CHAPTER

Evolving agricultural labor markets

77

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Chapter outline

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1 Introduction: Evolving farm labor markets

The narrative underlying this chapter, in a nutshell, is as follows.

Historically in today's high-income countries and currently in most low-income ones, agricultural employment, like crop production, is largely a family affair, centered in agricultural households. Economists going back to at least Arthur Lewis' (1954) classic work have considered the movement of workers off the farm as lying at the very heart of the development process and the so-called "agricultural transformation" (Timmer, 1988). Critical components of this transition include the shift from familial to commercial production and increased reliance on agricultural labor markets to supply workers to farms. As incomes increase, as economies become more diverse, and as domestic workers shift into off-farm work, farms have incentives to adopt labor-saving solutions and to consolidate, while seeking out new sources of farm labor. This process is well advanced in the world's high-income countries, and it is underway in developing countries across Latin America, Africa, and South Asia, where many countries now rely upon farmworkers from neighboring states. Immigration is the primary source of agricultural labor today in high-income countries, as well as in many not-so-high income ones.

As the agricultural transformation unfolds in migrant-source countries, fewer workers enter the agricultural migrant stream. In migrant-destination countries, political opposition to low-skilled immigration has reinforced socio-demographic trends in farmworker-source countries, leading to a rise in wages, localized farm labor shortages, and increased efforts to implement sophisticated labor-saving solutions, including robots in the fields.[1] This situation is currently unfolding in U.S. and European fruit, vegetable and horticultural (FVH) production.

Our chapter seeks to document the changing role of agricultural employment in developing and developed economies, drawing from a rich corpus of research offering insights into how agricultural labor markets evolve and the implications for workers, farmers, and rural economies. These studies employ a wide variety of analytical approaches. We highlight new empirical findings as well as emerging themes and policy implications.

Section 2 provides a discussion of labor demand and supply in agricultural households, which historically comprised the majority of farms in today's high-income countries and constitute the majority of crop producers in the developing world today. We define agricultural households as households that produce crops and consume all or part of their output. Most commercial family farms in developed countries sell all or nearly all of their agricultural production in markets. In developing countries, this is not the case. For example, in Sub-Saharan Africa, most agricultural households sell little, if any, of their basic grain production (Barrett, 2008).

[1]The term "low-skilled" is commonly used in the immigration literature. The term refers to individuals who have relatively low levels of formal education and are employed in occupations that tend to require a significant amount of physical effort.

Agricultural households in developing countries often have limited access to input and output markets, which has important implications for the supply and demand of farm labor. As the agricultural transformation unfolds, access to markets generally improves, and farms shift from relying primarily on family workers to employing more hired labor.

Section 3 discusses labor demand, supply, and mobility in localized, but interconnected farm labor markets characteristic of the United States and other relatively high-income countries. Most of the empirical papers we cite in this section focus on labor migration from Mexico to U.S. farms. There is a wealth of literature examining agricultural labor markets in the United States relative to other developed countries. Farm labor markets are in constant flux, with seasonally shifting labor demands, follow-the-crop migration, and increasing dependence on foreign-born agricultural workers. This section presents recent evidence of declining farm labor supplies as well as workers' willingness to engage in follow-the-crop migration.

Section 4 focuses on research efforts to estimate impacts of agricultural labor supply shocks; Section 5, on efforts to identify impacts of immigration policies; Section 6 on climate-induced migration; Section 7 on farmworker welfare; and Section 8 on early research on impacts of the COVID-19 pandemic. Ultimately, farms' ability to remain competitive depends on the development and adoption of labor-saving technologies, which take different forms in high and low-income countries. Section 9 discusses labor-saving management practices and technological change, including innovations to improve farmworker efficiency, mechanization, and the prospect of robots in the field. We conclude in Section 10 with some thoughts about future trends and research priorities, including the need to situate farm labor research within the context of the agri-food system (AFS).

2 Labor in an agricultural household

Overwhelmingly, agricultural workers around the world come from rural households (Taylor & Charlton, 2018). Rural households that engage in farm labor activities include agricultural households, which both produce and consume crops (Singh, Squire, & Strauss, 1986), and landless households that provide labor to farms, usually for a wage, and consume what they can purchase in the market. Distinguishing among rural household types has important implications for labor supply decisions. Taylor and Charlton (2018) present a textbook model of farm labor supply from both agricultural wage worker and producer households.

In an economy with well-functioning markets, where agriculture is the only production sector employing labor and households can purchase food and other goods in the market, the farm labor supply decision reduces to the standard labor supply decision covered in any microeconomics textbook. The household gains utility from consuming leisure (LE) and other goods (X) purchased in the market at a given price p. Utility maximization is subject to a time constraint (T) and a cash income constraint. There is an inherent trade-off between demanding leisure and obtaining cash to spend on non-leisure goods by working at a market wage w. The maximum cash income the household can attain is the value of its time endowment, or full income, wT. Cash and full income are the same if the household sells all of its time to the wage labor market. This would represent a corner solution, in which the household demanded no leisure at all. In real life, households allocate their full income to leisure (valued at the market wage, or opportunity cost of leisure) and purchased goods. Thus:

$$\text{Full income} = wT = wLE + pX$$

Maximizing utility subject to this full-income constraint yields the well-known condition that the marginal rate of substitution between leisure and other goods equals the negative ratio of market prices for labor (i.e., the wage) and other goods.

