood systems.

This is ever more critical, as populations in those countries undergoing rapid economic growth and transformation are experiencing the most rapid nutritional transition. Beginning in Asia, but increasingly for the rest of the developing world, diets are shifting away from staples and toward livestock and dairy products, vegetables and fruits, and fats and oils. As income in both rural and urban areas increases, demand for more diversified foods is increasing and agricultural production in turn is driven by the demand to further

diversify its products, which contribute to more-balanced diets (Fan, Yosef, and Pandya-Lorch 2019a).

At the same time, current food consumption patterns in much of the developing world are showing signs of convergence toward a Western diet. The diet transition is characterized by increased consumption of wheat, temperate fruits and vegetables, and high-protein and energy-dense food. Globalization and the consequent global interconnectedness of the urban middle class is the driving force behind the convergence of diets. The rapid spread of global supermarket chains and fast-food restaurants is reinforcing these trends (Hawkes, Harris, and Gillespie 2017). Growth in incomes in developing countries is driving particularly strong growth in per capita and total meat consumption, which in turn induces strong growth in feed consumption of cereals, particularly maize (Pingali 2006; Rosegrant, Leach, and Gerpacio 1999). The change in consumption trends has been slower in Africa and in some developing countries, especially in Africa south of the Sahara (Kearney 2010). The rapid urbanization of developing countries is another important factor, due to urban sedentary lifestyles and the rapid spread of food outlets for fast and energy-dense foods, as well as the increasing dependency on prepared food, usually consumed away from home (Caballero 2007; Ruel, Garrett, and Yosef 2017).

Globally, these changes in dietary patterns are particularly important in terms of the rise in overnutrition (that is, diet-related chronic disease) in many developing countries alongside persistent undernutrition (Kearney 2010; Hawkes, Harris, and Gillespie 2017). The dietary transition has in fact thrown a light on the new types of food insecurity that ought to influence the desirable path of agricultural development. In addition to rising overweight and obesity as described, the problem of undernourishment caused by insufficient intake of dietary energy and protein, as well as micronutrient deficiencies, all coexist. These three dimensions represent the "triple burden" of malnutrition (Gómez et al. 2013).

Overweight and obesity are the result of excessive dietary energy intake and are often associated with increased risk of diabetes and cardiovascular disease. These conditions are increasingly common in developing countries, with obesity reaching a global prevalence of 12 percent in 2008 (Gómez et al. 2013). According to the 2016 Global Burden of Disease (GBD) study, 72 percent of all cause-specific deaths worldwide were from noncommunicable diseases (NCDs), and most of the global burden of deaths and disabilities from these NCDs occur in low- and middle-income countries (Ecker 2019). Caballero

(2005) notes the increasing frequency in developing countries of underweight in children and overweight in adults, often within the same family. This phenomenon in developing countries occurs due to the changes in diet, food availability, and lifestyle in countries experiencing a socioeconomic and demographic transition. Moreover, evidence suggests that fetal undernutrition increases the risk of obesity and associated NCDs later in life (Ecker 2019).

Undernourishment contributes to negative health outcomes such as the prevalence of underweight (low weight for age), wasting (low weight for height), or stunting (low height for age), especially among children. Stunting measures the long-term negative effects of food intake deficiency and disease, and it afflicted 165 million children globally in 2011, for a prevalence of 26 percent. Stunting is caused primarily by maternal undernutrition and by poor nutrition and repeated infections in the first two years of a child's life. Wasting captures shorter-term, acute episodes of malnutrition. Underweight is a product of the other two indicators (Gómez et al. 2013).

Micronutrient malnutrition includes iodine, iron, and vitamin A deficiencies and can coexist with excessive consumption of macronutrients (that is, overweight and obesity). Vitamin A deficiency is the leading cause of blindness in children and harms proper growth and reproduction, leaving the body more vulnerable to infections (Gómez et al. 2013). Inadequate dietary intake and infectious disease are the most direct causes of undernutrition. Inadequate dietary intake weakens the immune system and increases susceptibility to disease. Infectious disease increases nutrient requirements and weakens the immune system by impairing absorption of essential nutrients and increasing nutritional requirements and decreasing purchasing power because of sickness, absenteeism, the inability to do work, and unemployment, as well as the increased time and money spent on treatment and care. Broader factors also influence nutrition, including economic, political, and social factors (UN Standing Committee on Nutrition 2010; Gómez et al. 2013). Particularly noteworthy is the empowerment of women within a household, as women are more conscious about nutrition and health than men.

Increasing productivity growth to expand food availability remains a high priority in many developing countries where undernourishment is still the dominant nutritional problem. Increases in food production are also essential to generate higher incomes in developing countries. But the broadening of malnutrition problems, together with the continued transformation of food systems in developing countries, calls for wider-ranging approaches and interventions to improving nutritional outcomes than have been used historically. Reducing the impact of these factors would require major changes in urban

planning, transportation, public safety, and food production and marketing (Caballero 2007; Ruel, Garrett, and Yosef 2017). Interventions and policies should take account of the need for more sustainable diets that would include a sufficient supply of micronutrient-rich foods without excessive consumption of energy-dense, nutrient-poor foods (Kearney 2010). In promoting nutrition- and health-driven policies, targeting those most in need, particularly children under age two and marginalized populations underserved by essential health services, will be important. Furthermore, filling the knowledge gaps through research, scaling innovation solutions, and fueling partnerships between health, nutrition, and agriculture will be crucial (Fan, Yosef, and Pandya-Lorch 2019b). These issues are discussed further in Chapter 10 as well as Chapter 9.

Markets, Food Value Chains, and International Trade

The Dynamics of Markets and Food Value Chains

Effective agricultural markets benefit both producers and consumers and offer greater income opportunities by integrating small-scale producers into upgraded value chains, spurring agricultural development. Establishing competitive and efficient markets is an important challenge in achieving agricultural growth. Among the most important constraints are those related to costs in the value chain, including transport, communication, and transaction costs. The high costs to farmers and other actors due to poor infrastructure, lack of information, insufficient credit, and policy distortions reduce the efficiency of value chains and impede producers' ability to connect to market systems. An agricultural value chain is the series of activities by agents and markets from farm to final consumption that build product value. Millions of low-income people participate in agricultural value chains as consumers, producers, small-scale traders, processors, and retailers. Improvement in the performance of value chains would benefit large numbers of people (Beamon 1999; Lohman, Fortuin, and Wouters 2004; IFPRI 2011).

Revolutionary changes in processing, wholesale, and retail segments of the value chain are taking place. This process has been moving quickly in developing countries during the past three decades, beginning in Latin America, then in Asia, and later and more slowly in Africa. The transformation includes consolidation of value-chain operations, rapid institutional and organizational change, and modernization of the procurement system. Among the changes are the rapid rise of supermarkets, large and modern food processors, and

logistics and wholesale firms. Reardon and Timmer (2012) show that "these changes have mainly been driven by the private sector, through both domestic and foreign direct investment, with public sector investment in infrastructure providing the underlying conditions."

