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Viewpoint

Viewpoint: The future of work in agri-food

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ABSTRACT

As countries develop, agriculture's role as domestic employer declines. But the broader agri-food system also expands, and the scope for agriculture-related job creation shifts beyond the farm. Historically, technological revolutions have shaped, and have been shaped by, these dynamics. Today, a digital revolution is taking hold. In this process of structural transformation, societies evolve from having a surplus to a shortage of domestic farm labor, typically met by foreign agricultural wage workers. Yet anti-immigration sentiments are flying high in migrant-destination countries, and agricultural trade may be similarly challenged. Robots in the fields and packing plants offer an alternative to a diminishing labor supply. COVID-19 will reinforce trends of digitization and anti-globalization (including in food trade), while slowing economic growth and structural transformation. In the world's poorest countries, particularly in Africa, labor productivity in agriculture remains at historically low levels. So, what role can the agri-food system play as a source of employment in the future? This viewpoint elaborates on these trends and reviews several policy options, including inclusive value chain development, better immigration policies, social insurance schemes, and ramp up in agricultural education and extension.

1. Introduction

Because of the employment opportunities and economic multipliers it creates, especially during the early stages of development, agriculture has long been at the center of discussions about poverty reduction and economic development (World Bank, 2007; Townsend et al., 2017). Increasingly, so are its related up- and down-stream activities in input supply, food logistics, food processing, retail, and food services, which, together with agriculture, make up the broader agri-food system (AFS). The AFS remains a major employer, particularly in poorer countries and for the poorer segments of society (Abdelaziz et al., 2020). Much hope is vested in the AFS to create badly needed jobs for youth in Africa, as well as for vulnerable populations and people in lagging regions elsewhere in the world (FAO, 2017; IFAD, 2019; IFPRI, 2020). In contrast, employment in the AFS has dropped to only 10 percent of the labor force in high income countries, where the majority of AFS jobs are now off-farm in food processing and services. There, the domestic workforce has shifted out of the AFS. New digital technologies are enabling the automation of some historically labor-intensive agricultural tasks and providing an alternative to domestic labor substitution through international migration. COVID-19 will likely reinforce these trends. Given these developments, what role will the AFS play in the future of inclusive job creation across different countries worldwide?

At the early stages of development, employment in the AFS largely coincides with employment in farming. A large share of the population lives in rural areas and engages in subsistence production. Food supply chains are short and, for the most part, local. As countries develop, however, populations urbanize and food supply chains become longer. The income elasticity of demand for food declines, agriculture's role as employer diminishes (Timmer, 1988), and the farm workforce becomes older, more wage-oriented, and more immigrant.[1]

Urban consumers, and those with rising incomes, demand foods that are more protein- and nutrient-rich, processed, and convenient to consume. This change in demand provides some scope for agriculture-related job creation beyond the farm, particularly in food processing and services. While these changes occur, jobs on the farm typically

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[1] The agricultural workforce also may become more feminized as men move off the farm more rapidly than women. But evidence on this is mixed (De Brauw et al., 2008; Slavchevska et al., 2019; UN FAO, n.d.; IFPRI, 2020).

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become more remunerative and competitive with jobs off the farm even though they dramatically shrink in terms of share and number.[2]

These dynamics, driven importantly by food demand behavior, have been observed across countries throughout history. They are broadly known as the structural transformation (from agriculture to non-agriculture) and the agricultural/dietary transformation (from unprocessed subsistence staples to processed, market-purchased, non-staples). Often, these transformations are accompanied by deeply wrought societal change in response to growing rural-urban income divides and ineffective policy responses, including agricultural protectionism, especially when investment in rural public goods and inclusive food value chain development lags behind (Anderson, 2010; Swinnen, 2018).

Technological revolutions further shape (and are shaped by) these dynamics (Hayami and Ruttan, 1971). Examples include steam power, railways and tractors in the 19th century, and electricity and cold storage in the 20th century. The current century is witnessing a rapidly-unfolding digital revolution (robotization, artificial intelligence, and information and communications technology), with another revolution in energy (solar, mini-grids, also for productive use) just around the corner (World Bank, 2020).

These technological advancements of the 21st century and the associated business and product innovations (such as PAYGo solutions and solar water pumps) are affecting structural and agricultural transformations across the globe. They have the potential to profoundly alter the global organization of the food system, as well as labor and skill demands. They dramatically reduce transaction costs in input and output markets, change economies of scale, and modify the optimal capital/labor mix in agricultural production, processing, and marketing. Because some agricultural tasks are arguably more automatable (more routine and less cognitive) than those in industry and services (Schlogl and Sumner, 2020), automation could accelerate the exit of labor out of agriculture in developing countries and transform farms and food processing firms in the developed world. A future with robots in the fields and packing plants, together with technology-savvy farmworkers to complement new technological solutions in specific commodities and tasks, already is taking shape. Solar driven water pumps (SWP), cold storage, and agro-processing equipment are also beginning to spread in rural India and East Africa, accelerating the transition away from subsistence production (Banerjee et al., 2017; World Bank, 2020).

Historically, during this process of structural and agricultural transformation, societies typically evolved from having a surplus to a shortage of domestic farm labor. Food prices dropped to offset technology-induced productivity gains because of income-inelastic food demand. Inefficient land markets and sluggish food value chain development slowed farm consolidation and diversification, and social protection for the self employed remained limited. As a result, farm incomes have struggled to keep up with more secure and faster-growing incomes off the farm. Domestic workers shifted from the primary sector to the secondary and tertiary.

More often than not, in developed countries farm labor shortages have been filled largely by foreign agricultural wage workers, especially for difficult-to-automate tasks like harvesting fresh fruits and vegetables. Migrant-sending households in low-income countries benefited through remittances. However, with anti-immigration sentiments flying high in migrant-destination countries, the structural transformation unfolding in migrant-source countries, and technology increasingly offering alternatives to hired labor everywhere, opportunities to close income gaps across countries through legal farm labor migration may be narrowing (Carolan, 2020).

The shift in policy dialogue away from immigration solutions to farm labor problems coexists with a bifurcating global demographic. Many developing countries, especially in Sub-Saharan Africa, struggle to provide employment for their young, rapidly-expanding populations, presenting a missed opportunity for development from the so-called "demographic dividend" (UNFPA, n.d.), including through international migration. Agricultural trade is similarly challenged in its role to help address global imbalances in farm labor, partly because of its purported contribution to global warming.