The comparative statics of a wage change adds a positive endowment effect to the usual Slutsky effects, resulting in an own-price (wage) elasticity of leisure demand change (and thus labor supply change) that is ambiguous. The Slutsky substitution and real-income effects of a wage change on leisure demand are both negative (and, by corollary, effects on labor supply are positive). Leisure becomes more costly relative to purchased goods (substitution effect) and real income declines when the "price" of leisure increases (real-income effect). However, a higher wage raises the value of the household's time endowment, which increases the household's demand for normal goods, including leisure. The positive endowment effect can partially or totally counteract the negative substitution and real income effects of a wage change, possibly generating a backward-bending labor supply curve.

An agricultural household model adds a profit effect to full income. Other things being equal, the profit effect of a wage change on leisure demand (labor supply) is negative (positive). This result emerges because, from the point of view of the agricultural household as a producer, labor is a cost. Farm profit decreases when wages rise, and this in turn negatively affects the demand for normal goods, including leisure. The negative profit effect on leisure demand makes it more likely that an increase in the agricultural wage will decrease an agricultural household's leisure demand, and thus increase its labor supply.

Income effects on farm labor supply appear to be empirically important. Several experimental studies of the impacts of social cash transfers (SCTs) in African countries find negative impacts of cash transfers on beneficiary households' supply of agricultural wage labor (Davis et al., 2016). Studies also find that SCTs stimulate crop production and input use, including family labor, probably by loosening liquidity constraints. In effect, exogenously raising incomes in poor rural households encourages beneficiaries to shift from wage work to family production activities. Together with an increase in local food demand when poor-household incomes rise, this can put moderate upward pressure on local wages (Davis et al., 2016; Filipski, Thome, Taylor, & Davis, 2015).

Agricultural households' demand for labor, like other inputs, is determined by profit-maximization criteria. When agricultural households are price takers in local or regional markets, including for wages, the agricultural household model is said to be separable or recursive. That is, production decisions are separate from consumption decisions. The demand for variable inputs, including labor, depends on crop output and input prices (including the wage), capital (assumed fixed in the short run), and technology (embodied in the production function), like in a conventional producer model. Consumption depends on production, however, because farm profit is part of the full income constraint. Shocks to the crop output price and/or wage affect consumption in an agricultural household model both directly and indirectly via the profit effect. As a producer, an agricultural household loses when the farm wage increases, because of the profit effect. As a consumer, it may win or lose. On one hand, a higher wage reduces farm profit and raises the opportunity cost of leisure, but on the other, it increases the value of family time (the time endowment effect). Generally, if the household is a net seller of labor, supplying more labor than it demands for its crop production, it will benefit from a positive agricultural wage shock. If the household is a net buyer of agricultural labor, demanding more labor than it supplies, it will be worse off. It is easy to see this at the extremes: a pure wage laborer household wins while a pure agricultural firm loses when the farm wage increases.

In an agricultural household, not only wage shocks but also price shocks potentially lead to changes in the supply and demand for agricultural family and wage labor. With perfect agricultural labor markets and perfect substitutability between family and hired labor, the agricultural household is indifferent between working on and off the farm and between employing its own or hired labor on the farm.

Farm labor supply in an agricultural household model with imperfect access to consumer or labor markets is more complex. If hired labor is not a perfect substitute for family labor, production and consumption decisions are inseparable; household-specific "shadow prices" and/or "shadow wages" link the two sides of the model, transmitting impacts from one to the other. For example, in the case of a missing labor market, the agricultural household must supply all of its labor needs and cannot sell its labor for a wage. This creates an inherent trade-off between agricultural production and leisure: other things being the same, the household cannot increase its leisure demand (reduce its labor supply) without sacrificing its crop output. Similarly, a missing product market forces the household to satisfy its consumption demand from its own production. In either case, the shadow prices linking supply and demand within the agricultural household reflect household characteristics and preferences, making the model inseparable. This idea was the basis for Benjamin's (1992) test for separability in an agricultural household model, which investigates whether household demographics affect labor demand. Failures in other markets (e.g., credit) can affect labor demand and supply in agricultural households. For example, a household without the liquidity to pay wages may be forced to rely solely on family labor for production. In this way, effects of failures in other markets can mimic effects of labor market failures, and it is far more difficult to ascertain the causes of inseparability than to test for separability.

Even in the United States, there is some evidence that family farms supply more of their own labor to agricultural production when there is an adverse shock to hired farm labor supply (Luo, Kostandini, & Jordan, 2018). This finding suggests that farm households in developed countries may not always have perfect access to labor markets. Nevertheless, we generally assume that there are well-functioning input and output markets in developed countries.

If there are other variable (fixed) inputs in the crop production function, their prices (quantities) also potentially affect farm labor demand as well as supply. If capital and labor are complements (substitutes), then increased capital investment will increase (decrease) the marginal product of labor. Labor-saving technology change can enable farm households to increase production while freeing up time for leisure or wage work, including migration off the farm (Lele & Mellor, 1981).