Information and communications technologies (ICTs) have substantial potential to improve value-chain performance. Sensors linked to digital information systems can improve links between farmers and processors; reduce losses (with consequent reduction in water used in producing final food products, because less water-using primary food production is required to generate the final product) with digitally enabled harvest loans and digital warehouse receipts; monitor storage conditions and track provenance to allow grading and inform consumers; reduce costs of transport; increase choice of different types of transport for farmers; and increase access to timely information so that farmers know if and when transport is arriving (USAID 2017). The use of ICT is also expanding on the farm input side of the value chain. Private- and government-run management information systems provide knowledge related to farm inputs and farm management practices such as planting methods, seeds to use, sowing time and application of fertilizers, and current market prices. ICT-enabled applications allow agricultural input supply companies to improve operations and build capacity to expand outreach and meet farmer needs and provide real-time weather information and forecasts and drought early warning systems to farmers. Farmers can buy inputs (seed, fertilizer, etc.) using cell phones, reducing transaction costs.

Progress is being made, therefore, to turn the potential of digital information systems into reality for agricultural value chains. Yet major efforts are still required to achieve large-scale adoption in developing countries. The prices of many ICTs remain high for most developing country applications. Both the market and donors have a role to play in speeding up cost reductions for sensors and related technologies and in supporting local development partners in testing and refining technologies for context-specific applications. Innovation is especially important to integrate sensor technology and data applications into locally appropriate products and services that address problems affecting smallholders. Governments, entrepreneurs, and private-sector actors all have roles to play in promoting adoption by creating and disseminating actionable information to smallholders and others along the agricultural value chains (Feed the Future 2016).

The food-value-chain transformation appears to be improving food security for cities, by reducing marketing margins, offering lower consumer prices, and increasing the quality and diversity of food (Reardon et al. 2014). But

evidence is mixed regarding the impact on farmers. Available evidence indicates that larger farmers with higher assets have higher participation rates in the transformation, even though smallholders increasingly participate in the production of high-value products (Otsuka, Nakano, and Takahashi 2016). Farmers who participate in transformed systems experience a net income gain and risk reduction, relative to those in only traditional markets. Gains can come both from rewards for quality differentiation and from a premium controlling for quality (Reardon and Timmer 2012).

Barrett et al. (2012) note that historically market sales of food have been heavily concentrated in the hands of a small number of large producers, even in regions and countries with broad-based market participation. The relatively high upfront investment required to participate in modern markets and the presence of fixed costs in making contracts are challenges to participation of smallholders, meaning major benefits of food-value-chain transformation may be concentrated in a relatively small share of farmers (Barrett et al. 2012). More recently, Ton et al. (2018) showed that smallholders can benefit from contract farming, yet the poorest farmers are rarely included, and contract farmers had significantly larger landholdings or more assets than the average farmers in the region. The authors also note that any broad assessment of the effect of contract farming on income is upwardly biased due to mechanically excluding contract farming arrangements that failed. Also, better specification of the services provided by the firm to the farmer is recommended to increase the relevance of the research for development practitioners and governments. Arouna et al. (2019) further provide insights from Benin that find that contracts that only included an agreement on price had nearly as large an impact as did contracts with additional attributes, suggesting that once price uncertainty is resolved, farmers are able to address other constraints on their own. More generally, Bellemare and Bloem (2018) review recent literature on contract farming, finding considerable heterogeneity across contexts that limit external validity, as well as issues relating to the credible causal identification of treatment effects that limit internal validity. Further, many findings almost always apply narrowly to a handful of crops, to a restricted geographical area, or to a single year, and the authors concluded that it is difficult to draw any broad policy-relevant conclusions from the literature on contract farming.

Minten et al. (2009) note that some literature points to modern retailing companies becoming increasingly dominant in international and local markets in fruits and vegetables, with mostly negative implications for small farmers in Africa, under the right circumstances. But they also show that, “given the right incentives and contracting systems, small farmers in developing

countries—and in Africa in particular—can participate successfully in these emerging value chains." Benefits are generated from improved access to inputs, credit, extension services, and technology adoption and from productivity spillover effects on other crops and enhanced income stability. A review of the literature by Otsuka, Nakano, and Takahashi (2016) also suggests that producer cooperatives spontaneously formed by smallholders attempt to reduce transaction costs between the buyers and a large number of smallholders. Earlier, Michelson (2013) found that farmers who supply supermarkets experience an increase in their stock of household assets of about 16 percent on average in Nicaragua. However, the location of supermarket procurement centers and the rate of household participation are strongly impacted by access to roads, markets, and sufficient water for crop production.

An important innovation linking small farmers to markets is the rapid spread of mobile phones and other information technology. As Aker and Mbiti (2010) note, access to mobile phones in Africa south of the Sahara has increased dramatically; 60 percent of the population had mobile phone coverage by 2010. Mobile phones can improve access to and use of information, thereby reducing marketing costs, improving coordination, and increasing market efficiency while also facilitating communication in response to shocks to reduce exposure to risk.

For example, Suri and Jack (2016) find that the Kenyan mobile money system, M-Pesa, has increased per capita consumption levels and lifted households out of poverty. The impacts, which are more pronounced for female-headed households, appear to be driven by changes in financial behavior and labor market outcomes, such as occupational choice, especially for women who moved out of farming and into business. Mobile money has therefore increased the efficiency of the allocation of consumption over time while allowing a more efficient allocation of labor, resulting in a meaningful reduction of poverty in Kenya (Suri and Jack 2016). Although M-Pesa has been very successful and mobile money is expanding several other economies, its use remains mostly limited to person-to-person transactions that take place over long distances and those that are in places where holding cash is risky. Outside these applications, there has been less success, and financial innovation around mobile money is still in its early stages. Expansion in the scope and impact of mobile money will require innovation in financial systems and regulations and payment modalities and growing knowledge and acceptance from consumers (Suri 2017).

The issue of dynamic changes in food value chains will be discussed in Chapter 12 as well as in Chapter 11.

International Trade and Price Stabilization

Trade policies are important determinants of agricultural development. Broad economic growth, based on stable macroeconomic environments, can help create trade and domestic markets for agricultural commodities and the generation of capital for investment in agriculture. In addition to setting the economic environment for overall economic growth, these policies can also have a profound impact on the performance of individual sectors of the economy such as agriculture. Trade policies can affect agriculture by either taxing (dis-protecting) or subsidizing (protecting) the sector. Trade restrictions have a direct effect on the domestic prices of tradable (often agricultural) goods and have an impact on the real exchange rate, which in turn affects the domestic prices of tradable goods in relation to locally produced goods. For example, import duties and quotas raise the domestic price of import-competing products in relation to exportables (including many agricultural commodities) and therefore encourage a shift away from export production. The same policy instruments reduce the demand for imports, which lowers the price of foreign exchange so that the domestic prices of tradable goods fall in relation to nontradable goods and hence indirectly bias production incentives against both import-competing and export goods such as agricultural products.