The domestic and global forces of structural transformation and food demand behavior, the new technological revolution and associated business innovation, and the deceleration of agricultural trade and labor migration provide much of the socioeconomic backdrop against which the future of work in the AFS unfolds across countries. These transformations are further affected by the recent COVID-19 pandemic. It already has set back income growth (and thus the speed of the structural and agricultural transformation). In the long run, the pandemic will reinforce existing trends in AFS automation and digitization and decrease reliance upon agricultural labor migration and trade, especially in the developed world. The pandemic has also exposed vulnerabilities in supply chains, as some countries experienced difficulty securing supplies of strategic goods (and migrant labor) and risks ushering in a new wave of protectionism (Siche, 2020; Richards and Rickard, 2020; Gruszczynski, 2020).[3]

How countries address these, and related, challenges will shape the extent to which the AFS can continue its historically crucial role in reducing poverty and fostering shared prosperity by raising smallholder incomes and creating employment opportunities for young, expanding workforces. We argue that a policy and business environment supportive of inclusive agricultural value chain development will be a critical component of the solution. Adequate competition policies to address the challenge of rising power concentration within the AFS need to be part of the solution, as does the provision of broad access to digital (and solar) infrastructure. Solutions will also require the provision of quality education to rural populations, including on the use of digital technologies,[4] so that the agricultural and rural workforce can maximally benefit from new technologies and off-farm employment opportunities. To mitigate problems that arise during the farm labor transition and help prevent a reversal to agricultural policy distortions, adequate social protection systems that mitigate calls for agricultural protectionism must be developed. The decoupling of social protection from employment holds promise in that regard (Packard et al., 2019), with the massive expansion of social protection provisions across the globe in response to COVID-19, especially through cash transfers, providing useful experiences and platforms to build upon.

The remainder of this paper discusses the impact and evolution of these different forces and reflects on a policy agenda that can leverage the future global food system to generate decent employment, accelerate

[2] With 7 out of 8 employees in the AFS employed on the farm, discussions about work in agriculture have typically been limited to on-farm primary production. Yet, as countries develop, the share of food processing and services in overall AFS employment increases, even exceeding that on the farm in high income countries. By including prospects for employment in the secondary and tertiary sectors along the food supply chain, this paper follows the shift in food policy analysis towards a more holistic "food system" approach, which recognizes the food system's effects on many food-related outcomes, including nutrition and health, climate and the environment, employment and poverty (IFPRI, 2020).

[3] Yet shifting relative resource endowments may raise the price of ignoring comparative advantage in trade, acting as a potent counteracting force. They include shifting water supplies due to climate change, urbanization and rising land prices. A surge in imports of land- and water-intensive crops, such as soybeans, in China illustrates the potential trade impacts of these trends (Christiaensen, 2013).

[4] Digital skills can be divided into user, specialist, and e-business skills. User skills enable safe use of information and communications technology (ICT) to support non-ICT tasks. Specialist skills refer to more advanced digital skills of ICT professionals (e.g. coding). E-business skills – a mix of digital and entrepreneurial skills – ensure users can identify and employ ICT for business.

poverty reduction, and attain shared prosperity.

2. The farm labor problem – from surplus to shortage

Work in agriculture tends to be seasonal and dispersed across space, with labor productivity often low and unpredictable. High fertility among rural and agricultural populations, partly in response to low and variable agricultural earnings, often contributes to low labor productivity. As countries become more affluent, their demand for nonfood goods and services increases, and their workforces shift out of agriculture into more stable, high-paying, jobs in industry and services.[5] The development of food manufacturing and services is particularly important in the process of narrowing cross-sectoral income differences. These nodes of the AFS tend to be more labor-intensive and less high tech than other industries and services, more likely to employ women and unskilled workers (Maertens and Swinnen, 2012), and less spatially concentrated (Cazzuffi et al., 2017).[6]

This pattern of structural transformation is evident historically in high-income countries and is currently unfolding in low-income countries (Fig. 1). Against this broad and sweeping background of structural transformation, what role will the AFS play as a source of employment and shared prosperity in the future?

First, on-farm work (both own-account and wage) will continue to be a major source of employment in poor countries. In low-income countries, as in much of Sub-Saharan Africa, a decrease in the share of the workforce employed in agriculture is still accompanied by an increase in agricultural employment in absolute terms. Given high population growth, the agricultural workforce is projected to continue swelling in the foreseeable future before it starts to decline (Christiaensen and Brooks, 2019; ILOSTAT, 2020). The population continues to grow fast while the amount of cultivated land (the "extensive margin") expands. Therefore, in low-income countries, where most of the global agricultural workforce is still concentrated, the transition out of agriculture in the short run does not necessarily imply a smaller agricultural workforce overall. In these settings, the primary challenge is to improve the quality of farmers' jobs, (i.e., increase their labor productivity and earnings) while also facilitating the transition out of agriculture. In many middle-income countries, on the other hand, as well as historically in high-income ones, the absolute number of agricultural workers has decreased over time,[7] farm populations have "grayed,"[8] and farm labor shortages in specific commodities at specific points in time have become a feature of the agricultural landscape.

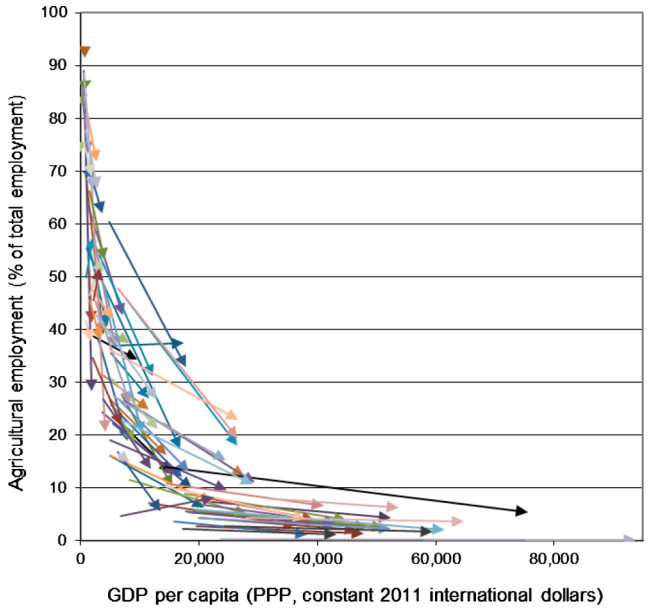

Fig. 1. Proportion of Countries' Workforce Employed in Agriculture vs. GDP per Capita. **Note:** The beginning of each arrow represents each country's position in 1991, and the arrowheads show where they wound up in 2017. Both the positions of the arrows and the fact that nearly every country arrow points to the southeast indicate that as countries get richer, the workforce becomes less reliant upon agriculture. **Source**: The data used in this figure were retrieved from The World Bank Group (https://data.worldbank.org).

Second, agricultural labor productivity will continue to rise.[9] The existence of a persistent and large productivity gap between nonagricultural and agricultural activities is received wisdom in development economics. It is often seen as proof that agriculture is intrinsically less productive and as suggestive that the policy solution for agricultural labor in the developing world lies in removing barriers that prevent people from exiting agriculture (Restuccia et al., 2008). Recent research, however, suggests that agricultural labor productivity is understated (Fuglie et al., 2020). Using micro household data instead of national macro accounts, controlling for skill differences, and expressing productivity in terms of value per hour of labor (instead of per person employed in the sector), labor productivity in agriculture is not lower than in other sectors (Gollin et al., 2014; Hicks et al., 2017; McCullough, 2017). This finding suggests that agriculture is not intrinsically less productive but, rather, underemployment in the sector is high, at least in the earlier stages of development. Underemployment is likely linked to the seasonal nature of agricultural production (de Janvry et al., 2018) and high fertility rates (many more people in developing countries are born in agriculture than outside of it).