There are a few notable economic studies that investigate the effects of shocks to input prices, including wages, on the demand for agricultural inputs, including labor. For example, Beaman, Karlan, Thuysbaert, and Udry (2013) find that women who received free fertilizer in a randomized experiment in Mali increased complementary inputs of hired labor and herbicides. Learning, or accumulation of human capital, can also be an important complementary input to new capital and technologies in agricultural production (see for example, Foster & Rosenzweig, 1996). Social networks, which can sometimes be gender specific, also may play a role in the decision to adopt new technologies (Conley & Udry, 2001, 2010; Vasilaky & Leonard, 2018).

2.1 Gender considerations

Heterogeneous returns to labor and differential access to resources can affect the farm labor supplies of individual household members. Udry (1996) finds that productive resources were allocated inefficiently across farm plots worked by men and women from the same households in Burkina Faso. Yields per acre of identical crops were 30% lower in plots managed by women even though women's and men's labor appeared equally productive when combined with the same non-labor inputs. The yield difference was attributed to under-application of fertilizer, as well as labor, on women's plots. Andrews, Golan, and Lay (2015) find a similar result in Uganda. In Tanzania, Slavchevska (2015) finds lower returns to factors, including male labor on female-managed plots, and concludes that increasing women's access to better factors of production alone would be insufficient to close the agricultural productivity gender gap. Akresh (2005) argues that differences in the productivity of male and female managed plots may be due to differences in transaction costs or the costs of monitoring labor over geographically dispersed areas; thus, differences in agricultural inputs may not be indicative of Pareto inefficient behavior. However, Akresh finds that households in Burkina Faso allocate resources more efficiently across male and female managed plots when they experience negative rainfall shocks, possibly because inefficiencies have more severe consequences in the presence of such shocks.

Numerous variables may affect the returns to labor and other inputs across male and female managed plots within the same household, including household structure (e.g., polygamous, monogamous, or multigenerational), traditions, norms, and customs (Slavchevska, 2015). Estimates of the substitutability of male and female labor on farms vary within countries. Oseni, Corral, Goldstein, and Winters (2015) find that, in Southern Nigeria, women would be as productive managing agricultural plots as men if they received equal inputs. In Northern Nigeria, however, women produced an estimated 28% less than men on average after controlling for observable factors of production.

Division of tasks between men and women within households is common. Jacoby (1992) finds evidence from Peru that women's labor was more productive in livestock production, whereas men's was more productive in crop production. Elad and Houston (2002) find that men and women divided agricultural tasks in Cameroon, the men clearing and preparing land for cultivation and the women harvesting the crops. Thus, women's production decisions in Cameroon depended critically on the availability of men's labor prior to the harvesting season. Filipski, Aboudrare, Lybbert, and Taylor (2017) find that saffron production in Morocco's Taliouine–Taznakht region entailed a stark gender division of labor, with men specializing in cultivation of the crocus flowers and women in removing the stigmas from the flowers. Women's wage income was found to be over three times more sensitive to changes in global saffron prices than men's wage income.

2.2 Rural labor becomes less agricultural

As economies evolve, non-farm production and employment expand—including in rural areas (Reardon, 1997). Many agricultural and wage labor households diversify their income sources away from staple production into other crops and activities, including non-farm wage work, and agricultural production becomes more reliant on purchased inputs, including hired labor. Over time, markets generally expand, and transport of goods and workers becomes more efficient. Agricultural households become rarer; large family farms or corporate farms with large economies of scale often hold a competitive advantage.

For example, rural Mexico supplies the majority of hired farmworkers to the United States as well as to Mexican agriculture. Nevertheless, by 2007, crop production plus local agricultural wages accounted for only 22% of total income in rural Mexican households, and rural households' nonfarm production plus local nonagricultural wages accounted for 44% (Arslan & Edward Taylor, 2012).[2] An examination of nearly 100 studies by Reardon et al. in 1998 finds that an average of 42% of rural total income in Africa was from nonfarm sources. The comparable numbers for Latin America and Asia were 40% and 32%, respectively. A study of a random sample of village households in northern China finds that nonfarm income (including remittances from rural-to-urban migrants) accounted for over 60% of rural total household income there (Taylor, Rozelle, & De Brauw, 2003).

These findings, consistent across countries, have several important implications for modeling agricultural labor markets. First, they complicate the labor supply decision in agricultural households, which overwhelmingly are engaged in multiple

[2]Remittances from migrants working in the United States accounted for 14% of total rural household income. Most international migrants from rural Mexico have nonfarm jobs in the United States.

production and work activities. Second, labor supply becomes decoupled from agricultural labor supply by the addition of nonfarm wage work—often involving migration—to the mix. Labor migration, internal or international, to farm or nonfarm work, expands the set of work options available to many rural households in the world while reallocating labor from farm to non-farm pursuits. Third, incentives and pressures build for agricultural producers to adapt by implementing labor-saving solutions, from tractors and harvesters to herbicides, and shifting from familial to commercial production. In this process, family migrants can play the role of financial intermediaries by providing liquidity and income insurance to their families' farms (Taylor & Castelhano, 2016).

