

The Future of Work in Agriculture

Some Reflections

Luc Christiaensen
Zachariah Rutledge
J. Edward Taylor



WORLD BANK GROUP

Social Protection and Jobs Global Practice

March 2020

Abstract

As countries develop (and food saturation takes hold), 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 been shaped by these dynamics. Today, a digital revolution is taking hold, affecting agricultural labor and skill demands. In this process, societies evolve from having a surplus to a shortage of domestic farm labor, typically met largely by foreign agricultural wage workers. Yet, anti-immigration sentiments are flying high in migrant-destination countries, and robots

in the fields and packing plants offer an alternative. Agricultural trade may be similarly challenged. In the world's poorest countries, particularly in Africa, labor productivity in agriculture remains at historically low levels. So, what can the role of agriculture as a source of employment be 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.

This paper is a product of the Social Protection and Jobs Global Practice. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at <http://www.worldbank.org/prwp>. The authors may be contacted at lchristiaensen@worldbank.org.

The Policy Research Working Paper Series disseminates the findings of work in progress to encourage the exchange of ideas about development issues. An objective of the series is to get the findings out quickly, even if the presentations are less than fully polished. The papers carry the names of the authors and should be cited accordingly. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.

The Future of Work in Agriculture - Some Reflections*

Luc Christiaensen, Zachariah Rutledge, and J. Edward Taylor

JEL classification: J43, J61, O13, Q16

Keywords: agricultural labor, digital technology, migration, agricultural value chain development, agricultural education and extension

* Luc Christiaensen (lchristiaensen@worldbank.org), World Bank; Zachariah Rutledge (zjrutledge@ucdavis.edu) University of California Davis, J. Edward Taylor (taylor@primal.ucdavis.edu) University of California Davis. This paper builds on the World Bank / IFAD / UC Davis workshop on The Future of Work in Agriculture held at The World Bank, Washington DC, March 19-20, 2019. The papers are available at <https://farmlabor.ucdavis.edu/future-work-agriculture-conference>. We thank all of the workshop participants for their contributions and the insightful discussions. The views presented here do not necessarily represent those of our respective institutions.

Introduction

Agriculture has been a major employer across the globe and is at the center of discussions about poverty reduction and economic development. As countries develop (and food saturation takes hold), agriculture's role as employer declines (Timmer 1988). The farm workforce becomes older, more wage-oriented, and more immigrant.¹ At the same time, the broader agri-food system (AFS) expands, and the scope for agriculture-related job creation shifts beyond the farm. The income elasticity of demand for food declines, but urban consumers with rising incomes demand more protein- and nutrient-rich foods, as well as foods that are more processed and convenient. These dynamics 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, they are accompanied by deeply wrought societal change and ineffective policy responses, including agricultural protectionism (Anderson 2010; Christiaensen 2013).

Technological revolutions both shape and are shaped by these dynamics (Hayami and Ruttan 1978). 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 (automation, artificial intelligence, and information and communications technology), with another energy revolution (solar, mini-grids) just around the corner. These technological advancements of the 21st century are affecting the structural and agricultural transformations across the globe in new and unprecedented ways. They dramatically reduce transaction costs in input, factor and output markets; they change economies of scale; and they modify the optimal capital/labor mix in agricultural production, processing, and marketing. This has the potential to profoundly alter the global organization of the food system as well as labor and skill demands. Because agricultural tasks are arguably more automatable (routine and less cognitive) than those in industry and services (Schlogl and Summer 2020), automation could accelerate the exit of labor out of agriculture in developing countries and transform farms and food processors in the developed world. A future with robots in the fields and packing plants, together with “tekked up” farmworkers to complement new technological solutions in specific commodities and tasks, already is taking shape.

Historically, societies typically evolved from a surplus to a shortage of domestic farm labor as they developed. More often than not in developed countries, farm labor shortages have been met largely by foreign agricultural wage workers, especially for tasks that were difficult to automate. Migrant-sending households in low-income countries benefited through remittances. However, with anti-immigration sentiments flying high in migrant-destination countries, the agricultural 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 closing (Carolan 2020). A 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 and rapidly expanding populations. This presents a missed opportunity for

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, see for example Slavchevska et al. (2019), UN FAO (nd), and De Brauw et al. (2008).

development. 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.

These domestic and global forces provide the socio-economic backdrop against which the future of work in agriculture unfolds. How countries address these and related challenges will shape the evolution of the global agricultural workforce, as well as agriculture's potential to continue its historically crucial role in reducing poverty and fostering shared prosperity. It calls for a policy and business environment supportive of inclusive agricultural value-chain development to leverage the food system for employment opportunities on and off the farm. It highlights the rising importance of rural education and digital upskilling of rural populations, so that the agricultural and rural workforce can maximally benefit from new technologies. It draws attention to the need for broad access to digital infrastructure and adequate competition policies to address the challenge of rising power concentration. It sheds an important and different light on the current migration debate. And finally, to mitigate the farm labor transition and prevent a reversal to agricultural policy distortions, it draws attention to the need for adequate social protection systems to mitigate populist calls for agricultural protectionism. The decoupling of social protection from employment holds promise in that regard.