If the productivity gap is much smaller than generally assumed, a disproportionate focus on policies to remove barriers to sectoral or spatial migration, however well-intentioned, may be misplaced. In fact, if agricultural labor is only in surplus during the agricultural slack season (between harvesting and planting, and planting and harvesting), such policies may prove ineffective, or they may even exacerbate agricultural labor shortages during planting and harvesting (peak labor demand periods). Improving agricultural productivity would enable a productive move out of agriculture, leaving a more productive agricultural labor force behind. This could be accomplished through the

[5] These jobs operate in more controlled production environments and are typically less subject to seasonality and production risk. As agriculture industrializes, it also becomes less weather dependent and more like industry, with the number of environmental inputs that can be controlled progressively increasing (e.g., water with irrigated agriculture, temperature and light with greenhouses, and land with vertical agriculture).

[6] Given their dependence on raw material, these AFS nodes are likely to locate in relatively poor regions, where they can better reach the poor and generate backward and forward linkages with other industries.

[7] In SSA, growth in the farm labor force (2.02 percent per year) drove more than two thirds of the annual agricultural output growth during 2001–2015. Elsewhere (except West Asia and North Africa), the absolute number of farmworkers declined by 1.21 percent per year on average in all developing countries and by 1.26 percent worldwide. The decline was especially stark in China (5.1 percent per year) (Fuglie et al., 2020, Table 1A.1b).

[8] The average smallholder age in many ASEAN countries is now between 50 and 60 years old (PWC, 2020).

[9] During 2001–2015, gross agricultural output per agricultural worker in the world grew by 3.77 percent per year (4.46 percent per year in developing countries). Worldwide, growth in Total Factor Productivity (TFP) and capital deepening (more land, capital and other inputs per worker) contributed about equally to growth in gross agricultural output. In the developing world, capital deepening contributed about 60 percent. The growth in labor productivity more than compensated for the decline in the agricultural labor force, resulting in total annual growth of gross agricultural output of 2.51 percent (3.25 percent in developing countries) (Fuglie et al., 2020, Table 1A.1b)

development of complementary activities during the slack season, such as double cropping through irrigation and mixed farming systems (crop-livestock).[10] These types of developments would maximize poverty reduction (Christiaensen and Martin, 2018), in contrast to a scenario in which people leave agriculture due to distress following underinvestment. The road *out* of agriculture runs importantly through a path that increases labor productivity *in* agriculture. This agricultural job paradox remains underappreciated. It will eventually leave far fewer people in farming, but they will have better employment conditions, and there will be greater quantities of relatively cheap food available for those in the rest of the economy. This process is still not underway in earnest in many African low-income countries (Barrett et al., 2017; Fuglie et al., 2020).

Third, the successful exit of labor out of agriculture is intimately tied to a successful agricultural transformation (Huang, 2016; Charlton, 2019). Food expenditure shares (and with them, agricultural employment shares) decline as incomes increase. Food consumption patterns also change from primary staples (grains, roots, and tubers) to more protein- and micronutrient-rich diets (meat, dairy, fruits, and vegetables).[11] Eventually, societies tend to demand more processed and prepared foods; they may even develop food consumption patterns that involve eating as an "experience."[12] Societies become more dependent upon the downstream AFS as a result. This, in turn, opens up new employment opportunities off the farm in food processing, marketing, logistics, food retail, and food services.

A fair number of farmworkers who leave the farm remain within the broader food supply chain. In many low-income countries, off-farm work in the AFS already makes up about 25 to 33 percent of overall off-farm work (see Table 1) (Allen et al., 2018). Off-farm AFS work is still relatively small as a share of total employment (7 percent in Eastern and Southern Africa, Table 1); however, it rises to 25 percent when expressed in full-time equivalent employment (hours worked) as opposed to the number of people employed (Dolislager et al., 2020).[13] The importance of off-farm employment (food manufacturing and food service) in the overall AFS rises with income, from 9 percent (7/80) of total AFS employment in Eastern and Southern Africa to 52 percent (16/31) in Brazil and 80 percent (8/10) in the United States (Table 1). The share of off-farm AFS employment in total employment first rises (from 7 percent in Eastern and Southern Africa to 16 percent in Brazil) and then falls (to 8 percent in the United States).

Asia's experience shows that more successful countries develop their off-farm AFS as they pass through the structural transformation, and this leads to a more rapid reduction in poverty (Huang, 2016). In China, India, and Vietnam, the "supermarket revolution" (i.e., the rise of modern retail food stores) has been more intense and rapid than in other developing regions, driven in part by private vertical coordination that has generated economic growth through the introduction of contracts, the creation of new credit and input markets, and tighter linkages between farmers and buyers (Swinnen and Maertens, 2007). As agri-food systems develop, processing, logistics, and wholesale operations (which account for 30% to 40% of the value added in food chains) become more consolidated, incorporating advanced technologies in order to reduce costs and ensure timely availability of quality goods (Reardon et al., 2012; Reardon, 2015). In China and Vietnam, there has been an emerging shift from small- to large-scale processing, logistics, and storage, driven by large foreign investments in fixed plants (Reardon, 2015). India and the Philippines enacted laws that prevented foreign direct investment from entering the retail food sector, leading to slower growth (Reardon et al, 2012; Barrett et al., 2020). Domestically-funded market hubs have emerged in India, and they are expanding rapidly, effectively bringing modern markets to farmers (Reardon et al., 2012).[14]

Non-farm AFS jobs are often also more easily accessible for women and poor workers leaving the farm, given their proximity and low entry requirements in terms of capital and skills.[15] A large part of employment opportunities within the AFS is happening in secondary cities and towns (Cazzuffi et al., 2017), increasing their potential for poverty reduction, as most of the poor live in the rural hinterlands of these intermediate centers (Ingelaere et al., 2018).

Several recent case studies support the beneficial effects of the AFS and related development of agri-food value chains on labor force participation, income, working conditions (including for the poor and for women), and, in some cases, smallholder participation in modern markets. Examples from the Future of Work in Agriculture conference include Sauer et al. (2019) for domestic food systems in Tanzania, Edwards (2019) for post farm oil-processing farms in Indonesia,[16] and Maertens and Fabry (2019) for horticulture exports from Senegal to European markets. The latter shows how vertical integration of production to meet the quality and standards requirements for European markets increased not only labor force participation, employment, and income in the source areas but also educational attainment and a reduction in fertility rates—evidence that the development of agri-export supply chains contributes to the broader socio-demographic transformation, in addition to reducing poverty.

COVID-19, by disproportionately affecting small and medium enterprises, may jeopardize the potential of these beneficial effects. The downstream AFS has expanded rapidly in developing countries across the globe as part of the transformation of food markets. Even in Africa and Asia, consumers now purchase 80 percent of all food consumed, implying that food value chains provide 80 percent of all food consumed (Reardon et al., 2019). As a result, food value chains in the developing world have become longer, stretching from rural to urban areas.

[10] As growth in overall agricultural output, following technological change and rising labor productivity, starts to meet less rapidly growing demand for food and other agricultural products, prices will drop, inducing an exit of less productive workers. These factors could introduce a price treadmill, wherein technological change and agricultural labor productivity struggle to outpace the decline in price. Agricultural exports provide one way out, at least temporarily, for some countries. The use of agricultural output as an input for the production of other, more price and income elastic, products such as biofuels or bioplastic could, in principle, provide another alternative. Yet, the appropriate policy packages necessary to broker this can be tricky, as seen in the case of biofuels (de Gorter et al., 2015).