Alternatively, trade policies can protect agriculture or specific commodities within the agricultural sector. Agricultural protection, by raising domestic food and agricultural prices above world prices, penalizes consumers and introduces inefficiency by attracting excess resources to production of the protected commodity or sector and by rendering unprotected sectors less competitive. Protectionist policies require large government fiscal outlays to farmers to pay price supports and subsidies and may also encourage excessive use of agricultural chemicals, thus damaging the environment. Despite these negative impacts of interventions, the agricultural and food sector has been subjected to some of the heaviest governmental interventions over most of the world and much of history, accounting for an estimated 70 percent of the global welfare cost of all merchandise trade distortions in 2004, even though the agricultural sector contributes only 6 percent of global trade and 3 percent of global gross domestic product (Anderson, Rausser, and Swinnen 2013).

For developed countries, the main reason for restricting food trade has been to protect domestic producers from import competition, but these measures harm not only domestic consumers and exporters of other products but also foreign producers and traders of food products. Agricultural protection and subsidies in developed countries have depressed international prices of farm products, reducing agricultural income in developing countries.

"Protectionist policies of developed countries have thus been partly responsible for international income inequality and poverty in developing countries," say Anderson et al. (2013). During the past decade, economic growth, changes in political economy induced by such growth, and changes in governance and media structures have driven some reduction of antiagricultural policies in developing countries. Reductions in the protection of agriculture have also occurred in some developed countries, especially in the European Union (Anderson et al. 2013).

Because of these negative effects of taxation and protection through biased trade policy, removal of these biased policies can generate large economic and food security benefits. Winters, McCulloch, and McKay (2004) provide a review of the evidence on trade liberalization and poverty, vulnerability, productivity, and governance revenue. Their review of the empirical evidence shows that trade liberalization will alleviate poverty in the long run and lends no support to the position that trade liberalization generally has an adverse impact on poverty. Anderson, Cockburn, and Martin (2011) provide more support in a recent review of global trade liberalization, with all but 2 of the 32 cases analyzed indicating that overall global trade reform decreases poverty.

Winters et al. (2004) also note that trade liberalization necessarily implies changes in the distribution of income; it may well reduce the well-being of some people in the short term, and some of these people may be poor. Supporting policies will sometimes be needed to reduce the adverse impacts of trade liberalization, including the impact on poverty. Poorer households are less able than richer ones to protect themselves against negative effects or to take advantage of the opportunities created by policy reform, increasing the desirability of supporting policies such as social protection. Winters et al. (2004) conclude that, "although trade liberalization may not be the most powerful or direct mechanism for addressing poverty in a country, it is one of the easiest to change. Thus, trade reform may be one of the most cost-effective anti-poverty policies available to governments."

Food price risks and instability have contributed to the reluctance of countries to liberalize food markets because of fears about the impacts on food price instability, or out of the belief that food prices have become more unstable in countries that have already liberalized food markets. Byerlee, Jayne, and Myers (2006) explain that policy that targets price stability, especially using public grain reserves, has often had poor results, with consumers facing greater instability in food prices and availability when strategic reserves are used. Policies should instead focus on long-run investments in sustainable market development and productivity growth and the use of market-based

instruments and targeted safety nets to manage the risks of adverse food market outcomes. “Such an approach can provide short-term relief from market shocks for the poor, while maintaining efficient long-run responses to market signals, thereby remaining compatible with longer-run market development,” say Byerlee et al. (2006).

Wright (2012) further addresses the role of grain reserves and related policies in managing grain market volatility. Sharply rising food prices in 2007 and 2008 and again in 2010 and 2011 were caused by several factors, including rapid growth in demand for biofuels; rising energy, fertilizer, and fuel prices; bad weather; and commodity speculation. Also in play were long-run trends in supply-and-demand fundamentals, including low investment in agricultural research and slow crop yield growth (Rosegrant, Tokgoz, and Bhandary 2013). Further exacerbating the increases in rice prices in 2008 was the activation of export controls by a few exporters, including India (November 2007), Viet Nam and Egypt (January 2008), China (January 2008), and Cambodia (March 2008), limiting the availability of rice in the world market and increasing the level and volatility of prices (Headey, Malaiyandi, and Fan 2009). Key wheat suppliers also imposed export bans or taxes (Wright 2012).

Despite the contributions of trade restrictions to increased levels and volatility in prices, the 2007–2011 food price increases led to increased interest in many countries in implementing price stabilization policies. As Wright (2012) notes, “many different policy interventions have been used in attempts to reduce grain price volatility or support price levels. These include controls or sanctions on private ‘hoarding’ or ‘speculation,’ buffer stocks, buffer funds, strategic reserves, use of options and futures, marketing boards, and price floors, all of which obviously affect storage incentives. Other measures that can also affect storage are trade barriers, export taxes, interest rate policies, and production controls.” In the past, a favored policy has been market stabilization using a price band bounded by the floor and ceiling prices to reduce the spikes and troughs typical of commodity prices. However, price-band schemes are unsustainable and expensive and can be extremely destabilizing when they fail (Wright 2012).

The demonstrated failure of many grain exporters to maintain uninterrupted market access to their supplies highlights the desirability of commitment-reinforcing mechanisms for international grain market participants. Among the proposals are an internationally coordinated global food reserve and a global virtual grain reserve. But Wright (2012) explains that such reserve schemes “are highly unlikely to have superior forecasting ability compared to the market as a whole, so will lose money on average, and

eventually exhaust its budget, as did similar schemes in the past." The critical role of undistorted international trade in improving poverty and boosting agricultural growth will be discussed in Chapter 13, followed by the analysis of political economy factors, which lead to the distortion of agricultural markets, in Chapter 14.

Agricultural Support Policies

Policies related to agricultural development, including public investment in agricultural research and development, rural infrastructure, and irrigation, as well as trade and price-stabilization policies were discussed above. This section focuses in more detail on several key policies, including input subsidy, agricultural credit, and crop insurance.

Input Use and Input Subsidies

Government subsidies are often justified as providing public goods or counteracting the impact of market failures. But instead, governments often intervene to provide large subsidies to private goods (such as fertilizer and credit), displacing the supply of public goods (research, roads, and education). Together with reducing the supply of infrastructure and other public goods, public expenditures on subsidies often result in underinvestment in research and development and in inadequate sanitary and environmental protection. López and Galinato (2007) show that "reducing the share of subsidies to private goods in the government's budget therefore has a large and significant positive impact on rural per capita income, reduces certain undesirable environmental effects associated with output growth, and contributes to poverty reduction."