Empirical findings on effects of labor migration on the productivity of migrant-sending agricultural households are mixed. Lucas (1987) finds that labor migration from rural households across southern Africa to South African mines generally had negative effects on household agricultural productivity, but these effects were partially offset when migrants sent home remittances. Rozelle, Taylor, and DeBrauw (1999) find similar outcomes in a study of migrant-sending agricultural households in rural China. Böhme (2015) finds that labor migration increases household investments in livestock and productive farm capital in Mexico. Gibson, McKenzie, and Stillman (2013) find positive effects of labor migration on the agricultural incomes of migrant-sending households in Samoa. They use a unique identification strategy leveraging exogenous selection into labor migration through a lottery system that permitted a select number of Samoans to migrate to New Zealand and become permanent residents. However, the effects of labor migration on agricultural productivity diminished each year after the initial migration. In a study of a similar lottery system that selected individuals to migrate from Tonga to New Zealand, Gibson, McKenzie, and Stillman (2011) find no effects of labor migration on agricultural incomes of migrant-sending households. Garip (2014) finds that losses from reduced household labor were larger on average than the gains from remittances and related investments for wealthier households in a sample of rural villages in Nang Rong, Thailand. However, poorer households more frequently experienced net gains from labor migration. Taylor and Lopez-Feldman (2010), using an endogenous-switching regression approach, find evidence that migration to the U.S. raised land productivity in rural Mexico.

As these studies suggest, impacts of migration on agricultural productivity reflect both lost-labor and remittance effects. Incentives for migrants to send remittances vary. Migrants from the Dominican Sierra remitted both to provide insurance for their parents and to invest in future productivity of the farm. However, male migrants were less likely than females to remit for insurance purposes (De la Briere, Sadoulet, de Janvry, & Lambert, 2002). Stark and Taylor (1989) find that some households in rural Mexico engaged in labor migration to improve their economic standing compared to their neighbors. Controlling for absolute income, relatively deprived households were more likely to send migrants to the United States (Stark & Taylor, 1991). In short, a variety of household and community variables can influence patterns of agricultural investment and productivity through labor migration and remittance decisions.

2.3 Seasonality of agricultural employment

The seasonality of farm production, and thus farm labor demand, creates livelihood challenges in rural economies with few other occupational prospects. Migration to urban centers plays a critical role in many households' survival through the lean season. Income and consumption in agricultural households often are lowest just prior to harvest, when work opportunities are few and grain prices high (Khandker, 2012). In Northern Bangladesh, the season just prior to harvest is called the Monga and is frequently characterized by famine (Bryan, Chowdhury, & Mushfiq Mobarak, 2014; Khandker, 2012). Income diversification could help reduce the incidence of seasonal poverty and potential starvation, but the non-farm sector in agrarian communities often is linked to agricultural activities; thus, labor opportunities are scarce (Khandker, 2012).

Given the scarcity of work in agrarian communities during the lean season, it might be profitable for many rural workers to migrate seasonally to urban centers where non-farm jobs are more plentiful. Bryan et al. (2014) investigate this potential consumption smoothing strategy by randomly providing households in rural Bangladesh with cash and credit incentives to cover the round-trip cost to the city conditional on a household member migrating during the Monga season. Their experiment induced labor migration that, in turn, increased food and non-food expenditures in migrants' rural households by 30–35%. Treatment households continued to migrate at higher rates in subsequent seasons.

Given positive returns to seasonal labor migration, Bryan et al. (2014) ask why households did not previously engage in this profitable labor market "technology" prior to receiving incentives. They conclude that migration is a risky activity, and the risk is greater the closer the household is to subsistence. Migrating to a new city entails unknowns, and failure could have drastic consequences for such households. The households least likely to migrate prior to the experiment were those nearest subsistence. Households nearest subsistence also were most responsive to the intervention, and individuals needed to learn about migration personally to discover whether it is economically beneficial. Insuring or subsidizing labor migration could enable individuals to learn about migration and increase the welfare of agricultural households.

An alternative strategy is to create new jobs in rural areas capable of sustaining employment and consumption during the lean season. Governments throughout the world have implemented programs to increase rural work opportunities. The largest such program is the National Rural Employment Guarantee Scheme (NREGS), implemented in communities in India as early as 2005.[3] The objective of this program is to provide public works employment for people involuntarily unemployed during the agricultural lean season or those seeking escape from a cycle of poverty and debt (Basu, 2013). Imbert and Papp (2015) find that NREGS increased rural employment in public works and raised private sector wages. There was little change in

[3]NREGS was later renamed the "Mahatma Gandhi National Rural Employment Guarantee Act" or "MGNREGA."

the number of workers who reported being unemployed, suggesting that the program likely increased the marginal product of labor and reduced the hours that workers toiled on farms. There is also evidence of medium-term positive returns to agricultural productivity through public works projects that benefit farms, such as irrigation (Deninger & Liu, 2019).

Guaranteed employment programs such as NREGS can have myriad economy-wide impacts on rural communities and households, including changes in income distribution and children's schooling. For example, Imbert and Papp (2015) report positive welfare effects of NREGS for the poorest workers in the community and negative welfare effects for the wealthier members of the community who act as employers, inasmuch as NREGS increases private sector wages. Basu and Chau (2004) find evidence that NREGS alleviates debt-bondage for children and adults. There is also evidence that NREGS diminishes the adverse effects of negative weather shocks on children's schooling (Ajefu & Abiona, 2019; Foster & Gehrke, 2017). However, Ajefu and Abiona (2019) find that NREGS generally leads to less schooling and increased hours of work for older children, for whom the returns to labor rise after NREGS is introduced. Finally, NREGS reduces households' need to participate in seasonal labor migration (Das, 2015).