[11] For recent evidence of these historically observed trends from low and lower-middle income countries, see Colozza and Avendano (2019) (Indonesia), Subir et al. (2020) (Vietnam) and Rashid et al. (2020) (South Asia). In Tanzania, the shift away from staples has been mostly towards sugary and more conveniently consumed foods so far (not greater dietary diversity), increasing the risk of obesity and noncommunicable disease (Cockx et al., 2018).

[12] With only a couple of percentage points of the working age population in the European Union left to work in agriculture, despite substantial EU subsidies, Swinnen et al. (2012) argue that the "experience economy" in which consumers are willing to pay premium prices for products and services that provide additional intangible "experiences" may well present one pathway for European farms to mitigate further exits.

[13] While many more people have agriculture as their primary sector of employment, the number of hours actually worked in the sector is sizably less given seasonality and underemployment (McCullough, 2017).

[14] These hubs are "one stop shops" where individuals can access retail food stores, farm input markets, output buyers, and insurance, banking, and health services.

[15] Whether any of the AFS subsectors are more poverty reducing is not immediately clear. Dorosh and Thurlow (2018) identify agri-manufacturing, transport, and trade as the most poverty-reducing subsectors outside of agriculture, although neither one dominates across the different countries they study.

[16] Edwards (2019) shows how the introduction of post-farm AFS firms, such as oil-palm processing factories in Indonesia, can create positive spillovers through the development of economic linkages, infrastructure, and local market integration. These spillovers can lead to the expansion and birth of towns and the introduction of new firms and other economic and social organizations.

Table 1
As Incomes Rise, More Food System Jobs Are in Food Manufacturing and Services.

Sectoral share of employment (%)		Low-income countries (Eastern and Southern Africa)	Middle-income countries (Brazil)	High-income countries (United States)
Food system	Farming	73	15	2
	Food manufacturing	2	8	1
	Food services	5	8	7
	Total AFS	80	31	10
Non-food system	Off-farm (non-food related)	20	70	90

Source: World Bank and the International Fund for Agriculture Development (IFAD), 2017. The total for Brazil does not add up to 100 due to rounding error.

Fragmented into many labor-intensive, informal, small and medium enterprises,[17] AFS nodes often operate in clusters such as dense sets of food processing SMEs, scores of meal vendors at truck stops, and dense masses of wholesalers and retailers in public wholesale and wet markets (Reardon et al., 2020). This concentration of activity is vulnerable to lockdowns and other restrictions. Since the COVID-19 outbreak, food supply chain disruptions have been widely observed across the developing world. Many of the system's smaller actors are undercapitalized, informal, and ineligible for (or unaware of) government support. They stand to suffer the most without adequate SME support, paving the way for accelerated consolidation and lower labor intensity in the mid and downstream AFS nodes.

Fourth, fears of a mass exodus of African youth out of agriculture, disproportionate with normal patterns of youth transition out of agriculture as countries develop, appear to be overblown. Given Africa's youth bulge, youth employment is especially high on the continent's policy agenda. There is a perception that African youth may no longer be interested in agriculture (IFAD, 2019). Exit from agriculture is a normal part of the structural transformation, and rural youth, in general, are less involved in agriculture than their older cohorts. It is mostly through youth that the structural transformation occurs: young people on average are more agile, educated, and adaptive to changing labor market conditions. Rural youth typically have less access to land than their parents did at the same age because many parents are not ready to transfer the farm (or the farm is too small to set all children up with viable farms) and land rental markets are underdeveloped.

A recent study of sectoral employment transitions in six African countries shows that both adults and youth are leaving agriculture, but not disproportionately relative to these countries' level of development (Maïga et al., 2015). In their 13-country study, after controlling for location and agricultural potential, Dolislager et al. (2020) find that youth do not spend fewer (or more) hours in on-farm work than older adults in general, and only younger adults spend less time in own farming (though more time working for wages on others' farms). Youth appear to access off-farm AFS employment more easily than non-AFS jobs, especially wage work in urban and peri-urban zones. For rural youth, gaining access to opportunities both inside and outside the AFS is important, but promoting employment opportunities within the AFS is more likely to bring employment opportunities within reach of the rural poor.

Fifth, sociodemographic changes, including decreasing fertility rates, rising rural schooling levels, and increasing participation of women in the rural workforce, further stimulate labor to move from farm to the non-farm AFS as well as to non-AFS jobs. Liu et al. (2020), for example, find that, in Vietnam, the potential for agriculture to address youth unemployment is limited. However, as wages converge between rural and urban sectors, the rural economy is diversifying into non-farm activities, and access to education (rather than access to land) has become the key driver of improvements in rural household well-being.

Gender differentiated preferences may affect the farm-nonfarm labor transition, as well. A field experiment in Ghana uncovered evidence that traditional gender roles lead to a division of labor that causes women to prefer investments in non-agricultural activities (Kramer and Lambrecht, 2019). This finding highlights the need to recognize women's preference to diversify into nonfarm activities in regions where gender roles preclude women from engaging in agricultural production. Arslan et al. (2019) echo this conclusion, finding that opportunities for wage employment contribute to the empowerment of young women and the rural economic transformation by speeding up the demographic transition.

The dynamics described above raise the prospect of farm labor shortages over time, especially shortages of wage workers needed to meet the growing demand for food and agricultural products. This situation is already observed in high (and even not so high) income countries across the world. Global press coverage documents labor shortages and reliance on immigrant farmworkers on every continent where crops are commercially grown (see https://farmlabor.ucdavis.edu/news/links-selection-press-coverage). The COVID-19 pandemic has served as a stark reminder of high income countries' reliance on immigrant agricultural labor.

There are four options to deal with farm labor shortages, which Martin (2017) characterizes as the 4 ***S***'s: ***S****atisfy*, ***S****tretch*, ***S****ubstitute*, and ***S****upplement*. Farmers can *satisfy* and retain existing workers by offering them higher wages, less onerous working conditions, benefits, and bonuses to make work on the farm more competitive. Farm employers can *stretch* the workforce by increasing worker productivity, providing workers with better technology like slow-moving conveyor belts to carry harvested produce that enable workers to pick faster. The option to *substitute* may entail replacing laborers altogether by labor-saving technologies or relying on food imports instead of local production. And finally, farmers can *supplement* the existing workforce with foreign guest workers.

All four strategies are being deployed to different degrees, depending on countries' preferences and their position in the evolving labor surplus-shortage continuum. The corresponding public policy domains are labor and social protection, innovation and competition, agricultural trade, and migration. These go well beyond the traditional realm of the Ministry of Agriculture. This broad global assessment of the future of AFS work zooms in on the roles of productivity-enhancing innovation and technology and immigrant agricultural labor. The choice is motivated by persistent low labor productivity in African agriculture, the salient digital revolution, and rising anti-immigration sentiment in current policy debates.