Fertilizer subsidies have been among the most common and most expensive subsidies in agriculture, intended to increase fertilizer use, crop production, and income. Ricker-Gilbert, Jayne, and Shively (2013) review the evidence on fertilizer subsidies in Africa, noting that "policy recommendations about returns to alternative investments must compare the benefits and costs of subsidizing fertilizer with other alternative public investments and policies capable of promoting smallholder food security and poverty reduction." They find some evidence of positive increases in maize production from fertilizer subsidies in Malawi, but these are small relative to the size and scope of Malawi's subsidy program. Moreover, the impacts of greater maize production must be weighed against the unintended effects of the subsidies, including the displacement of other crops by maize, crowding out of the private

seed and fertilizer sectors, and the impact of reduced crop diversification on agricultural sustainability, smallholder vulnerability, and nutritional balance (Ricker-Gilbert, Jayne, and Shively 2013).

Given the negative effects of subsidies, are there appropriate uses for them? Small-scale "smart" fertilizer subsidies to farmers may be cost-effective in stimulating farmers to adopt and utilize fertilizer appropriately together with new production technology. Temporary subsidies during the early stage of fertilizer adoption may be effective in overcoming the fixed costs related to adoption of new technology and in inducing farmer experimentation and learning during periods of rapidly changing technological potential. Such temporary subsidies should be phased out as adoption and appropriate use of fertilizer become widespread. But the phaseout of subsidies becomes difficult once they are in place and develop political support.

Duflo, Kremer, and Robinson (2011) suggest an innovative variation on a smart fertilizer subsidy, based on some farmers being biased toward the present and tending to procrastinate on decisions, postponing fertilizer purchases until later periods. Under these conditions many farmers in Western Kenya fail to make apparently profitable fertilizer investments, but they do buy fertilizer in response to small, time-limited discounts on the cost of buying fertilizer just after harvest. Results suggest that this policy can yield higher welfare than either no subsidies or heavy subsidies. Small, time-limited reductions in the cost of purchasing fertilizer at the time of harvest induce substantial increases in fertilizer use, comparable to those induced by much larger price reductions later in the season (Duflo, Kremer, and Robinson 2011).

This approach may provide a design for effective small-scale "smart subsidies," but smart subsidies have often grown into costly large-scale input subsidy programs. Policymakers must consider whether input subsidy programs can be sustainable given their high direct and opportunity costs (Ricker-Gilbert, Jayne, and Shively 2013). A more appropriate role for the government in enhancing fertilizer use would be to provide public goods, including extension services to advise farmers on the appropriate quantity, quality, and timing of fertilizer applications. Several studies have concluded that commercial farmers should pay for extension advice, while the government should provide extension services to small producers free of charge (Rivera 2001). Extension policies and strategies need to define an effective division of labor between public extension and farmer-to-farmer extension (Takahashi, Muraoka, and Otsuka 2020) and identify overall objectives for public sector involvement in extension (Rivera 2001). Another challenge to privatizing extension services is the lack of private providers, especially in remote areas (Jagger and Pender

2003). But in some countries that have privatized provision of advisory services, many service providers have emerged. For example, in Mali and Uganda, there are many nongovernmental organizations (NGOs), private companies, and semiautonomous bodies engaged in delivering extension advice to farmers (Qamar 2002). Improved coordination of multiple extension service providers is also required. Moreover, governments should upgrade infrastructure affecting supply and distribution, such as roads and ports. Instead of relying on subsidies, improved fertilizer policy should be accompanied by integrated soil fertility management based on both organic and inorganic fertilizer application and intercropping of staple crops with beans for sustainable productivity growth (Otsuka and Muraoka 2017).

Mechanization is another private good that often has received public policy support. Binswanger (1986) shows that "mechanization is most profitable and contributes most to growth where land is abundant, where labor is scarce relative to land, and where labor is moving rapidly off the land." Mechanization facilitates the trend toward larger farms, and large farms adopt new forms of machinery considerably faster than small farms. However, when rental or contract operations are developed, mechanization can also spread to smaller farms (Binswanger 1986). Evidence shows that, in recent years, contracting of machinery has become more widespread in Asia, as is consolidation of farm management into larger units while ownership of individual smallholdings is often maintained (see, for example, Yang et al. 2013).

While mechanization rarely leads directly to increase in yields, it can stimulate growth when it makes a new method of crop production profitable, as in the case of irrigated farming using pumps (Binswanger 1986). Pump irrigation has been a major driver of agricultural growth in Asia, including at least four very different situations: (1) the use of tube wells to tap deep aquifers for irrigation, as are commonly found in the semiarid regions of Punjab in India, and in the North Central Plain of China, and to supply water to urban areas; (2) the use of low lift pumps to tap shallow alluvial aquifers that are usually replenished every year; (3) pumping of water (either for irrigation or for drainage) in major river deltas such as the Chao Phraya and the Mekong; and (4) other situations where pumps are used to recycle water from rivers and drains (Barker and Rosegrant 2007).

Government interventions to push mechanization have had little success and have been very costly. Pakistan subsidized big tractors and prohibited imports of all but a few brands, making it almost impossible for innovating firms to import smaller foreign designs for local adaptation. Thailand's contrasting laissez-faire policy "resulted in the development of indigenous power

tillers and small tractors, a wider choice of machinery, and few adverse social consequences" (Binswanger 1986). Only when private tube well imports and markets were deregulated did the small-scale tube well revolution take off in Bangladesh (Barker and Rosegrant 2007). Similarly, state-led mechanization pushes in Africa often failed due to lack of understanding of the nature of demand for mechanization technologies among farmers and insufficient knowledge of private-sector functions (Diao, Silver, and Takeshima 2016). Until recently in Africa south of the Sahara, power tillers and small tractors were seldom used. However there has been increasing demand for mechanization there with increasing rural wages and urbanization that has increased demand for labor-intensive crops. The rising demand for mechanization and the increased number of medium-scale farmers owning tractors in some countries have created a private tractor hiring market in some African countries (Diao et al. 2016). Governments can support research and development to manufacture smaller machinery suitable to local conditions and demonstrate its advantages with training programs and reduce tariffs for imports of machinery and spare parts but should not repeat the history of failures of government-run or government-subsidized promotion of mechanization. Rather than subsidies, Merrey and Lefore (2018), based on a review of recent pilot studies, find that the most promising models to support small farmer adoption of irrigation are "partnerships among microfinance and other institutions (e.g., manufacturers, retailers, agricultural advisors); 'pay-as-you-go' or rent-to-own models that spread out payments and enable farmers to begin benefiting immediately, while minimizing risk because the pump is the collateral; and contractor or utility models where entrepreneurs offer irrigation services rather than selling equipment."