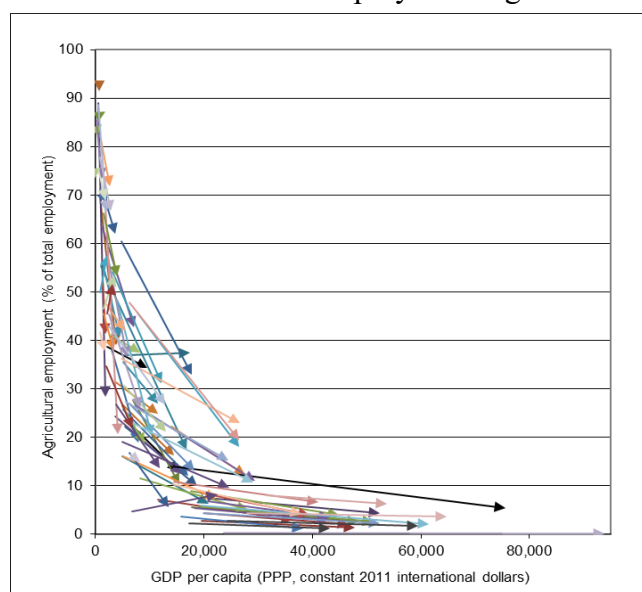
The remainder of this paper discusses the impact and evolution of these different forces in turn and reflects on a policy agenda that can leverage the future global food system to generate decent employment, accelerate poverty reduction, and attain shared prosperity.

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 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.² Over time, cross-sectoral income differences virtually disappear (Taylor and Charlton 2018). This pattern of structural transformation is evident historically in high-income countries and is currently unfolding in low-income countries (Figure 1). Against this broad and sweeping background, what can the role of agriculture as a source of employment be in the future?

² These 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 (water with irrigated agriculture; temperature and light with green houses; land with vertical agriculture).

Figure 1. Proportion of Countries' Workforce Employed in Agriculture vs. GDP per capita



Note: Data were retrieved from The World Bank Group (<https://data.worldbank.org>). The beginning of each arrow represents each country's position in 1991, and the arrowheads show where they wound up in 2017. Nearly every country has an arrow that points to the southeast, indicating that as countries get richer, the workforce becomes less reliant upon agriculture.

First, agriculture will continue to be a major employer 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, as the population continues to grow fast and cultivated land (the “extensive margin”) expands. 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). 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 challenge is largely to improve the quality of farmers' jobs, (i.e., increase their labor productivity and earnings), including to facilitate 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, farm populations have “grayed,” and farm labor shortages in specific commodities at specific points in time have become a feature of the agricultural landscape.

Second, agricultural labor productivity will continue to rise. 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 of agriculture being intrinsically less productive and taken as suggestive that the policy solution for agricultural labor in the developing world lies in removing barriers that prevent people from exiting agriculture (Restuccia, Yang and Zhu 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, Lagakos and Waugh 2014; Gollin and Udry 2019; Hicks et al. 2017; McCullough 2017). This

suggests that agriculture is not intrinsically less productive, but rather that 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) as well as higher fertility rates (many more people in developing countries are born in agriculture than outside agriculture).

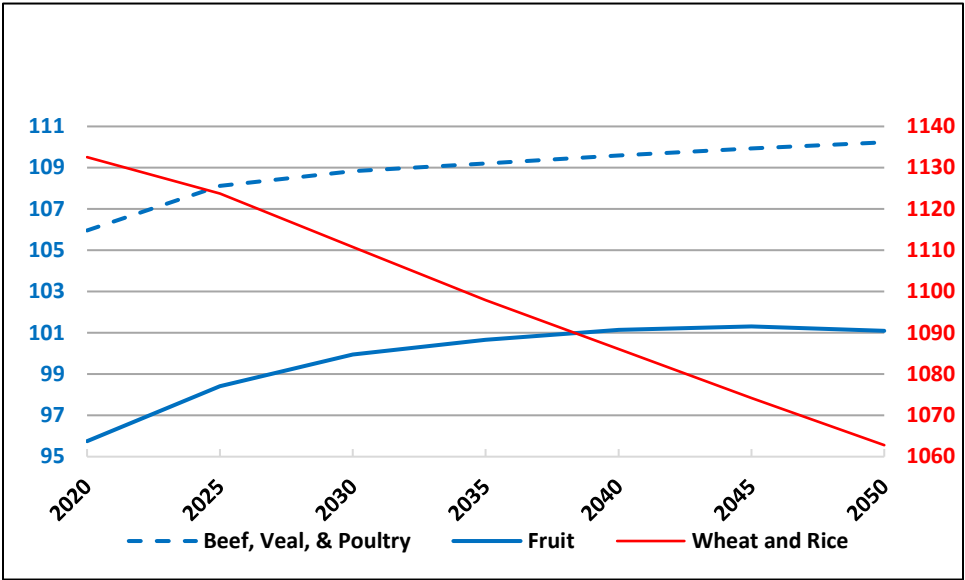
If the productivity gap is much smaller than generally assumed, a disproportionate focus on policies to remove barriers to sectoral or spatial migration of labor, however well-intentioned, may be misplaced. In fact, if agricultural labor is only in surplus during the agricultural slack season (between harvesting and planting, and planting and harvesting), such policies may prove ineffective, or they may even exacerbate agricultural labor shortages during peak demand periods (planting and harvesting). 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 development of complementary activities during the slack season, such as double cropping through irrigation and mixed farming systems (crop-livestock).³ It 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, as illustrated by low cereal yields (1.5 ton/ha on average, compared with about 3 ton/ha in India and about 6 ton/ha in China) (Beegle and Christiaensen 2019).

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 micro-nutrient rich diets (meat, dairy, fruits and vegetables) (see Figure 2). Eventually, societies tend to demand more processed and prepared foods, and they may develop food consumption patterns that involve eating as an “experience”.⁴ Societies become more dependent upon the downstream AFS as a result. This in turn opens up important new employment opportunities off the farm, in food processing, marketing and logistics, and food services.

³ 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. This could introduce a price treadmill, whereby 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 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).