3 Farm labor demand, supply, and mobility

3.1 The problem of farm labor demand

The seasonality and uncertainties of crop production and labor demand have important implications for commercial producers, as well as agricultural households. The production of FVH products is particularly labor-intensive. Most fruits and vegetables are still harvested by hand, and fruit trees are often pruned by hand, but workers are not needed to perform the same intensity of tasks year-round.

Agricultural labor demand is fraught with uncertainty. Crops do not ripen at the same time each year, and yields vary from one year to another. Simulations using multi-stage production functions reveal that weather shocks early in the growing season can lead to disproportionately large variations in labor demand at harvest time (Taylor, 2010). The timing of farm labor demand and the number of workers needed on each farm each year can be difficult to predict.

If commodity prices fall, or if pests or poor weather conditions diminish the quality of the produce, the marginal value product of labor shifts inward, reducing labor demand. These factors vary widely across regions as well as across seasons. Imagine, for example, that there is a major freeze in Florida destroying citrus crops and driving the marginal value product of labor in a Florida orange grove to zero. However, due to the anticipated shortage of fresh oranges, the price of California oranges increases, and the marginal value product of citrus labor in California shifts outward. Farmworkers in Florida cannot easily move to California to fill seasonal jobs.

With or without weather shocks, as the crop season progresses, seasonal labor demands vary (in the Western United States, typically shifting northward). Labor demand shifts inward in some localities and outward in others. As a result, most FVH farms require workers who are mobile, that is, willing to move from one farm to another as labor demands change throughout the year. Follow-the-crop migration links multiple localized farm labor markets, enabling local labor supplies to shift in tandem with local labor demands (Taylor & Charlton, 2018, Chapter 4). In Mexico, export-oriented agriculture, which is critical in supplying U.S. produce markets during winter months, draws workers from poor mountainous areas and from southern Mexico (Escobar, Martin, & Stabridis, 2019). High worker mobility makes it possible to satisfy a given pattern of localized seasonal labor demands with a smaller total agricultural labor supply than otherwise would be possible. However, disruptions in follow-the-crop migration, for example, due to a late harvest in one locality, can create labor shortages in other localities even if the total farm labor supply is sufficient to meet all labor demands in a normal crop year.[4] Similar seasonal phenomena in developing countries can sometimes lead to famine in the absence of labor migration, as mentioned in the preceding section.

The seasonality of labor demand creates challenges for workers as well as farmers. Farmworker earnings may not amount to very much over the course of a year, even if the hourly wage is competitive with other industries. Given seasonal and geographically-shifting labor demands, combined with the drudgery of farm work (at least with existing technologies) and low wages (a reflection of low worker productivity), it is not surprising that domestic workers move out of farm jobs as opportunities open up for them in other sectors of the economy. In virtually all high-income countries and many middle-income ones, immigrants fill the void.

Martin and Taylor (2003) show that U.S. agricultural employment increased the incidence of poverty by attracting immigrant farmworkers, who are mostly unauthorized immigrants from rural Mexico, to fill a growing number of low-wage seasonal jobs in the late 20th Century. Using a simultaneous-equation econometric model with census tract data from multiple censuses, they show that agricultural employment and new immigration to rural counties in the United States reinforced one another between 1970 and 1990. From 1970 to 1980, farm employment reduced rural poverty rates, as many single, young workers came to the United States to perform farm work, often returning to Mexico at the end of the crop season. However, this pattern changed from 1980 to 1990. Beginning in the 1980s, both farm employment and immigration increased rural poverty rates, as immigrant farmworkers began to settle in the communities where they found jobs, often joined by other family members from Mexico. Seasonal farm work was inadequate to pull workers and their families out of poverty, so farm employment growth redistributed poverty from rural Mexico to the rural United States.

[4] An often-cited example is the *New York Times* front-page coverage of pears rotting in the orchards of Lake County, California, due to a labor shortage resulting from a late harvest in Sacramento County, to the south (Preston, 2006).

This phenomenon is not isolated to FVH employment. For example, the U.S. meatpacking industry employs almost exclusively immigrants, pays poor wages, and generally involves considerable health and safety risks. As the meat processing industry vertically integrated in the United States, meat processing facilities moved to rural U.S. towns in the Midwest and South. These facilities attracted numerous immigrants into formerly ethnically homogenous communities, since domestic workers generally were not interested or willing to work in meatpacking. From 1980 to 2002, average real hourly wages in meatpacking dropped from \$10.30 to \$6.46 (1982–1984 dollars), line speeds nearly doubled, and labor turnover rates and injuries rose (Champlin & Hake, 2006). Despite the economic importance of meatpacking in the rural United States, there are relatively few studies examining labor markets and working conditions in this industry, making this a high-priority research area.