3. Productivity-enhancing technology is key

The induced innovation hypothesis, first advanced by Hicks (1932), posits that changes in relative factor (input) prices drive the development of new technologies. As wages rise, so do the incentives for researchers at private and public institutions to develop labor-saving

[17] These transitional food value chains are characteristic of more than half (50–80 percent) of African and Asian developing countries. Modern food value chains, which typically consist of large players, including capital-intensive processing firms and supermarkets, are more prevalent (30–50 percent of food systems) in China, Latin America, and Southeast Asia (Reardon et al., 2020).

solutions (Hayami and Ruttan, 1971). Others view research and development (R&D) as largely an exogenous, self-perpetuating process: new inventions lead to others by lowering the cost of technological development over time (e.g., Arrow, 1962; Levin, 1988). Both could be at work in practice, with the development of digital technologies, for example, partly driven by forces exogenous to agriculture, but their adaptation and adoption in agriculture partly driven by the rising costs of labor.

A famous example of labor-saving technology in fruit and vegetable production was the processing tomato harvester developed by researchers at the University of California, Davis (UC Davis) and commercially released by Blackwelder in the mid-1960s (Coatney, 2006). Within five years of its commercial release, virtually 100 percent of processing tomato farms in the United States used the harvester, and most planted a tomato variety genetically engineered (also at UC Davis) to go with it. Integrating mechanical engineering and agronomics was a novel feature of the tomato harvester's genesis. Over the next 35 years, harvest labor requirements per ton of processing tomatoes dropped by 92%, while the U.S. processing tomato harvest more than doubled (from 4.1 million to 9.4 million tons).[18]

Recently, R&D has combined mechanical engineering with information and technology to find labor-saving solutions for more difficult-to-mechanize crops and activities (Vougioukas and Fountas, 2019). Automated harvest of fresh fruits, like peaches and strawberries, is particularly challenging, requiring "smart" technological solutions like mobile robots, mechatronic systems with precision sensing, actuation capabilities, and robots that can handle soft, flexible, and complex objects. These machines and other sensors also gather data, which, in combination with cloud connectivity, advanced analytics, and machine learning algorithms, create a world of new possibilities to manage and increase efficiency along agri-food chains. The result can include a reduction in the use of other inputs, as well as labor, reducing the adverse impacts of food production on the environment as well as on farmworkers' health, for example, by reducing chemicals in the food chain. Many of these high-tech solutions are still in the development and experimentation stages, but others are "on the shelf" and already in common use (Charlton et al., 2019). Clearly, if ever it was accurate to think of agriculture as an intrinsically low productivity sector, that time has passed.

California's tomato harvesters and "robots in the fields" seem far away from farms in low-income countries. Nonetheless, increasing agricultural labor productivity in the developing world will require increased use of technologies that enable the agricultural labor force to become more efficient and remain inter-sectorally competitive (Fuglie et al., 2020). As a result, agricultural productivity gains in much of the world may need to be induced primarily by more basic technologies, like small tractors, or mechanical devices that automate repetitive labor-intensive tasks, such as mechanical rice transplanters.

In some places, expansion of agricultural machinery services offers the possibility of increased mechanization on farms too small to justify the outlay to purchase machinery themselves. For example, Yang et al. (2013) report that in China, "in response to a rising wage rate, the most power-intensive stages of agricultural production, such as land preparation and harvesting, have been increasingly outsourced to special - service providers." In China, the use of these services has promoted a more efficient division of labor, allowing urban migrants to maintain higher-wage employment off the farm during the planting and harvest seasons (Zhang et al., 2017). The increasing use of machinery services is not confined to Asia. It is also observed in Africa and increasingly facilitated by digital platforms, such as Hello Tractor in Nigeria,[19] an app-based Uber connecting smallholder farmers to affordable tractor service providers. Nonetheless, many organizational hurdles to developing the integrated machinery chain needed to make it profitable remain (Diao et al., Forthcoming). Socioeconomic constraints can also stand in the way. Gulati et al. (2019), for example, report low adoption of mechanical rice transplanters in India due to women's weak bargaining position in the household decision making process.

Mechanization is often associated with a reduced demand for labor. In theory, the impact of mechanization on labor demand and wages is unpredictable. This is because of two opposing effects: substitution and scale. Agricultural mechanization often occurs in response to rising rural wages, following the structural transformation of national economies towards industry and services, which draws labor out of the agricultural sector. As rural-urban migration expands, greater urban income earning opportunities become the main driver of agricultural wages. Higher wages induce farmers to mechanize and substitute capital for labor, as has now also been observed in (land scarce) Vietnam (Liu et al., 2020).

Mechanization can also enable farmers to expand the scale of their production and increase their income. This can even happen without an original increase in wages, especially in land abundant countries. In fact, it can even induce an increase in real agricultural wages and hired labor (Adu-Baffour et al., 2019; Hassan and Kornher, 2019), though the use of some intermediate labor-saving inputs like herbicides can mitigate this (Reardon et al., 2019). An observed concurrence of rising agricultural wages with mechanization would suggest that wages induce farmers to adopt labor-saving methods, but when scale effects outweigh substitution effects, mechanization does not necessarily reduce rural employment.

It is not surprising, therefore, that the evidence on the labor effects of mechanization is mixed. Kirui (2019) reports that in African countries where land expansion previously was limited, mechanization has led to scale effects through an increase in the amount of cropland cultivated (extensification). Scale effects have been accompanied by input intensification, higher productivity in maize and rice production, and greater labor use (or the substitution of hired for household labor (e.g., Senegal, Zimbabwe)). However, in a number of countries, he also finds that mechanization displaces labor (e.g., the Arab Republic of Egypt, South Africa) and induces off-farm work in some cases. Policy interventions and research efforts need to be tailored to specific regions and contexts.

Overall, where there are limits to agricultural extensification, for example, due to labor scarcity and rising wages, increasing labor productivity through technological change, including mechanization, is the key to expanding food supplies.[20] As technology changes, better-educated and trained workers will have to be available to complement new advanced technologies. Digitized agriculture and food systems also require a digitally-skilled workforce. In most cases, technologies and skill demands in poor countries are not as advanced as in high-income countries like the United States, Western Europe, or Japan. Nonetheless, studies from developing countries reinforce the need to train workers for more skill-intensive employment, not only on farms but throughout the food supply chain, as the agricultural transformation unfolds and digital agriculture takes hold (Takahashi et al., 2020). The COVID-19 crisis may present an opportunity to accelerate the digitization of the agri-food system, helping players across the globe in all nodes of the AFS become more efficient and informed while bridging the rural-urban divide by improving participation in modern markets (FAO, 2020).

Solar energy and mini-grids also offer important opportunities to increase labor productivity in agri-food, especially now that the cost of productive use leveraging solar energy (PULSE) products, such as solar

[18] Other examples of successful mechanical innovations that substantially reduce labor demand include dry-on-the-vine raisin grapes, shake-and-catch systems to harvest tree nuts and juicing fruits, and wine grape harvesting machines (Charlton et al., 2019).

[19] See https://www.hellotractor.com/home.