⁴ 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, Van Herck and Vandemoortele (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.

Figure 2. Changes in the Composition of Global Per-Capita Daily Calorie Demand For Selected Commodities



Source: FAO (<http://www.fao.org/global-perspectives-studies/food-agriculture-projections-to-2050/en>).

Many farm workers who leave the farm remain within the broader food supply chain. In many low-income countries, off-farm work in AFS already makes up about 25 to 33 percent of overall off-farm work (see Table 1) (Allen, Heinrigs, and Heo 2018). It 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. 2019).⁵ The importance of off-farm employment (food manufacturing and food service) in the overall agri-food system (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 the more successful countries develop their agri-food system as they pass through the structural transformation, and that this leads to a more rapid reduction in poverty (Huang 2016). Non-farm AFS jobs are often easily accessible for poor workers leaving the farm as well as for women, given their proximity and low entry requirements in terms of capital and skills. A large part of employment opportunities within the AFS is happening in secondary cities and towns (Cazzuffi et al. 2017), and most of the poor live in the rural hinterlands of these intermediate centers (Ingelaere et al. 2018).

⁵ 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).

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

Sectoral share of employment (%)		Low-income (Eastern and Southern Africa)	Middle- income (Brazil)	High-income (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 IFAD, 2017. The total for Brazil does not add up to 100 due to rounding error.

The downstream AFS is indeed expanding rapidly in developing countries across the globe as part of the transformation of food markets. Several recent case studies support the beneficial effects of the AFS and related development of agri-food value chains for labor force participation, income, and working conditions, including for the poor and for women. Examples from the Future of Work in Agriculture conference include Sauer et al. (2019) for domestic food systems in Tanzania (2019), Edwards (2019) for post farm oil-processing farms in Indonesia,⁶ 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 lower fertility rates—evidence that the development of ag-export supply chains contributes to the broader socio-demographic transformation.

Fourth, fears of a mass exodus of African youth out of agriculture, disproportionate with normal patterns of youth transitions 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 are 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, 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 (Christiaensen et al. 2015). In the 13-country study mentioned previously, after

⁶ 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.

controlling for location and agricultural potential, researchers found that youth do not spend less (or more) hours in on-farm work than older adults in general, and only younger adults spend less time in own farming (though more for wages on others' farms) (Dolislager et al. 2019). 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, the farm-non-farm labor transition is also affected by societies' socio-demographic features. The findings above suggest growing competition for labor between farm and non-farm activities as countries develop and the structural transformation unfolds. In part, this is because of a growing demand for workers in downstream, nonfarm, AFS activities as well as growing labor demand from non-agriculture related industries and services. Socio-demographic 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 non-farm AFS as well as to non-AFS jobs. Liu et al. (2019), 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-non-farm labor transition as well. A field experiment in Ghana (Kramer and Lambrecht 2019) uncovered evidence that traditional gender roles lead to a division of labor that causes women to prefer investments in non-agricultural activities. This finding highlights the need to recognize women's preference for diversification 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 to 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 is already observed in high (and 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>). Four options present themselves to deal with this, which Martin (2017) characterizes as the 4 S's: *Satisfy*, *Stretch*, *Substitute*, and *Supplement*. 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. They can *stretch* workers by increasing their productivity, providing them with better technology like slow-moving conveyor belts to carry bags or trays of 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.

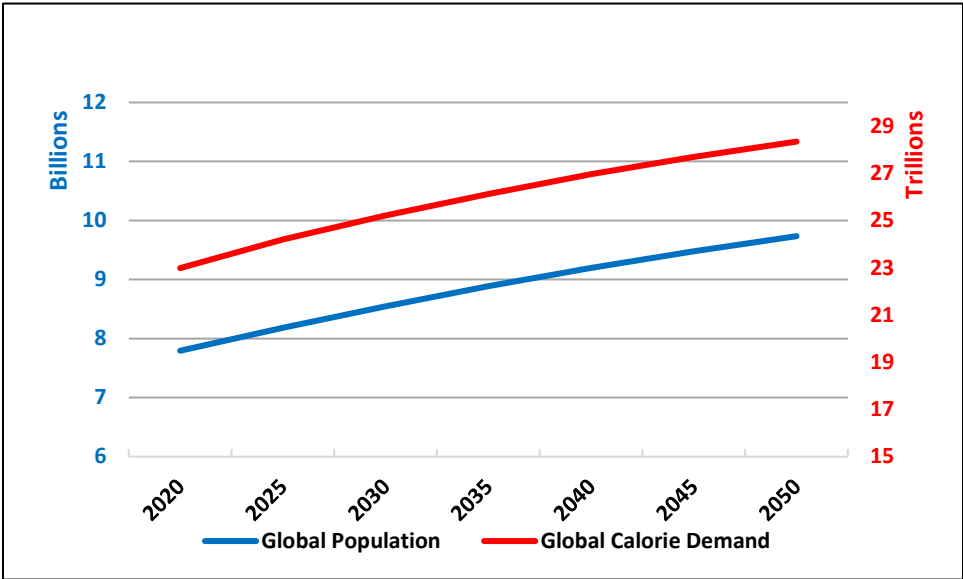
All four strategies are being deployed to different degrees depending on countries' preferences and their position in the labor surplus-shortage continuum. The corresponding public policy domains are labor and social protection, innovation and competition policies, agricultural trade, and

migration. These go well beyond the traditional realm of the Ministry of Agriculture. Motivated by persistent low labor productivity in African agriculture, the salient nature of the digital revolution and rising anti-immigration sentiment in the current policy debates, this broader global assessment of the future of work in agriculture zooms in on the role of productivity-enhancing innovation and technology and immigrant agricultural labor.