Remote sensing and precision agriculture coupled with ICT have potential to boost agricultural productivity and income through improved input markets and input-use efficiency. Precision agriculture has mainly been for large-scale farming, and these and other advanced technologies coming on stream could be characterized by economies of scale or barriers to entry based on expertise and financial start-up costs, which can make advanced and larger farmers more efficient than small farmers. Thus, it is essential to develop precision technologies suited to small farmers, as well as enabling conditions such as credit and contracting services for precision equipment. Promising applications are seeking to bridge this gap for small farmers. Hello Tractor is an example of a custom tractor company that seeks to fill the demand for tractor hire services mentioned above. It is a business platform of entrepreneurs operating in Africa and Central America, in which small farmers use their mobile

phones to contract with Hello Tractor for tractors to plow and harvest their fields, track when they will arrive, and make mobile money payments. Hello Tractor uses smart tractors linked to the cloud with a GPS antenna and international SIM card for remote monitoring (Davies and Garrett 2018).

Ekekwe (2017), summarized in Rosegrant (2019), identifies some promising remote-sensing applications for small farmers. Aerial images from satellites or drones, weather forecasts, and soil sensors are making it possible to manage crop growth in real time. Zenvus, a Nigerian precision-farming start-up, measures and analyzes soil data like temperature, nutrients, and vegetative health to help farmers apply the right fertilizer and optimally irrigate their farms. The system can improve farm productivity and reduce input waste by using analytics to facilitate data-driven farming practices for small-scale farmers. UjuziKilimo, a Kenyan start-up, seeks to use big data and analytic capabilities to transform farmers into a knowledge-based community with the goal of improving productivity by adjusting irrigation. SunCulture, which sells drip irrigation kits that use solar energy to pump water from any source, can make irrigation affordable.

One example of precision agriculture for irrigation in Africa is FruitLook, used by farmers in the Western Cape in South Africa, which is a state-of-the-art information technology that helps deciduous fruit and grape farmers become water efficient and climate smart. A second example is the Chameleon and Wetting Front Detector sensors that have enabled small-scale farmers in Mozambique, Tanzania, and Zimbabwe to cut irrigation frequency and improve productivity (Ncube et al. 2018).

While these new ICT-enabled technologies show promise, they would still need to be upscaled to achieve broader impact. Aker et al. (2016) state that, although there is substantial potential for ICT-based services to address farmers' and traders' information and credit market constraints, economic research suggests that the impacts of such services on agricultural adoption, behavior, and welfare are mixed. To improve their effectiveness, information services need to be high quality and preferably from a trusted source. Services are best "delivered via platforms that build upon local ICT access and usage, paying particular attention to the gender digital divide" (Aker et al. 2016). IFPRI, CCAP, and Asian Development Bank (2019) show that government policies can facilitate the effective application of ICT, including e-commerce, in rural China: investing in storage and transportation for the development of e-commerce in agriculture; investing in farmers' capacity building through practical training; providing financial and credit supports for farmers, particularly to small farmers; facilitating farmers working together in e-commerce; and

improving market regulations and providing a favorable market environment for the development of agricultural e-commerce.

Agricultural Credit and Crop Insurance

Simultaneous reform to liberalize and integrate domestic financial capital markets would reduce the costs of increased price variability through risk pooling on an economywide basis. Financial integration for risk spreading and asset accumulation is critical at the rural household level as well. To exploit the income-enhancing potential of the commercialization of agriculture, financial markets must accommodate the increased ability of households to save and build productive asset bases and improve human resources. The process of commercialization itself can provide the critical market size required for efficient, unsubsidized rural banking with low overhead costs. Effective rural financial institutions can in turn assist in the spread of the benefits of commercialization more widely across the community and region.

Farmers' financial needs are becoming more complex and diverse and include access to deposit and savings accounts and possibly also investment loans for nonfarm business activity as well as for agriculture. There is also increasing demand for financial services by many small-scale and part-time nonfarm businesses, especially in the service sector, as witnessed by the recent explosion in microfinance in rural areas. More flexible and customer-oriented financial services are required to meet these needs. In the face of these growing needs, government intervention has often had negative impacts on rural financial markets, limiting their ability to serve not just the rural nonfarm economy but even farmers themselves. Government interventions have included lending requirements imposed on banks, refinance schemes, loans at preferential interest rates, credit guarantees, and lending by government-operated development finance institutions. But these interventions have in most cases had limited impact on the adoption of new technology or on agricultural production, while seriously impairing the banks, cooperatives, and specialized agricultural development banks that have tried to implement them. Moreover, government interventions in rural financial markets have often failed to provide savings and other financial services demanded by farmers. The general failure of directed and subsidized credit calls for a new approach that limits the role of financial markets to financial intermediation rather than serving as a tool to stimulate production, compensating for distortions in other markets, and alleviating poverty. The appropriate roles for government are to help the poor while recognizing high fixed costs of lending to the poor and to create an environment in which misallocation of financial resources by

financial institutions, arising not only from moral hazard and adverse selection but also from other failures, can be minimized. Among other things, this means macroeconomic stability, reasonably low levels of inflation, procedures to enforce contracts, the protection of property rights, and a regulatory and supervisory system that can ensure prudent financial operations (Rosegrant and Hazell 2000).

More recently, careful development of products, policies, institutions, and supportive infrastructure has led to greater success than the old paradigm of subsidized credit to farmers. Meyer, Zander, and Fritsche (2011) note that analysis of the past use of credit subsidies has led to guidelines for "smart" or "market-friendly" subsidies. These guidelines include the following: invest in the creation of public goods that benefit the entire financial sector; subsidize institutions rather than borrowers to reduce distortions, particularly where there is natural spillover to nonsubsidized institutions; but require quantitative performance measures to maintain incentives for high performance matching contributions from grant recipients to demonstrate commitment.

Nevertheless, for poor households, private financial markets may not work. Santos and Barrett (2011) examine social networks and loans to pastoralists in Ethiopia and find that the persistently poor are often excluded from the social networks needed to obtain loans. This social exclusion leaves the poor vulnerable to shocks and largely without credit networks to fall back on in times of need. In this context, worries about the crowding-out effect of public interventions targeted to the poorest appear misplaced, because there is a high probability of poorer members being left uninsured. Empirical results suggest that, up to some wealth level, public transfers may even increase private transfers (Santos and Barrett 2011).

Microfinance programs to assist very small farms and part-time nonfarm activity (especially among women and the poor) have expanded significantly in recent decades and are serving a segment of the rural nonfarm economy that has not been widely reached before. Yet, the ultra poor, who cannot afford to repay the loans, are usually denied access to microfinance. Even if this is the case, microfinance programs may well lead to favorable poverty-reduction effects for the direct beneficiaries. However, whether they lead to growth in total nonfarm income and employment has been a difficult question to answer because microfinance clients are self-selected, which can invalidate comparisons over time between clients and nonclients. Thus, Banerjee et al. (2013) and Banerjee, Karlan, and Zinman (2015) include rigorous impact evaluation case studies of six microcredit programs in selected countries. These studies find little evidence of transformative effects, lacking clear

evidence of reductions in poverty, substantial improvements in living standards, or improvements in social indicators. However, there is stronger evidence that businesses expand, though to a limited extent, with some increases in profits. Authors also find some evidence of effects on occupational choice, business scale, consumption choice, female decision power, and improved risk management. At the same time, studies find little evidence of harmful effects, even with individual lending (in Bosnia and Mongolia) and even at a high real interest rate (in Mexico). Microfinance is discussed further in Chapter 16.