[20] Land and water scarcity can also limit the extensification of agriculture in some contexts.

driven water pumps (SWP), cold storage, and agri-processing equipment, is falling, appliance efficiency is increasing, and new business models (e.g., PAYGO systems) are emerging.[21] The two main policy areas for promoting mini grid expansion and greater adoption of PULSE products are (i) becoming financially sound, through charging cost recovery tariffs and/or targeted government subsidies[22] and (ii) having regulations that specify what happens when the large grid reaches the mini-grid areas. On both fronts, many initiatives are ongoing (Banerjee et al., 2017; Tenenbaum et al., 2014; World Bank, 2020). The adoption of these technologies could accelerate agricultural labor productivity growth, especially in Africa and South Asia; enable the development of delocalized agri-processing through refrigeration (as in Bihar, India (Minten et al., 2010)); and facilitate a more productive release of farm labor.

4. Migration (and Trade) can help

In countries further along in the development process, the transition out of agricultural work is often accompanied by an inflow of immigrant workers, who help grease the wheels of farm labor markets by replacing native-born workers no longer willing to do farm work (Taylor et al., 2012). Reliance upon immigrants has been a quintessential feature of the history of farm labor in the United States, particularly in the state of California, where two thirds of the nation's fruits and nuts and one third of vegetables are grown. It is also widespread in other high-income economies, as well as many not-so-high-income ones like Costa Rica (with its farm workforce from neighboring Nicaragua), Dominican Republic (Haiti), and South Africa (Zimbabwe and other southern African nations).

In recent decades, California farmers have relied overwhelmingly on unauthorized migrant workers from Mexico. However, rural Mexicans are also transitioning out of farm work as families become smaller, children become better educated, and non-farm employment expands (Charlton and Taylor, 2016; Hill, 2019). Workers have become less willing to travel far away from their homes to work on farms for extended periods of time (Fan et al., 2015). Yet, when farmworkers are less mobile, even more are needed to meet seasonal labor demands.[23] The declining supply of immigrant farmworkers and their reduced mobility has induced local labor shortages. In some cases, this has prevented farmers from being able to harvest high-value fruit and vegetable crops, which have simply rotted away in the fields (Preston, 2006).

Expansion of the U.S. H-2A agricultural guest worker program is unlikely to offer a long-term solution, as labor recruiters compete with Mexican farmers for a diminishing number of farmworkers. Mexico is expanding its fruit and vegetable production, in part, by importing farmworkers from Guatemala, while sending fewer farmworkers to the United States. Increased immigration enforcement has further led to an exit of immigrants from local farm labor markets and pushed unauthorized Mexican migrants further into the desert to avoid apprehension, leading to an increase in the number of border-crossing deaths (Kostandini et al., 2013; Ifft and Jodlowski, 2016; Jones, 2020). These factors have exacerbated an already deteriorating situation for U.S. farmers and have led to a humanitarian crisis on the U.S.-Mexico border.

These trends are not specific to California or Mexico. They have been observed across high-income countries (Donaldson, 2015; Agerholm, 2018) and are evident in other middle-income countries. Agricultural guest worker programs are common on all continents, in countries with vastly different incomes, and they tend to be controversial everywhere. The extent to which middle- and high-income countries already rely on immigrant labor has been highlighted by the COVID-19 pandemic, which caused governments across the world to enact emergency measures to relax mobility restrictions for agricultural workers to safeguard food production. Examples include the U.S. (allowing agricultural guest workers already in the country to extend their work visas), Canada, Germany, and Spain (making special exceptions permitting seasonal migrant workers to enter the country), and Portugal and Italy (conditionally regularizing undocumented migrant workers) (Beatty et al., 2020; Cortignani et al., 2020; Haley et al., 2020; Ramiro, 2020; Santa Fe Relocation, 2020; USCIS, 2020).

Migration can benefit migrant-receiving areas, beyond the farmers themselves, to the extent that migrants complement native workers, make agricultural operations more competitive, and stimulate the demand for goods and services. More importantly, from a development perspective, migration can benefit those who remain in the migrant-sending economy (Taylor and Castelhano, 2016). Migrant farmworkers often earn much more than they could in their place of origin, and the income they remit to family members can help loosen constraints on household production activities, generate income spillovers for other households, and create other positive externalities.[24] A natural experiment from a migration lottery in New Zealand finds evidence that migrant earnings stimulate remittance flows (Gibson et al., 2018) and generate better mental health outcomes (Stillman et al., 2013).

If outmigration causes the local labor supply to decrease, this can put upward pressure on wages, which can be beneficial to local workers but potentially harmful to farmers who rely on hired labor. Filipski et al. (2019) find econometric evidence that migration from Mon state in Myanmar to Thailand caused Mon state wages to rise. However, migrant remittances offset the negative effects of higher wages on Mon production, as the infusion of remittances into the local economy stimulated productive investments and created spillovers by raising the demand for local goods and services. The role of agriculture as a driver of remittances becomes more marginal as migrant networks develop and information about non-farm employment opportunities spreads. In the U.S., for example, immigrants have become increasingly prevalent in all of the other low-skilled sectors of the economy (see Fig. 2), revealing agriculture's diminishing role over time.

The World Bank predicts a significant reduction in remittances (as much as 23% in SSA) due to lockdown measures from the COVID-19 crisis that prevent migration (Bisong et al., 2020). The decrease in remittances poses a huge threat to development, which could potentially push a significant number of people back into poverty. Restrictions on mobility and work have particularly affected workers who are ineligible to receive benefits from social safety nets due to their informal working arrangements or legal status. In Southeast Asia, aggregate agricultural production is predicted to decline by three percent as a result of reduced labor mobility and access to input and output markets, which could increase the number of people in poverty by as much as three percent (Gregorio and Ancog, 2020). Ultimately the revival of remittances will depend on the mobility of labor after the crisis calms down.

Migration by men can affect the empowerment of women and the types of work in which they engage. Kar et al. (2018) find that, in Nepal, male outmigration induces women to become the primary decision makers on the farm rather than simply providing labor to agricultural production. Women's employment outcomes tend to improve if

[21] While not all off-grid farmers will adopt SWPs, with 67 million smallholder farmers worldwide off the grid (of which 43 million in Sub Saharan Africa), the potential SWP market is huge. SWPs can also help relieve the strain on overstretched main grids. There are six-and-a-half million smallholder farmers working in the dairy and horticulture sectors in SSA who are off-grid and in need of cooling technologies. The potential demand for solar mills and threshers in Sub-Saharan Africa is estimated at around 940,000 units (World Bank 2020).

[22] The 150,000 solar water pumps sold in India to date, for example, have been bolstered by government subsidies.

[23] There is a striking analogue between this and the velocity and supply of money in macroeconomics.

[24] Remittances can permit vehicle purchases, housing improvements, and youth education. A general discussion of remittance impacts is available in Taylor (1999).