Technology Is Key

Over the next 30 years, global calorie demand is expected to rise in tandem with the population, which is projected to increase by about 25% to nearly 10 billion people (see Figure 3). Ultimately, farmers will have to grow more food with fewer workers, and this will require the development and adoption of new labor-saving technologies. 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 solutions (Hyami and Ruttan 1971). Others view research and development (R&D) as largely an exogenous, self-perpetuating process: new

Figure 3. Projected Global Population and Calorie Demand



Source: FAO (<http://www.fao.org/global-perspectives-studies/food-agriculture-projections-to-2050/en>).

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 are partly driven by the rising costs of labor.

The classic example of labor-saving technology in fruit and vegetable production is 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 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. 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 wine grape harvesting machines (Charlton et al. 2019).

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). The harvest of fresh fruits, like peaches and strawberries, is particularly challenging. It requires optical and machine-learning technology to identify which fruits to pick and mechanical harvesting solutions to replace gentle human hands in harvesting fragile fruits. “Smart” technological solutions include mobile robots, mechatronic systems with precision sensing, actuation capabilities, and robots that can handle soft, flexible, and complex objects.

While performing what once were labor-intensive tasks, these machines and other sensors also gather data. These data, 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 be a reduction in other inputs, as well as labor, and increasing yields. Smart technologies also offer the potential to decrease adverse impacts of food production on the environment as well as on farm workers’ 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. For example, lettuce starts need to be thinned to about 10 inches apart, and thinning is one of the most labor-intensive operations in lettuce production: workers with hoes walk the fields, deciding which lettuce starts to keep and removing the rest. New automated lettuce thinners use advanced optics and machine learning to identify which starts to keep and eliminate the unwanted starts with a jet spray of concentrated fertilizer. This reduces labor demands from 7.31 person-hours per acre to only 2.03 (Mosqueda et al. 2017).

Using artificial intelligence algorithms similar to those used in facial recognition software, robotic weeding technologies can distinguish weeds from productive plants and then target the weeds with miniscule jets of herbicide (or directly spray crop plants with fertilizer), minimizing chemical use. Robotic milking systems (RMSs) can reduce labor demand in dairies while monitoring milk output and animal health.

Clearly, if ever it was accurate to think of agriculture as an intrinsically low productive sector, that time is past. But California’s tomato harvesters and “robots in the fields” seem far away from farms in low-income countries. Highly advanced agricultural technologies are expensive, and most of the world’s farms are too poor and small to buy them. Nonetheless, increasing agricultural labor productivity in the developing world will equally require increased use of technologies that enable the agricultural labor force to become more efficient and remain intersectorally competitive. 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, like 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.”

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,⁷ an app-based Uber connecting smallholder farmers to affordable tractor service providers. Nonetheless, many hurdles to developing the integrated machinery chain needed to make it profitable remain (Diao et al. forthcoming). Socio-economic 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.

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 Korhner 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.

As such, it is not surprising 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 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.⁸ As technology changes, better-educated

⁷ <https://www.hellotractor.com/home>

⁸ Land and water scarcity can also limit the extensification of agriculture in some contexts.

and trained workers will also have to be available to complement new advanced technologies. Tekked-up agriculture and food systems require a tekked-up 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 (Takahasi et al. 2020).

Migration (and Trade) Can Help

In countries that are 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 who are 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 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, a nation that shares a border with the state and has relatively low wages. However, rural Mexicans are transitioning out of farm work as families become smaller, children become better educated, and non-farm employment expands (Charlton and Taylor 2016; Hill 2019). The changing composition of the farm workforce has contributed to a decline in the number of immigrants willing to engage in follow-the-crop migration; workers become less willing to travel far away from their homes to work on farms for extended periods of time as they age, settle down, and have families (Fan et al. 2015). When farm workers are less mobile, more are needed to meet seasonal labor demands.⁹ Because farm labor markets are local and farm labor is not always mobile, the declining supply of immigrant farm workers 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).

The U.S. H-2A agricultural guest worker program is expanding, but it is unlikely to offer a long-term solution to a shrinking farm labor supply because labor recruiters compete with Mexican farmers for a diminishing number of farm workers. Mexico is expanding its fruit and vegetable production, in part, by importing farm workers from Guatemala, while sending fewer farm workers to the United States. Several academic papers have further found that increased immigration enforcement has led to an exit of immigrants from local farm labor markets, revealing that the threat of deportation may exacerbate an already deteriorating situation for U.S. farmers (e.g., Ifft and Jodlowski 2016; Kostandini et al. 2013).

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

⁹ There is a striking analogue between this and the velocity and supply of money in macroeconomics.

countries. Agricultural guest worker programs are common on all continents, in countries with vastly different incomes, and they tend to be controversial everywhere.

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, it can also benefit substantially those who remain in the migrant-sending economy (Taylor 1999). 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.¹⁰

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. Filipinski et al. (2019) find econometric evidence that migration from Mon state in Myanmar to Thailand has 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 stimulates productive investments and creates spillovers by increasing the demand for local goods and services.

Migration by men can affect the empowerment of women and the types of work in which they engage. Kar et al. (2019) 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 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 enabling women to become more productive farmers and entrepreneurs in migrant-source economies.