Smith and Glauber (2012) show that the range and scope of crop insurance products have rapidly expanded over the past 50 years, particularly in developed countries. This expansion has been driven by a wide range of government support, including subsidized premiums and delivery and public provision of reinsurance services. Government support made multiple-peril or all-risk insurance widely available for crops and attractive to farmers as an income-support mechanism. However, willingness-to-pay and demand studies show that few farmers are willing to pay the full commercial cost of crop insurance, most likely because they have many other, cheaper ways of managing risk. Some developing countries, such as India and Mexico, have established large-scale, highly subsidized insurance programs like those in developed countries. But the heavy subsidies paid by agricultural insurance programs for multiple-peril insurance in developed countries are usually not fiscally sustainable for governments in developing countries with limited financial resources.

The alternative insurance instrument most often proposed is index-based insurance. Miranda and Farrin (2012) provide a succinct description of index insurance: "Unlike conventional insurance, index insurance indemnifies the insured based on the observed value of a specified 'index.' Ideally, an index is a random variable that is objectively observable, reliably measurable, and highly correlated with the losses of the insured, and additionally cannot be influenced by the actions of the insured. The most widely used in index insurance contract designs is rainfall." Because index insurance relies on publicly available information, is standardized and transparent, and cannot be manipulated by the insured, it is less costly to administer than general insurance. However, index insurance suffers from "basis risk," which is the difference between the losses actually incurred and the losses insured. Since the indemnity provided by index insurance is based on an index rather than on verifiable losses, the insured can suffer a significant loss without an insurance contract payout. Others may receive payouts without suffering losses, at a financial loss to the program. Because of basis risk and the high cost of reinsurance, the results of

many index insurance pilot programs have been disappointing. Significant uptake of index insurance has usually occurred only if subsidies are provided or if it is bundled with other benefits, such as low-interest loans (Miranda and Farrin 2012).

Many index insurance pilot projects are assessing different ways to overcome the problem of basis risk. Dercon et al. (2014) examine the potential of offering weather insurance contracts to groups. Groups could improve understanding of the product, could be better placed to enforce insurance contracts, and could be a means to manage basis risk, if basis risk is not perfectly correlated among its members. The empirical results of Dercon et al. (2014) show that demand for insurance was increased when groups were provided training that encouraged sharing of insurance within groups, and one mechanism for this higher demand may come from the ability of groups to mitigate some of the basis risk inherent in these products. Other approaches being tested to alleviate basis risk include gap insurance, which insures against basis risk. Recent research shows significant potential for reducing the cost of weather-based index insurance through picture-based insurance using smartphones (Ceballos, Kramer, and Robles 2019). Widespread adoption of index insurance requires a solution to basis risk (see Chapter 17 for further details). Long-term public goods investments, such as weather-reporting stations and basic data collection and analysis, can help to create the conditions and infrastructure for robust insurance markets. Complementary investments are also needed in basic methods of mitigating risk through low-cost irrigation, drought-resistant seed varieties, improved sanitation, and preventive healthcare (Meyer, Zander, and Fritsche 2011).

Natural Resource Management and Sustainable Productivity Growth

Land, Water, and Climate Change

LAND

Globally, the largest area of managed land is used for production of crops and livestock. Agricultural land covers 38 percent of the world's land surface. The largest amount of this area, nearly 70 percent, is for land use activities related to livestock rearing, including feed crop production and pasture. With growing demand, farmers and herders can intensify production either through technological improvements or by bringing new land into production. The

potential for further expansion of land for food and feed production is limited by physical and economic constraints to conversion of currently unused land and is also limited by competition for land use from biofuels, urban expansion, forests, climate change mitigation, and biodiversity. Expansion of farmland into forests increases greenhouse gas (GHG) emissions, exacerbating climate change. Under these conditions, sustainable intensification of existing croplands is essential.

Further challenges arise from land degradation, which is the loss of goods and services from ecosystems and includes desertification, deforestation, salinization, and soil erosion. Farm-level land degradation, often driven by unsustainable management practices, has direct on-farm production costs in the form of lower crop yields or greater production costs as more fertilizers and other inputs are applied to offset yield losses. It also has off-site costs in the form of excessive runoff of fertilizers and pesticides, siltation of dams and irrigation systems, eutrophication of lakes and oceans, and damage to mangrove swamps (Rosegrant, Nkonya, and Valmonte-Santos 2009). Underlying causes of land degradation include high population density, poverty, insecure and unclear land rights, and lack of access to extension, infrastructure, and markets (Nkonya et al. 2011). Distorting trade policies, output price policies, and input subsidies, particularly for water and fertilizer, have also driven excessive use of these inputs, leading to land degradation.

A fundamental underlying condition for sustainable land management is effective land rights. Secure property rights to land provide incentives for producers to invest in land improvement, new crop varieties, improved crop management, and appropriate levels of input use (Otsuka and Place 2001). Place (2009) examines the results from economic studies of the relationships between land tenure security and agricultural productivity in Africa and how these results have been incorporated into policies. Property rights need to be clearly defined, understood, and secure. The need for secure tenure is particularly important for women, who currently face insecure tenure, which leads not only to inefficient use of resources but also to weak bargaining position within households (see Chapter 15).

A highly debated tenure policy for Africa and other regions is land registration and titling. Land registration is sometimes promoted as the only approach to guaranteeing secure land tenure, but in many cases traditional land tenure systems can provide adequate security without introducing costly, contentious, and complex land registration and titling systems (Place 2009). In other cases, traditional or communal systems lead to highly ineffective management, with centralized or disputed ownership that prevents

individual farmers from investing in and managing their land efficiently. "In these cases, instead of costly titling systems, an alternative can be land banks that serve as land aggregators that can resolve conflicts related to ownership, separate property use rights from ownership rights, and reduce the transaction costs of transferring use rights," recommends Udry (2012). Land banks encourage participatory processes for delineating customary land, terms of leases, and processes for ensuring adequate compensation and can be a tool to enable customary groups to participate in the formal economy while retaining their group ownership and identity. The wide diversity of land tenure types and outcomes suggests that there is no "best practice" model for land tenure reform; rather, context is key, with land tenure regimes suited to particular locations and driven by community leadership as well as national concerns. The issue of sustainable use of farm land will be taken up in Chapter 18.