In the early part of the 20th century, Southern plantation owners in the United States hired black workers to keep farm wages low (wages paid to black workers were lower than those paid to whites). They offered these workers non-pecuniary benefits, including protection from abusive, discriminatory actions from other local residents, to entice them to remain at their plantations. However, many workers were displaced from their homes by the Great Mississippi Flood of 1927, thus losing non-pecuniary benefits that their employers had used to gain their loyalty. Many black workers migrated to the North, where they hoped to receive higher wages doing non-farm work. Southern plantations in the flood zone consolidated and adopted more capital-intensive production practices as the low-wage labor supply shifted inward (Hornbeck & Naidu, 2014). These findings, combined with those of Martin and Taylor (2003), illustrate how an abundant labor supply can keep farmworkers in poverty and discourage the adoption of labor-saving technologies (see also Anand & Kanbur, 1993; Kuznets, 1955). Conversely, reduced availability of low-wage workers can stimulate economic development via capital investments that increase the marginal product of labor (Acemoglu, 2010).

3.2 Diminishing farm labor supply

The movement of labor off the farm is a fundamental feature of the agricultural transformation (Timmer, 1988). Arthur Lewis (1954) modeled a two-sector economy in which increased capital investment in the manufacturing sector boosted the marginal product of labor in manufacturing and drew workers away from the farm sector. However, Barrett, Reardon, Swinnen, and Zilberman (2020) argue that simplified two-sector models overlook the important role of expanding agri-food value chains in the agricultural transformation. In the United States, the agricultural share of Gross Domestic Product (GDP) shrank from 8.5% in 1929 to 0.7% in 2017, and over the same time range the farm share of consumer food expenditures fell from 40% to 50% to less than 15%. In low- and middle-income countries today, the farm share of consumer expenditures is falling rapidly as the agricultural transformation unfolds, while agri-food value chains play an increasingly important role. Barrett et al. (2020)

contend that agri-food value chains create a critical entry point for foreign direct investment, facilitate technology transfer, generate foreign exchange, and employ a much larger workforce than the farm sector does as economies grow. Studies of farm labor markets would benefit from a more holistic view of the evolving agri-food system in the context of the agricultural transformation (Christiaensen, Rutledge, & Taylor, 2020).

The agricultural transformation has complex welfare effects on farm and non-farm households. Ma, Lin, and Sexton (2021) find negative welfare effects for small-holder farm households, positive effects for urban dwellers, and net positive income effects across the pooled population in their simulation of the conversion from small-holder farming to more consolidated commercial farming of domestic staple crops in low- and middle-income countries. These findings suggest that a Pareto efficient outcome is possible via income transfers, but consolidation of farming during the agricultural transformation does not necessarily benefit everyone—at least not in the short run.

Liu, Barrett, Pham, and Violette (2020) find income growth in both farm and non-farm sectors as a result of rapid structural transformation in Vietnam from 1992 to 2016, but there was relatively little farm consolidation in this context. They find decreases in the share of farming households, the share of agricultural labor within farming households, and the agricultural share of rural-household income. They also find that increasing education led to real wage growth in both the farm and nonfarm sectors, small landholdings did not inhibit mechanization, and human capital accumulation became an increasingly important factor in household wellbeing as the agricultural transformation progressed. In Myanmar, labor migration combined with agricultural mechanization increased real rural wages, improving the economic well-being of the landless poor (Belton & Filipski, 2019). Restuccia, Yang, and Zhu (2008) emphasize the importance of removing barriers to adoption of modern agricultural inputs in poor countries as the agricultural transformation takes place.

Historically, many countries have attempted to usher in economic development by pursuing policy reforms that promote employment in the industrial sector. However, investment in industrial employment without complementary investments in agricultural productivity can lead to food price inflation that stalls economic development (Johnston & Nielsen, 1966; Lele & Mellor, 1981). This finding underlines the importance of increasing agricultural productivity as an economy's industrial sector expands (Johnston & Mellor, 1961; Ohkawa, 1961; Timmer, 1988). Higher productivity in agriculture can raise rural wages and rural households' demand for manufactured goods while freeing up labor from food production and rechanneling it to sectors with greater labor productivity (Gollin, Parente, & Rogerson, 2002).

The distributive bias of technological change is of critical importance in shaping agricultural and non-farm employment and wages (Lele & Mellor, 1981). Bustos, Caprettini, and Ponticelli (2016) demonstrate empirically that factor bias of technological change in agriculture affected industrial employment growth and wages in rural Brazil. In the case of improved maize varieties, labor demand per acre increased, and the increase in agricultural productivity was not associated with a rise in industrial employment. However, improvements in soy production reduced labor per unit of land, putting downward pressure on farm wages and increasing local industrial employment and out-migration of rural labor.

Investment in humans as productive agents in agriculture is critical to economic growth (Schultz, 1956). In India, the Green Revolution led to increased investment in children's education because there were strong complementarities between primary school education and the new agricultural technology (Foster & Rosenzweig, 1996). Returns to Green Revolution technologies were greater in communities with higher levels of education. Rural education can accelerate the agricultural transformation. Charlton and Taylor (2020) find that secondary school construction in rural Southern Mexico increased the probability that individuals grew up to work in the non-farm sector. Their findings demonstrate that rural school construction does not necessarily benefit everyone equally.[5] In Sub-Saharan Africa, rural education has expanded rapidly, but the quality of education often is poor. Thus, many African youth remain jobless and unable to find employment in the non-farm sector (Filmer & Fox, 2014). Numerous studies show that households in developing countries utilize child labor, and children's schooling may decrease in response to negative agricultural income shocks (Beegle, Dejejia, & Gatti, 2006; De Janvry, Finan, Sadoulet, & Vakis, 2006). Thus, social safety nets may be critical to maintain investments in human capital in agrarian societies where households are highly exposed to risk. Fergusson, Ibáñez, and Riaño (2020) show that exposure to violence in Colombia in the mid-twentieth century reduced children's schooling attainment and the probability that children grew up to work in higher-skilled nonfarm jobs, stunting structural transformation.