Farmers and countries could also switch out of labor-intensive crops. An alternative to producing labor-intensive commodities is to import them from lower-wage countries. According to Tom Nassif of the U.S. Western Growers Association, "Our [agricultural] industry is going to rely on a foreign workforce. It's only a question of whether that workforce harvests crops in this country or in another country and builds up the economy of that country" (as quoted in Glaister 2006).¹¹ Some U.S. farm operations have 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

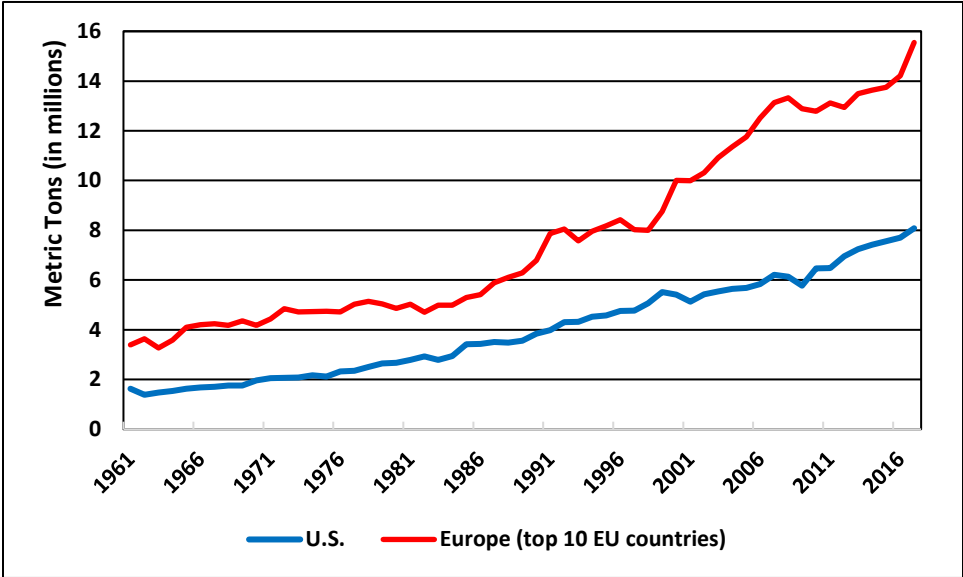
¹⁰ Remittances can permit vehicle purchases, housing improvements, and youth education. A general discussion of remittance impacts is available in Taylor (1999).

¹¹ The Western Growers Association is an organization that represents local and regional family farmers growing fresh produce in Arizona, California, Colorado, and New Mexico. Their members and the workers they employ produce over half of the nation's fresh fruits, vegetables, and tree nuts (see <https://www.wga.com/about-western-growers>).

less labor-intensive crops like tree nuts, which are harvested using “shake-and-catch” machines (Rutledge and Taylor 2019; Rutledge et al. 2019). However, consumer demand for fresh fruits and vegetables, both in the United States and abroad, continues to rise, and food imports are expanding (see Figure 4). Consumers’ demand and willingness to pay for locally-grown produce increases as incomes rise, and this creates 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).

Figure 4. Fruit Imports for Europe and the United States



Source: FAO (<http://www.fao.org/faostat/en/#data>).

Ways Forward

The agricultural 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 this means for policy 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, that continues to do so while leveraging the poverty reducing powers of the food system, and that mitigates the social adjustment costs inherent to this transition to avoid the introduction of inefficient policies such as a closure of borders for agricultural goods or laborers. This has been the challenge in the past and continues to be so when looking at the future of work in agriculture. 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, and this creates important employment opportunities in the off-farm AFS. This means 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 investments in infrastructure, from irrigation to information, marketing institutions, and roads, played a critical supporting role in facilitating the labor exit out of agriculture. This has 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 China, agricultural wages are keeping pace with non-farm wages, and this underlines the important role of agricultural investments in the development process. 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, and higher (less volatile) prices in exchange for a consistent volume of high-quality produce, provides a market-based solution to do so. Given the challenge to develop self-enforcing incentive compliant contracts, however, 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).

Second, the scope for iVCD to raise smallholder incomes and benefit the poor and women is greater for non-staples. It 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 are needed. 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. 2019; 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, however, 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 (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 agricultural transformation progresses in farm labor-exporting countries and political resistance to importing low-skilled farm workers 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 much needed counternarrative needs to take hold rapidly. If not, its days may be numbered prematurely.

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. Society 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 tekked-up AFS requires a tekked-up 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 farm workers 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 farm workers, particularly older ones, will have a difficult time shifting to new commodities and tasks; the more tekked-up farm workforce of the future is likely to be younger and better educated than current workers. Decoupling social insurance from employment, as proposed in Gentilini 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. 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 add a new voice to rising populism.