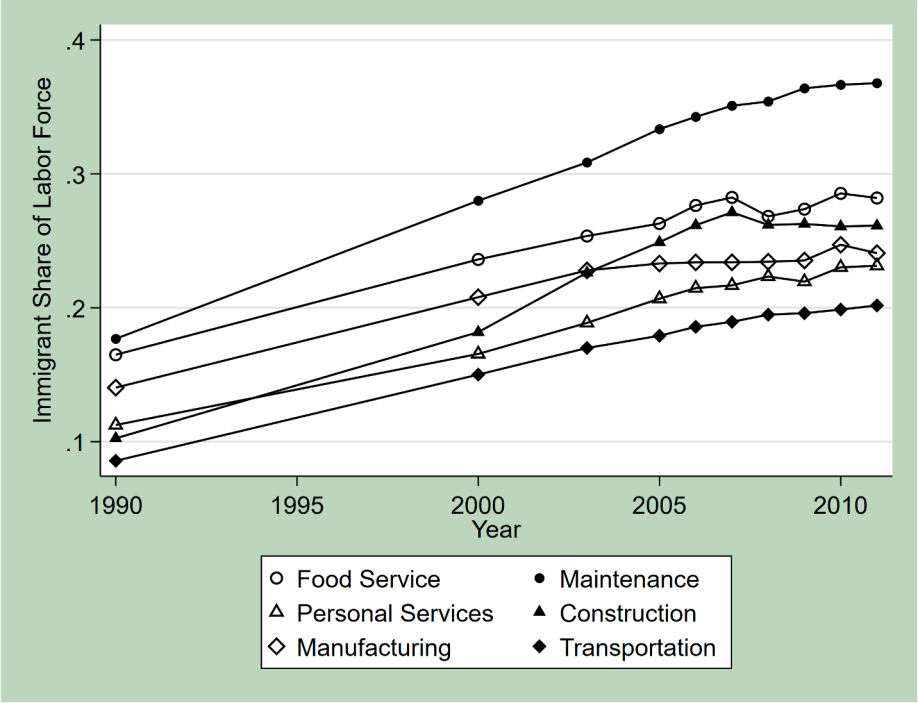

Fig. 2. Evolution of the Immigrant Share in Low-Skilled Sectors of the U.S. (1990–2011). **Source:** U.S. Census and American Community Survey data processed by authors.

remittances accompany male migration. The receipt of remittances facilitates group membership and financial integration, as evidenced by the possession of bank accounts. However, in the absence of remittances, spouses of international migrants tend to be worse off with regard to several domains of empowerment, including decision making about certain productive activities, agricultural income, and access to information. In Senegal, when household members migrate but do not send remittances home, households become more food insecure. These findings underscore the importance of programs to reduce remittance costs and improve extension services that enable women to become more productive farmers and entrepreneurs in migrant-source economies.

To reduce reliance on immigrant farm labor, farmers and countries could switch out of labor-intensive crops and import them from lower-wage countries. Some U.S. farm operations already expanded into Mexico in order to meet the year-round demand of their customers. In fact, about half of the fresh fruit consumed in the United States and a third of fresh vegetables are imported. There is some evidence that farmers are planting more land in less labor-intensive crops like tree nuts, most of which are harvested by machines that shake the nuts off the tree and sweep them off the ground (Rutledge and Taylor, 2019; CFBF and UC Davis, 2019). However, consumer demand for fresh fruits and vegetables, both in the United States and abroad, continues to rise, and food imports are expanding. Consumers' demand and willingness to pay for locally-grown produce increases as incomes rise, creating limits to countries' reliance on food imports as a solution to the farm labor problem.

At the other end of this trade often are countries with much lower land per laborer, such as China. Since the turn of the century, China has dramatically raised its exports of labor-intensive fruits and vegetables, while increasing its imports of less strategic, and more land (and water) intensive ones such as soybeans and corn for animal feed, much of it from the United States (soybeans) and Brazil (Christiaensen, 2013).[25]

5. Ways forward

The structural transformation is a quintessential part of economic development everywhere; people move off the farm and pressure on agriculture grows to feed a growing population. What policies are required to address these issues logically depends on what stage of the development process a country is in and what institutions and social norms are in place. But at the core must lie a policy package that raises labor productivity in agriculture while leveraging the poverty-reducing powers of the AFS, mitigating the social-adjustment costs inherent to this transition, and avoiding the introduction of inefficient policies, such as the closure of borders for agricultural goods and labor. Accomplishing these tasks has been challenging in the past and will continue to be a

[25] At the turn of the century, China had about 20 percent of the world's population, 35 percent of the world's agricultural labor force, but only 11 percent of the world's agricultural land, and less than 6 percent of its water resources. Following China's WTO accession in 2001, soybean imports surged from about 10 to about 50 mmt between 2001 and 2008–2010. The reversal from maize export to maize import (the other cereal feed) followed soon after. Soybean production is almost four times as water intensive as maize (3200 versus 850 m3 of water per ton output) and both are much more water intensive than most vegetables. Importing soybeans and corn thus equates with importing vast amounts of water, giving rise to a virtual international trade in water. This provides a welcome relief to the rapidly shrinking water tables in northern China, where the oft irrigated production of cereals has been widespread.

challenge moving forward, with technological shifts, altering attitudes towards globalization, and climatic change further setting the boundaries of what's possible and desirable. We conclude by pointing out a trio of policy entry points for developing countries, at the early to middle stages of the agricultural transformation, and for high-income countries at the late stages.

The starting point for thinking about policy responses in developing countries is to recognize that agricultural labor productivity in many African countries continues to be dismally low, that current and future generations of young people are less willing than their parents to perform low-paying and onerous farm work, and that agricultural exports and emigration may offer fewer employment opportunities than in the past. However, domestic food demands continue to increase and diversify, creating important employment opportunities in the off-farm AFS. These changes mean that both traditional and new digital technologies can be leveraged to induce a productive exit out of agriculture in Sub-Saharan Africa while maintaining a competitive agricultural workforce on and off the farm in the chains elsewhere. Three key policy implications emerge.

First, productivity-enhancing investment in agriculture must accelerate in the lower-income countries and proceed at least in tandem with the movement of workers off the farm elsewhere. Populations will continue to grow despite slowing birthrates, and food production will have to expand to keep pace. The movement of workers off the farm to meet the demand for other goods requires producing more food with fewer workers, once underemployed labor has been activated. Historically in today's high-income countries, agricultural extension and public investments in infrastructure, from irrigation to information, marketing institutions, and roads, played a critical supporting role in facilitating the labor exit out of agriculture. They enabled the remaining farmers to earn a living commensurate with nonfarm sectors, as competition for workers with the non-farm sectors (including migration to urban areas) and downstream food processors intensified. This agenda holds as much today as then.

In Sub-Saharan Africa, the agricultural share of public spending continues to be well below that in East Asia (3 percent on average during 1980–2012 versus 8 percent in Asia). Myriad input, factor, and output market constraints hold agricultural labor productivity back, and integrated solutions that simultaneously overcome a number of these constraints are needed. Inclusive value chain development (iVCD), which links farmers with buyers in contracting arrangements, offering knowledge, access to credit and inputs (Reardon et al., 2003), and higher (less volatile) prices in exchange for a consistent volume of high-quality products (e.g., Dries and Swinnen, 2004; Dries et al., 2004), provides a market-based solution to do so, though smallholders' lack of legal protections can be an obstacle (Singh, 2002; Birthal, 2008). Given the challenge to develop self-enforcing incentive compliant contracts, iVCD typically does not work well for raising staple crop productivity. Yet, in low income countries, this is where the need and scope for raising labor productivity and poverty reduction is highest. For raising labor productivity in staple crops, more and better public investment in public goods is needed (Beegle and Christiaensen, 2019; Fuglie et al., 2020).