In highly developed countries, few people work in agriculture. In the United States, less than one percent of the population lives on farms (Lusk, 2016), and more than three-quarters of the crop workforce is foreign-born.[6] Other developed countries, as well as not-so-developed ones, depend on immigrants to provide agricultural labor. For example, New Zealand brings guest workers from Pacific Island nations; Canada from the Caribbean and Mexico; Spain from Morocco, Latin America, Romania, and other low-income countries; the United Kingdom from Poland; Costa Rica from Nicaragua; and South Africa from Zimbabwe (Taylor & Charlton, 2018). Historically, labor-intensive agricultural production in California expanded through the employment of waves of Chinese, Japanese, Hindu,[7] Armenian, and Mexican immigrants (Taylor & Charlton, 2018). About two thirds of crop workers in the United States in 2016, excluding H-2A guest workers, were born in Mexico.[8]

[5]De Janvry and Sadoulet (2001) similarly found that Indigenous individuals in Mexico were less likely to participate in non-farm work for any given level of education, suggesting that rural labor supply may become segmented.

[6]Based on authors' analysis of the Department of Labor's 2016 round of the National Agricultural Workers Survey (NAWS). The NAWS excludes H-2A agricultural guest workers, who constituted an estimated 10% of the full-time equivalent crop workforce in 2020 (Costa & Martin, 2020).

[7]Hindus primarily migrated from India and were referred to as "Hindus" at the time.

[8]Based on authors' analysis of the Department of Labor's National Agricultural Workers Survey. This share would be even larger if H-2A workers were included in the survey.

With almost no exception, the share of country workforces employed on farms decreases as per-capita gross domestic products (GDPs) rise (Christiaensen et al., 2020).

3.2.1 Diminishing farm labor supply from Mexico and implications for the United States

The case of Mexico's agricultural transformation is particularly well-documented thanks to the availability of farmworker data from both Mexico and its primary emigration destination the United States. Immigrant flows swelled to fill U.S. FVH jobs in the late 1900s, but Mexico's agricultural transformation was already underway, with profound long-term implications for U.S. farms. Edward Taylor, Charlton, and Yúnez-Naude (2012), using data from the 2003, 2008, and 2011 rounds of the Mexico National Rural Household Survey, provide suggestive evidence that the share of rural Mexicans working in agriculture was declining over time. The 2008 and 2011 survey rounds were unique in that they bracketed the so-called "Great Recession," beginning in 2008. The recession created a quasi-natural experiment to test whether the trend in farm labor supply from rural Mexico changed in ways consistent with the demographic transformation. Although nonfarm employment, particularly in construction, contracted severely, agricultural labor demand did not change, supported by the relative inelasticity of the demand for food and the need to continue maintaining perennial crops, for example, tree orchards and vineyards.

Economic theory would predict that rural Mexican immigrant workers in U.S. nonfarm jobs (many of whom previously had worked on farms in Mexico or the United States[9]) would shift to agricultural jobs during the recession. The data show a decline in rural Mexico-to-U.S. migration to both nonfarm and farm jobs, and the percentage decrease was greater in farm than nonfarm jobs. Work histories showed that more rural Mexicans switched from U.S. farm to nonfarm work than the reverse. These findings are consistent with a downward shift in farm labor supply from rural Mexico concurrent with a contraction in non-farm employment, evidence that Mexicans were transitioning out of farm work.

Once farmworkers switch to other sectors of the economy, they are unlikely to return to farm work. Richards and Patterson (1998) model hysteresis in the movement of low-skilled labor from non-farm to farm jobs, due to irreversible investments, either in human capital or in the change of physical location to obtain a non-farm job. When the investment decision is made with uncertainty, a real option value arises, and workers require additional compensation to transition from the non-farm to the farm sector to cover the initial cost of investment to obtain the non-farm job. This helps explain why, even when non-farm wages decreased relative to farm wages during the Great Recession, there is no evidence of substantial migration from the non-farm to the farm sector.

[9]New immigrants from Mexico to the United States often initially work on U.S. farms, but the probability of working in agriculture decreases with time spent in the United States (Kossouji & Cobb-Clark, 2000). Martin (2002) and Taylor (2010) describe agricultural work as a springboard for new immigrants to job opportunities in other sectors of work.

Charlton and Edward Taylor (2016) estimate a panel econometric model with nationally representative individual-level data from rural Mexico from 1980 to 2010. They find a significant negative trend in farm labor supply: between 1980 and 2010, rural Mexicans transitioned out of farm work at a rate of about 1% per year. Expanding the model to include explanatory variables related to the agricultural transformation reveals that growth in the Mexican non-farm economy, declining birth rates in rural Mexico, and rising rural education—all concomitants of the agricultural transformation—contributed significantly to the decline, whereas rising U.S. farm wages partially counteracted it. These findings offer compelling evidence that the era of farm labor abundance, when the labor supply was relatively elastic, is coming to an end.