References

- Adu-Baffour, F., Daum, T. and Birner, R., 2019. Can small farms benefit from big companies' initiatives to promote mechanization in Africa? A case study from Zambia. *Food policy*, 84, pp.133-145.
- Agreholm, Harriet. 2018. Brexit: Farmers Allowed to Recruit 2,500 Migrants A Year Under New Government Plan to Plug Seasonal Workforce Gap. *Independent*, Sept. 6.
- Allen, Thomas, Philipp Heinrigs, and Inhoi Heo. 2018. "Agriculture, Food and Jobs in West Africa." West African Papers No. 14, Organisation for Economic Co-operation and Development (OECD), Paris.
- Anderson, Kym. 2010. Ed. The Political Economy of Agricultural Price Distortions. Cambridge University Press: New York, USA.
- Arslan, Aslihan, Egger, Eva-Maria, and Tschirley, David E. 2019. Gender Gaps in Youth Employment: A Spatial Approach. Presented at the Future of Work in Agriculture Conference of the World Bank Group, Washington D.C.: https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/3.%20%20Arslan_Gender%20gaps%20in%20youth%20employmt_FOWAG_WB%2020-03-2019.pdf.
- Barrett, Christopher, Thomas, Reardon, Johan, Swinnen, and David Zilberman. 2019. Structural Transformation and Economic Development: Insights from the Agri-Food Revolution. Mimeographed.
- Beegle, Kathleen, Aline, Coudouel, and Emma, Monsalvo. Eds. 2018. *Realizing the Full Potential of Social Safety nets in Sub-Saharan Africa*. World Bank Group: Washington D.C.
- Beegle, Kathleen, and Christiaensen, Luc. 2019. Eds. *Accelerating Poverty Reduction in Africa*. World Bank Group: Washington D.C.
- Carolan, Michael. 2020. Automated Agrifood Futures : Robotics, Labor and the Distributive Politics of Digital Agriculture. *The Journal of Peasant Studies* 47-1: 184-207.
- Cazzuffi, Chiara, Mariana, Pereira-Lopez, and Isidro, Soloaga. 2017. Local Poverty Reduction in Chile and Mexico: The Role of Food Manufacturing Growth. *Food Policy* 68: 160-185.
- CBS Sacramento. 2017. *California Farmers Facing Labor Shortage Amid Immigration Changes*. Retrieved from Youtube.com: <https://www.youtube.com/watch?v=LtE6qW4ugh0>.
- Charlton, Diane. 2019. *Development of Agricultural Supply through Structural Changes in Labor Inputs* (Working Paper). Retrieved from the UC Davis Farm Labor website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Diane%20Charlton%3B%20Ag%20Supply%20and%20Labor.pdf>.

- Charlton, Diane and Taylor, J. Edward. 2016. A Declining Farm Workforce: Analysis of Panel Data from Rural Mexico. *American Journal of Agricultural Economics*. 98 (4): 1158-1180.
- Charlton, Diane, Taylor, J. Edward, Vougioukas, Stavros, and Rutledge, Zachariah. 2019. Innovations for a Shrinking Agricultural Workforce. *Choices*, 34(2).
- Christiaensen, Luc. 2013. *When China Runs Out of Farmers*. In Barrett, C.B., 2013. Food Security and Socio-political Stability. Oxford University Press
- Christiaensen, Luc, and Martin, Will. 2018. Agriculture, Structural Transformation, and Poverty Reduction: Eight New Insights. *World Development* 109: 413-416.
- Christiaensen, Luc, and Brooks, Karen. 2019. *In Africa, More Not Fewer People Will Work in Agriculture*. Consultative Group for International Agricultural Research (CGIAR) [blog]. <https://pim.cgiar.org/2018/11/21/in-africa-more-not-fewer-people-will-work-in-agriculture>.
- Christiaensen, Luc. 2020. Agriculture, Jobs and Value Chains in Africa. Jobs Group, World Bank. Mimeographed.
- Coatney, Kathy. 2006. The Machine that Revolutionized a Harvest. *Ag Alert*, March 15, <http://www.agalert.com/story/?id=554>.
- De Brauw, A., Li, Q., Liu, C., Rozelle, S. and Zhang, L., 2008. Feminization of agriculture in China? Myths surrounding women's participation in farming. *The China Quarterly*, 194, pp.327-348.
- De Gorter, Harry, Dusan, Dabrik and David, Just. 2015. The Economics of Biofuel Policies – Impacts on Price Volatility in Grain and Oilseed Markets. Palgrave Studies in Agricultural Economics and Food Policy. Palgrave Macmillan US.
- De Janvry, Alain, Claire Duquennois, and Elisabeth Sadoulet. 2018. Labor Calendars and Rural Poverty: A Case Study for Malawi. *Working Paper*, University of California, Berkeley.
- Diao, Xinshen, Silver, Jed, Takeshima, Hiroyuki, and Zhang, Xiaobo. Forthcoming. "Introduction." In *A New Paradigm of Agricultural Mechanization Development: How Much Can Africa Learn from Asia?* edited by Xinshen Diao, Hiroyuki Takeshima, and Xiaobo Zhang.
- Dolislager, Michael, Reardon, Thomas, Arslan, Aslihan, Fox, Louise, Liverpool-Tasie, Saweda, Sauer, Christine, and Tschirley, David. 2019. Youth Agrifood System Employment in Developing Countries: A Gender-Differentiated Spatial Approach. *International Fund for Agricultural Development (IFAD) Research Series*, No 43.
- Donaldson, Maggy. 2015. French Farmer: Without Migrants, European Agriculture Will Not Survive. *Quartz*, Oct. 7.
- Edwards, Ryan B. 2019. *Spillovers from Agricultural Processing* (Working Paper). Retrieved from author's personal

website:https://static1.squarespace.com/static/57d5edcf197aea51693538dc/t/5cd219f5971a184ca3bad7e1/1557273102948/aps_1905_compressed.pdf.