Second, the scope for iVCD to raise smallholder incomes and benefit the poor and women is greater for non-staples. iVCD also creates jobs off the farm, in the chains and beyond (through consumption linkages). Success factors of iVCD include careful diagnosis of the competitiveness and sustainability of the product value chain chosen, starting small, involving financial institutions, monitoring producer-buyer relationships, and sustaining capacity building. This is in addition to creating an economic environment that is conducive to investment generally. Developing systems to monitor and enforce food quality standards in the AFS is equally critical.

There is clearly a role for agricultural ministries, as well as for the private sector, to ensure that the development and use of labor-saving technologies keeps pace with the movement of workers off-farm. Many questions remain, however, especially on the best entry points for support: through farmer organizations/cooperatives, large anchor firms and/or SMEs, or externally initiated stakeholder platforms. More experiments (and careful evaluations) are needed. In the meantime, appropriate measures will be needed to help SMEs in the transformative food chains see through the decline in liquidity caused by COVID-19 and avoid undue concentration of activity in the long run. Labor-market regulations and other social protections can also be useful in protecting vulnerable populations from exploitation as they transition into non-farm work (Swinnen and Kuijpers, 2017; Barrett et al., 2020; Christiaensen, 2020).

Third, investment in people is critical to raise agricultural labor productivity and to make sure that those leaving can access the new jobs in the AFS, as well as other non-farm sectors, and meet the rising economic aspirations of rural youth. Continued investment in quality rural education, which continues to largely underperform in developing countries, is needed (World Bank, 2018). Increasing educational attainment in rural areas facilitates technology adoption, as well as occupational mobility, and reduces income inequality. This is also important for young women facing social norms that make it difficult to escape from traditional gender roles.

Nontraditional skill-building programs and effective agricultural extension systems will be equally needed to build up human capital in regions where traditional education has proven ineffective. The extension system is particularly weak in Sub-Saharan Africa and has been largely neglected for the past couple of decades by governments and donors alike. The 2010s have witnessed a surge in studies on social network or farmer-to-farmer technology extension, which proves more promising especially in combination with public extension than traditional public-sector extension approaches. But several issues remain such as the choice and compensation of appropriate lead farmers (Takahashi et al., 2020).

Policy implications are different, but just as immediate, in high-income countries. Rich-country farmers will be required to produce more and higher-quality fresh and processed foods for a growing, and increasingly affluent, domestic and global population, and they will be required to do so under increasingly stringent environmental and animal welfare standards. However, they will have to do this with fewer workers. The transition of domestic workers out of farm work largely has run its course in rich countries. The option of importing foreign workers is gradually closing, due to a declining farm labor supply in farm labor-exporting countries and a less supportive political environment for immigration, particularly of low-skilled workers, in high-income countries. Three key policy implications emerge for high-income countries in this era of growing farm labor scarcity:

First, farmers in high income countries (as well as the sending countries) will increasingly need to look beyond immigration policy as an answer to farm labor scarcity (or surplus)—especially in the medium and long run. Guest worker programs can expand as a short-run response to farm labor scarcity. However, as the structural transformation progresses in farm labor-exporting countries and political resistance to importing low-skilled farmworkers intensifies, the immigration solution to the farm labor problem becomes less of an option. This does not mean that immigration will not continue to play a central role in farm labor markets throughout the developed world for some time. But farmers will need to take steps to retain an aging, mostly immigrant, workforce while pursuing available options to contract new workers from abroad. International farm labor migration could continue to be a much-needed channel for sharing prosperity across nations and reducing poverty in the world's poorest countries. For this, however, a counternarrative needs to take hold rapidly. If not, its days may be numbered prematurely, especially now that the COVID-19 pandemic so clearly exposed the agri-food sector's dependence on immigrant labor and the logistical challenges this may entail, eroding support for reliance on immigrant agricultural labor even further.

Second, increasingly sophisticated technological change is going to be a fundamental feature of the food supply chain, from farming to food

processing. Productivity-enhancing investments likely will include the use of highly-advanced robotic systems that will dramatically reduce the need for workers (the workers will change, too; see below). Scouring the landscape in today's high-income countries, we find automation success stories like the ones described earlier in this paper, as well as major challenges. There is a danger that automation will not happen quickly enough to enable farmers to maintain their competitiveness in a high-wage, labor-scarce, world. Farmers can respond by shifting their production into less labor-intensive crops. However, more affluent consumers will demand fresh, locally-grown fruits and vegetables, as well as specific qualities like organics, environmentally friendly production practices, fair trade, and possibly better labor practices, all of which tend to increase labor demands compared to field crops where automation is more advanced. Prices of these fresh fruits and vegetables will rise, causing farmers to think twice about abandoning production as wages rise while intensifying pressure on public and private researchers and policy makers to accelerate the development of labor-saving technologies and deploy the necessary digital infrastructure to run it, including in remote rural areas. Policymakers will need to keep an eye out for undue concentration of power in the supply of these new technologies and devise adequate policies to ensure competition (Carolan, 2020).

Third, a technologically advanced AFS requires a technology-savvy workforce, with more engineers and people capable of working with increasingly complex technologies. As agricultural and food processing technologies become more IT intensive, so do human capital demands all along the AFS. To some extent, developments in IT can help respond to human capital shortages; viz. bar codes in supermarkets and hamburger buttons at fast-food restaurants. Nevertheless, the numbers of workers with little education who pick themselves a living wage will diminish. As new technologies become available for relatively easy-to-mechanize crops and routine tasks, the farm workforce will move out of those crops and tasks into ones that have not yet been mechanized and are non-routine (e.g., farm tourism). A major policy challenge is to prepare the future farm workforce for technological change while also ensuring that employment opportunities expand as new technologies release workers from crop production. There is no magic bullet to guarantee that automation, human capital formation, and new job creation move apace.

It is undeniable that the future holds far-reaching changes in mechanization and automation in developing and developed countries alike. Without it, agriculture and the AFS generally will not be able to keep up with rising food demands and a declining farm labor supply. Inevitably, many farms and farmworkers will have difficulty adjusting. Some farms and farmers, particularly larger, wealthier and better educated ones, are in a far better position to experiment with and adopt new labor-saving technologies, including advanced robotics. And some farmers and farmworkers, particularly older ones, will have a difficult time shifting to new commodities and tasks; the more technology-savvy farm workforce of the future is likely to be younger and better educated than current workers. Decoupling social insurance from employment, as proposed in Packard et al. (2019), could be a worthwhile social insurance model to mitigate adverse consequences of this transition and avoid the introduction of ineffective agricultural and food policies. The need for greater food system resilience, highlighted by the COVID-19 experience, would also be better served by food trade diversification instead of a reversal to protectionism and food self-sufficiency. Yet, without successful social insurance schemes to help mitigate the adjustment costs and rapid ramp up in agricultural education and extension, the ongoing evolution in the agricultural labor force is bound to raise inequality as well as anti-trade sentiment, including in agri-food.

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