WATER

Rapidly increasing nonagricultural demands for water, changing food preferences, global climate change, and new demands for biofuel production put increasing pressure on scarce water resources. Challenges of growing water scarcity for agriculture are heightened by the transfer of water from irrigation to household and industrial uses, the increasing costs of developing new water sources, soil degradation, groundwater depletion, increasing water pollution, the degradation of water-related ecosystems, and wasteful use of already developed water supplies. If these challenges are to be met and if enough food is to be produced to meet growing demand, a strong irrigation sector remains vital. The rapid increases in agricultural yields and outputs over the past three decades could not have been achieved without expansion of irrigation. Although irrigation is sometimes associated with adverse environmental and sometimes also negative social impacts, it remains one of the most critical inputs into farming. Irrigation also contributes to poverty reduction, affordable food prices, and—through its significant multiplier effects—improvements in many other livelihood outcomes, such as health and nutrition (Rosegrant, Ringler, and Zhu 2009). A major challenge is how to make irrigation more effective for increased agricultural production while reducing socially wasteful use of irrigation water. Because new investments in irrigation and water supply are increasingly expensive and politically sensitive, large-scale water infrastructure investment has a reduced role globally compared with past decades (Rosegrant 2019). But small-scale systems, using both surface water and groundwater, have substantial potential. The World Bank's Africa Infrastructure Country Diagnostic study concluded that Africa

has the hydrological and economic potential to add at least 16 million hectares of profitable, large-scale irrigation and 7 million hectares for farmer-led irrigation. The internal rate of return was substantially larger for individual systems and those managed by farm communities (You et al. 2011). An even larger potential was shown for profitable smallholder irrigation expansion in Africa south of the Sahara, up to 30 million hectares for motor pumps (Xie et al. 2014).

While cost-effective irrigation development remains important, past mistakes in development need to be avoided and alleviated. De Fraiture, Molden, and Wichelns (2010) point out that poorly conceived or poorly implemented water management interventions can have high social and environmental costs, including inequity in the allocation of benefits and undesirable impacts on natural resources. Irrigation (and domestic and industrial water use) has encroached on common pool resources such as rivers and wetlands. Dam building has displaced some communities, often without adequate compensation (de Fraiture, Molden, and Wichelns 2010).

A promising avenue for addressing water shortfalls and avoiding environmental damage from wasteful water use is to implement incentive policy reform to enhance the efficiency of existing water use, supported by infrastructure investment to modernize and upgrade existing irrigation and water delivery systems. Establishment of clear water rights for water users is an important tool, inducing users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to economize on the use of water. Improvements in the irrigation sector to increase water use efficiency must be made at the technical, managerial, and institutional levels. Establishing physical controls on water usage within the river basin, including rationing or quotas, through enforcement of water rights would increase the likelihood that local irrigation efficiencies from irrigation technology and management reform translate to basin-level efficiency and real water savings. Building on water rights, introducing market (or market-style) incentives into water use decision-making can also improve the efficiency of water use. Marginal cost pricing is not likely to be successful in the irrigation sector. Prices high enough to induce significant changes in water allocation or recover capital costs will severely reduce small farm income in developing countries (Perry 2001). In addition, measurements of water use by individual farmers are difficult to obtain, and without them price incentives to save water cannot be provided to individual users (Kajisa and Dong 2017). The water rights approach is therefore preferred to water pricing to support water

efficiency in the irrigation sector (Rosegrant 2019). With appropriate policies and water management practices, much can be done in the irrigation sector to conserve water, and enhanced domestic sewage treatment and industrial recycling and effluent treatment will also be important in improving water availability in many developing countries (Rosegrant, Ringler, and Zhu 2009).

Under some conditions, community management of water resources is more effective than market-based approaches. Water can often be considered a common pool resource (CPR), as defined by Ostrom et al. (1999): "CPRs include natural and human constructed resources in which exclusion of beneficiaries through physical and institutional means is especially costly, and exploitation by one user reduces resource availability for others." In this situation, individuals following their own short-term interests can cause overexploitation of the commons and collapse of the resource, the so-called tragedy of the commons. But the tragedy of the commons is not inevitable. Ostrom et al. (1999) lay out the key principles for success in managing the commons. Cox, Arnold, and Tomás (2010) and Holden and Tilahun (2018) further assess these principles empirically. Although tragedies of the commons have occurred, for thousands of years people have also self-organized to manage CPRs, devising long-term, sustainable institutions for governing these resources (Ostrom et al. 1999). Community management of water resources with establishment of customary water rights and rules governing water allocation is one such approach to governing the commons that can lead to effective water management. How to deal with growing scarcity of water is further discussed in Chapter 20.

CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) has shown that global average temperatures have risen by roughly 0.13°C per decade since 1950, and they expect a faster pace of about 0.2°C per decade over the next two to three decades (Lobell, Schlenker, Costa-Roberts 2011). Modeling by Lobell et al. shows that "global maize and wheat production declined by 3.8 and 5.5 percent, respectively, relative to a counterfactual without climate trends." The estimated change in crop production excluding and including carbon dioxide (CO_2) fertilization translates into average commodity price increases of 18.9 and 6.4 percent. "Climate trends were large enough in some countries to offset a significant portion of the increases in average yields that arose from new improved technology, CO_2 fertilization and other factors" (Lobell et al. 2011). Thus, climate change is becoming a major challenge to agricultural development.

A recent systematic review by Knox et al. (2012) summarized by Wheeler and von Braun (2013) found that average crop yields may decline across Africa and Asia by 8 percent by the 2050s. "Across Africa, yields are predicted to change by −17 percent (wheat), −5 percent (maize), −15 percent (sorghum), and −10 percent (millet) and, across South Asia, by −16 percent (maize) and −11 percent (sorghum) under climate change. No mean change in yield was detected for rice" (Wheeler and von Braun 2013). A global review of crop model results by Challinor et al. (2014) found similar orders of magnitude for wheat, maize, and rice (with slightly negative impacts on rice), and greater negative yield effects in tropical regions than in temperate regions.

Nelson et al. (2014) presented climate change results from a model comparison exercise with 10 of the leading global economic models that have significant representation of agriculture. These models account for the initial biophysical impacts of climate change on crop yields estimated from crop models but also take into account the subsequent feedback effects from economic responses that will tend to dampen the initial crop yield impact. The results show a great deal of variation across models, but the average yield impacts of climate change across models and scenarios in 2050 after economic adjustments are −12.5 percent for coarse grains (mainly maize), −9.3 percent for rice, and −9.9 percent for wheat. Prices are projected to increase on average by 11.8 percent for maize, 13.9 percent for rice, and 15.9 percent for wheat (Nelson et al. 2014). An earlier review of climate change results from economic models (Parry et al. 2009) showed slightly higher increases in food prices, with a range of price increases of about 10 to 30 percent by 2050 due to climate change, and a median estimate of around 20 percent. The projected impact of climate change on the risk of hunger showed increases in hunger of about 10 to 20 percent by 2050. A detailed assessment of climate change impacts, and the possibility of mitigation of and adaptation to climate change in agriculture, is provided in Chapter 19.