- Fan, M., Gabbard, S., Pena, A. A., and Perloff, J. M. 2015. Why Do Fewer Agricultural Workers Migrate Now? *American Journal of Agricultural Economics*, 97(3):665–679.
- Filipski, Mateusz, Lee, Hak Lim, Hein, Aung, and Nischan, Ulrike. 2019. Emigration and Rising Wages in Myanmar: Evidence from Mon State. *The Journal of Development Studies*. DOI:10.1080/00220388.2019.1626834.
- Fisher, D. U., and Knutson, R. D. 2012. Uniqueness of Agricultural Labor Markets. *American Journal of Agricultural Economics*, 95(2):463–469.
- Fox, Louise. 2019. Economic Participation of Rural Youth: What Matters? *International Fund for Agricultural Development (IFAD) Research Series*. No. 46
- Fox News. 2017. Immigration Raids Leading to Farming Labor Shortages? Feb 21. Retrieved from Youtube.com: <https://www.youtube.com/watch?v=bd0ect-9hBE>.
- Fuglie, Keith, Gautam, Madhur, Goyal, Aparajita, and Maloney, William. 2020. *Harvesting Prosperity – Technology and Productivity Growth in Agriculture*. World Bank Group: Washington D.C.
- Ugo Gentilini, Truman G. Packard, Margaret E Grosh. 2019. *Protecting All: Risk Sharing for a Diverse Diversifying World of Work*. Washington DC: The World Bank; <https://www.worldbank.org/en/topic/socialprotectionandjobs/publication/protecting-all-risk-sharing-for-a-diverse-and-diversifying-world-of-work>.
- Glaister, Dan. 2006. US Crops Left to Rot as Mexicans Leave the Fields for Better Paid Jobs. *The Guardian*. February 3, 2006. Retrieved from: <https://www.theguardian.com/world/2006/feb/04/usa.uk>.
- Gollin, Douglas, Lagakos, David, and Waugh, Michael E. 2014. “The Agricultural Productivity Gap” *Quarterly Journal of Economics* 129-2: 939-993.
- Gollin, Douglas, and Udry, Christopher. 2019. “Heterogeneity, Measurement Error, and Misallocation: Evidence from African Agriculture.” *NBER Working Paper 25440*, National Bureau of Economic Research, Cambridge, MA.
- Gulati, Kajal, Ward, Patrick S., Lybbert, Travis J., Spielman, David J. 2019. *Intrahousehold Valuation, Preference Heterogeneity, and Demand for an Agricultural Technology in India* (Working Paper). Retrieved from the University of California’s Escholarship website: <https://escholarship.org/content/qt6r15m8mp/qt6r15m8mp.pdf>.
- Hassan, Fuad, and Kornher, Lukas. 2019. *Let’s Get Mechanized – Labor Market Implications of Structural Transformation in Bangladesh* (Working Paper). Retrieved from the UC Davis Farm Labor website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Fuad%20Hassan%3B%20Technology.pdf>.

- Hicks, J. H., M. Kleemans, N. Y. Li, and E. Miguel. 2017. "Reevaluating Agricultural Productivity Gaps with Longitudinal Microdata." NBER Working Paper 23253, National Bureau of Economic Research, Cambridge, MA. doi: 10.3386/w23253.
- Hill, Alexandra. 2019. *The Labor Supply of U.S. Agricultural Workers* (Working Paper). Retrieved from UC Davis Farm Labor website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Ali%20Hill%3B%20US%20Labor%20Supply.pdf>.
- Huang, Jikun. 2016. "Fostering Inclusive Rural Transformation in China and Other Developing Countries in Asia." Presentation at the Latin American Center for Rural Development (RIMISP) International Conference on Territorial Inequality and Development, Puebla, Mexico, January 25–27.
- Ifft, Jennifer, and Jodlowski, Margaret. 2016. Is ICE Freezing US Agriculture? *Impacts of Local Immigration Enforcement on US Farm Profitability and Structure* (AAEA Conference Paper). Retrieved from Ideas: <https://ideas.repec.org/p/ags/aea16/235950.html>.
- Ingelaere, Bert, Luc Christiaensen, Joachim De Weerd, and Ravi Kanbur. 2018. "Why Secondary Towns Can Be Important for Poverty Reduction: A Migrant Perspective." *World Development* 105: 273–82.
- IFAD. 2019. Rural Development Report: Creating Opportunities for Rural Youth. *International Fund for Agricultural Development (IFAD)*: Rome.
- Kangasniemi, Mari, Marco, Knowles, and Panagiotis, Karfakis. 2020. The Role of Social Protection in Inclusive Structural Transformation. Food and Agriculture Organization: Rome.
- Kar, Anuja; Slavchevska, Vanya; Kaaria, Susan; Taivalmaa, Sanna Lisa; Mane, Erdgin; Ciacci, Riccardo; Hoberg, Yurie Tanimichi; Townsend, Robert; Stanley, Victoria. 2018. Male Outmigration and Women's Work and Empowerment in Agriculture: The Case of Nepal and Senegal (English). Washington, D.C.: World Bank Group. <http://documents.worldbank.org/curated/en/653481530195848293/Male-outmigration-and-womens-work-and-empowerment-in-agriculture-the-case-of-Nepal-and-Senegal>.
- Kim, Jeongha. 2019. *Innovative Technology in the Agricultural Sector: Opportunities for Green Jobs or Exacerbation of Rural Youth Unemployment* (Conference Paper). Retrieved from the UC Davis Farm Labor website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Jeongha%20Kim%3B%20Ag%20Tech.pdf>.
- Kirui, Oliver K. 2019. The Agricultural Mechanization in Africa: Micro-Level Analysis of the State Drivers and Effects. *ZEF-Discussion Papers on Development Policy*, No. 272.
- Kostandini, Genti, Mykerezi, Elton, and Escalante, Cesar. 2013. The Impact of Immigration Enforcement on the U.S. Farming Sector. *American Journal of Agricultural Economics*, 96(1):172–192.