In addition to the production and price effects, frequent occurrence of extreme weather events, such as drought and floods, is likely to increase variability in food supply, which in turn affects variability of household incomes and food security. Wheeler and von Braun (2013) conclude that the "strong evidence on the negative impacts of climate change on food security supports the need for considerable investment in adaptation and mitigation actions toward a 'climate-smart food system' that is more resilient to climate change influences on food security."

Sustainable Food System for the Future

Garnett et al. (2013) address key challenges for a sustainable food system. Food needs to be produced in ways that place far less pressure on the environment and that sustain its capacity to continue producing food in the future. Increased production must be met through higher yields because increasing the area of land in agriculture imposes major environmental costs. Expansion of agricultural land will in many places encroach on forests, wetlands, or grasslands, whose conversion would increase GHG emissions and the loss of biodiversity and important ecosystem services. But sustainably increasing production is not enough. Richer countries should reduce consumption of resource-intensive foods (such as meat and dairy products) and food loss and waste should be reduced in both developing and developed countries (Garnett et al. 2013).

Godfray et al. (2010) provide a broad overview of the key components of sustainable production growth. *First is reducing the yield gap* by moving farmers toward existing yield potential by reducing constraints to farmer access to seeds, water, nutrients, pest management, soils, biodiversity, finance, and knowledge. *Second is increasing production limits* through modern genetic techniques and a better understanding of crop physiology to allow for a more directed approach to selection across multiple traits. Gene sequencing and marker-assisted selection are speeding up the development of new, stress-tolerant and high-yielding varieties. Genetically modified (GM) crops also have potential to provide a broader combination of desirable traits, including the introduction of new traits such as drought tolerance. *Third, waste can be reduced.* Food losses can occur at any point in the value chain—from production (crop damage, spillage) to postharvest and processing stages (attacks from insect or microorganisms during storage), distribution (poor infrastructure, cold storage), and retail sale through home consumption (spoilage, table waste). In developing countries, losses occur mainly due to constraints in harvesting methods and techniques, lack of storage and/or cooling facilities, and poor marketing and transport systems. In developed countries, the biggest losses occur mainly after food reaches retail, restaurants, and home consumption. The potential scope for economically reducing food losses remains uncertain, but investments in reducing food loss and waste can be a complement to increasing productivity growth (Rosegrant et al. 2018). *Fourth, diets should change*, to include more fruits and vegetables and less meat in those regions that currently consume high-meat diets. *Fifth, aquaculture should be expanded on a sustainable basis* through advances in hatchery systems, feed

production and feed-delivery systems, disease management, and better stock selection and potentially through larger-scale production technologies, aquaculture in open seas and larger inland water bodies, and the culture of a wider range of species (Godfray et al. 2010).

In the past few years, gene editing has emerged as a key new tool for crop improvement, with great potential for enhancing agricultural productivity, food security, and resilience to climate change. Gene editing differs from GMOs because it does not splice foreign genes into an organism. It may therefore be subject to an appropriately lower regulatory burden than GMOs and may avoid the negative public perception surrounding genetically altered crops, although debates are continuing. Gene editing technology such as CRISPR is more accessible to smaller companies and labs than genetic modification technology, allowing far broader participation and competition, particularly if the regulatory costs are indeed significantly lower, as argued in Chapter 21.

Thornton (2010) provides a comprehensive summary of trends in the livestock sector. Livestock systems have a global asset value of at least US$1.4 trillion, employ at least 1.3 billion people globally, directly support the livelihoods of 600 million poor smallholder farmers in the developing world, and account for about one-third of agricultural value-added. Livestock products contribute 17 percent to kilocalorie consumption and 33 percent to protein consumption globally, with far higher per capita consumption in rich countries. Rapid growth in livestock production is being driven by the rapidly increasing demand for livestock products, with this demand being driven by population growth, urbanization, and increasing incomes in developing countries (Thornton 2010).

The expansion of livestock production needs to take place in a way that allows poorer consumers to benefit from increased production and that reduces its impact on the environment, while balancing trade-offs between food security, poverty, equity, environmental sustainability, and economic development. Key innovations are needed in breeding and feeding programs that will focus not only on production and productivity, but also on product quality, animal welfare, disease resistance, and reduction in GHG emissions and other environmental impacts (Thornton 2010).

Pingali and Rosegrant (2000) review the ecological consequences of intensive rice production as typified by the Green Revolution. In the long run, if not managed properly, intensification can impose significant environmental costs. Environmental consequences of lowland rice intensification include "(i) the build-up of salinity and waterlogging; (ii) the depletion/pollution of

(ground) water resources; (iii) the formation of a hardpan (subsoil compaction); (iv) changes in soil-nutrient status, nutrient deficiencies, and increased incidence of soil toxicities; and (v) increased pest build-up, pest-related yield losses, and associated consequences of increased and injudicious pesticide use" (Pingali and Rosegrant 2000). However, intensification per se is not the root cause of environmental and ecological damage. Environmental degradation in intensified agriculture occurs mainly when incentives are incorrect, due to bad policy, missing markets, or a lack of knowledge of the underlying processes of degradation.

Policies that support more sustainable and intensified agriculture while protecting the environment include "the removal of incentive-distorting subsidies and taxes; the establishment of secure property rights; increased investments in research, education, and training; improved public infrastructure; better integration of international commodity markets; and a greater inclusion of populations in developing countries into these markets. Appropriate policies will provide farmers with the incentives to invest in more sustainable land and crop-management practices" (Pingali and Rosegrant 2000).

Halberg et al. (2006) note that modern noncertified organic farming is a potentially sustainable approach in regions such as parts of Africa, which have low yields due to poor access to inputs or low yield potential, because it involves lower economic risk than technologies based on purchased inputs. In these regions, locally adapted agroecological methods can improve the yields and sustainability of smallholder farms and increase local food security. But in higher-yielding production regions, yields of organic farming are between 15 and 35 percent lower than present yields when comparing single crops (Halberg et al. 2006). Two recent metastudies showed that yields of organic agriculture average 20 to 25 percent less than conventional agriculture, but with large variations (de Ponti, Rijk, and van Ittersum 2012; Seufert, Ramankutty, and Foley 2012). Nitrogen leaching and emissions of nitrous oxide and ammonia are lower in organic agriculture than in conventional agriculture on an area basis, due to lower nitrogen inputs, but they are usually larger per unit of product because of conventional agriculture's higher crop yields per hectare (Pimentel et al. 2005; Balmford, Green, and Phalan 2012; Tuomisto et al. 2012).

As was pointed out in Chapter 1, how we build a new food system that is simultaneously nutrition and health driven, productive and efficient, environmentally sustainable and climate smart, inclusive, and business friendly is a challenge we must face. We will discuss key elements of such a food system and strategy to achieve it in Chapter 22.

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