- Kramer, Berber, and Lambrecht, Isabel. 2019. Gender and Preferences for Non-Farm Income Diversification: A Framed Field Experiment in Ghana. *International Food Policy Research Institute (IFPRI) Discussion Paper*, No. 1855. Retrieved from Social Science Research Network website: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3430750.
- Lewis, W. Arthur. 1954. Economic Development with Unlimited Supplies of Labor. *Manch. Sch.*, 22(2): 139-191.
- Liu, Yanyan, Barrett, Christopher B., Pham, Trinh, and Violette, William. 2019. The Intertemporal Evolution of Agriculture and Labor over a Rapid Structural Transformation: Lessons from Vietnam (Conference Paper). Retrieved from UC Davis Farm Labor website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Liu%20et%20al%20Vietnam%2014%20Mar%202019.pdf>
- Maertens, Miet and Fabry, Anna. 2019. *Creating More and Better Jobs in Global Value Chains* (Conference Paper). Retrieved from UC Davis Farm Labor website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Miet%20Maertens%3B%20Global%20Value%20Chains.pdf>.
- Maïga, Eugenie, Christiaensen, Luc, and Palacios-Lopez, Amparo. 2015. *Are the Youth Exiting Agriculture en Masse?* (Working Paper). Retrieved from: https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=CSAE2016&paper_id=746.
- Martin, Philip L. 2017. Immigration and Farm Labor: Challenges and Opportunities. *Giannini Foundation Information Series*: 18(1).
- McCullough, Ellen. 2017. "Labor Productivity and Employment Gaps in Sub-Saharan Africa." *Food Policy* 67: 133–52.
- Mosqueda, E., R. Smith, D. Goorahoo, and Shrestha, A. 2017. Automated Lettuce Thinners Reduce Labor Requirements and Increase Speed of Thinning. *California Agriculture*, 72(2):114–119.
- Packard, Truman, Ugo, Gentilini, Margaret, Grosh, Philip O’Keefe, Robert, Palacios, David, Robalino, and Indhira Santos. 2019. *Protecting All: Risk Sharing for a Diverse Diversifying World of Work*. World Bank Group: Washington D.C.
- Preston, Julia. 2006. Pickers Are Few, and Growers Blame Congress. *The New York Times*, Sept. 22.
- Restuccia, D., D. T. Yang, and X. Zhu. 2008. "Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis." *Journal of Monetary Economics* 55 (2) 234–50. <https://doi.org/10.1016/j.jmoneco.2007.11.006>.
- Rutledge, Zachariah, and Taylor, J. Edward. 2019. "California Farmers Change Production Practices as the Farm Labor Supply Declines." *ARE Update*, 22(6).

- Rutledge, Zachariah, Taylor, J. Edward, Neagu-Reed, Sara, Little, Bryan, and Kranz, David. 2019. Still Searching for Solutions: Adapting to Farm Worker Scarcity Survey 2019. California Farm Bureau Federation, News Release.
- Sauer, Christine, Dolislager, Michael, and Reardon, Thomas. 2019. *Spatialized Links Between the Afri-Food System and Employment in Tanzania* (Working Paper). Retrieved from the UC Davis Farm Labor Website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/luc%20Sauer%20Dolislager%20et%20al%20march19%202019%20final%20sent%2010h24est.pdf>.
- Slavchevska, V., Kaaria, S. and Taivalmaa, S.L., 2019. The Feminization of Agriculture. *The Oxford Handbook of Food, Water and Society*, p.268.
- Scholgl, Lukas, and Andy Sumner. 2020. Disrupted Development and the Future of Inequality in the Age of Automation and Structural Transformation in Developing Countries, pp. 51-78, Rethinking International Development Series: Palgrave Macmillan
- Swinnen, Johan, and Rob Kuijpers. 2017. “Inclusive Value Chains to Accelerate Poverty Reduction in Africa.” Background note prepared for *Accelerating Poverty Reduction in Africa*, World Bank, Washington, DC.
- Swinnen, Johan, Kristine, Van Herck, and Thijs, Vandermoortele. 2012. The Experience Economy as the Future for European Agriculture and Food? *Bio-based and Applied Economics* 1-1: 29-45.
- Takahashi, Kazushi, Rie, Muraoka, and Keijiro, Otsuka. 2020 Technology Adoption, Impact, and Extension in Developing Countries’ Agriculture: A Review of the Recent Literature. *Agricultural Economics* 51: 31-45.
- Taylor, J. Edward. 1999. The New Economics of Labour Migration and the Role of Remittances in the Migration Process. *International Migration* 37(1), pp.63-88, <https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-2435.00066>.
- Taylor, J. Edward, and Charlton, Diane. 2018. *The Farm Labor Problem: A Global Perspective*. Amsterdam: Elsevier Academic Press.
- Taylor, J. E., Charlton, D., and Yúnez-Naude, A. 2012. The End of Farm Labor Abundance. *Applied Economic Perspectives and Policy*, 34(4):587–598.
- Timmer, C. Peter (1988). The Agricultural Transformation. *Handbook of Development Economics*, Volume 1: 275-331.
- United Nations Food and Agricultural Organization (FAO, nd). Is there a “Feminization” of Agriculture and the Rural Economy in Latin America? <http://www.fao.org/3/y4940e07.htm>.

Vougioukas, Stavros, and Fountas, Spyros. 2019. *Smart Automation in the Agri-Food Chain. State of the Art, Prospects, and Impacts on Workforce Demands* (Working Paper). Retrieved from the UC Davis Farm Labor Website: <https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Paper%20Vougioukas%20Fountas.pdf>.

Yang, Jin, Huang, Zuhui, Zhang, Xiaobo, and Reardon, Thomas. 2013. The Rapid Rise of Cross-regional Agricultural Mechanization Services in China. *American Journal of Agricultural Economics* 95, no. 5: 1245-1251, <https://academic.oup.com/ajae/article/95/5/1245/48870>.

World Bank and the International Fund for Agriculture Development. 2017. Rural Youth Employment. Paper prepared as input document for the G20 – Development Working Group. https://www.researchgate.net/publication/322578396_Rural_Youth_Employment

World Bank. 2019. World Development Report 2018: Learning to Realize Education’s Promise. World Bank Group: Washington D.C.