Hanson, Liu, and McIntosh (2017) show that declining birth rates in Mexico caused total immigration to the U.S. from Mexico to decline during the Great Recession and in the following years. Their study does not investigate sector-specific impacts, but its findings are consistent with Charlton and Edward Taylor's (2016) study suggesting that U.S. farms could suffer from declining birth rates in Mexico. Card and Lewis (2005) show that the probability that newly arrived immigrants from Mexico worked in agriculture decreased between 1990 and 2000, while the probability that they worked in construction (for men) and retail trade (for women) increased by nearly as much. This is consistent with Charlton and Edward Taylor's (2016) findings that the agricultural transformation was well underway in rural Mexico during this time period.

One implication of a declining farm labor supply in Mexico is that the prospects for immigration to offer a solution to U.S. farm labor scarcity diminish over time. The U.S. hired farm workforce is aging (Martin, 2017), farm wages are rising faster than nonfarm wages in many U.S. regions, and the female share of hired farmworkers is rising—trends consistent with a diminishing farm labor supply from Mexico (Castillo & Simnitt, 2020; Zahniser, Taylor, Hertz, & Charlton, 2018).

As Mexican immigrants transition out of agricultural work, just as U.S.-born natives did in the 20th century, Martin (2021) argues that the U.S. has four potential solutions, which he dubs the "4S's": *S*tretch, *S*upplement, *S*atisfy and *S*ubstitute. First, farmers can stretch the existing workforce by increasing worker productivity through the use of improved time management practices or mechanical harvest aids. Stretching the workforce might include strategically forming work crews. For example, Hill and Burkardt (2021) find that worker productivity in strawberry crews responds positively to the work effort of peers, peer effects being strongest among workers of the same gender and similar ability. Stretching can also include movement along a single isoquant through adoption of mechanical harvesting aids that reduce labor time required for certain routine tasks, thus producing the same quantity of output with more capital and fewer labor inputs. Second, the domestic workforce can be supplemented by seeking out new sources of labor, in particular by hiring foreign guest workers through the U.S. H-2A visa program (see below). Third, employers can retain workers by satisfying them with higher wages, benefits, and better working conditions. The average U.S. farm wage as a percentage of the average nonfarm wage rose from 51% to 57% between 1990 and 2017 (Zahniser et al., 2018). Lastly, substitution includes the development of new technologies to replace workers and/or increased reliance upon imports to meet consumer demand. Clemens, Lewis, and Postel (2018) found evidence of both labor-saving technology adoption, such as the widespread adoption of the mechanical tomato harvester, and transition away from the production of labor-intensive crops in the years following termination of the Bracero program in 1964. Development of new technologies can be illustrated through new isoquants that use different ratios of labor and capital to create the same level of output (see for example, Charlton, Taylor, Vougioukas, & Rutledge, 2019b).

U.S. farmers are supplementing the labor supply by increasing their use of the H-2A temporary agricultural guest worker visa program, particularly in states that produce FVH crops, including Florida, Georgia, Washington, California, and North Carolina (see Fig. 1). H-2A employment grew more than 450% from 2001 to 2019, from 45,000 to 258,000 workers (Castillo & Charlton, 2021). H-2A workers constituted an estimated 10% of the U.S. full-time equivalent crop workforce in 2020 (Costa & Martin, 2020). However, hiring workers through the H-2A program is costly. Farmers who use the H-2A program must make employment decisions based on their expected labor demand before weather and market conditions are realized. Other disadvantages of using the program include costs associated with learning and implementing program regulations, applying for H-2A positions, and recruiting guest workers from abroad. Most H-2A workers, like the majority of U.S. hired farmworkers, are from Mexico; thus, a declining farm labor supply in Mexico is likely to limit the extent to which this program will avert farm labor shortages in the long run, and prospects for recruiting enough workers from other countries to fill the void appear limited (Taylor & Charlton, 2018).

Without affordable access to new sources of agricultural labor in other countries, rising farm wages will likely induce farmers to adopt labor-saving technologies and/or shift to less labor-intensive crops (Charlton et al., 2019b; Charlton, Taylor, Vougioukas, & Rutledge, 2019a; Zahniser et al., 2018). Rising U.S. farm wages partially counteract the effects of factors pushing and pulling rural Mexicans out of agriculture. Charlton et al. (2019a) estimate that at least a 10% increase in the U.S. real farm wage (approximately a 30% nominal wage increase) would be required to maintain the current farm labor supply from Mexico over 10 years. Recent studies offer additional evidence that the aggregate farm labor supply is becoming inelastic (Hill, 2019; Li & Reimer, 2020). In contrast, Buccola, Li, and Reimer (2012) reports a highly elastic supply of labor for some subsectors of U.S. agriculture in particular locales.

Historically, labor economists argued that the supply of labor at the firm level is perfectly elastic. Perfectly elastic (or highly elastic) labor supply at the firm-level implies a labor market that is in a state of perfect competition (or that perfectly competitive markets are a good enough approximation to reality; Manning, 2003).

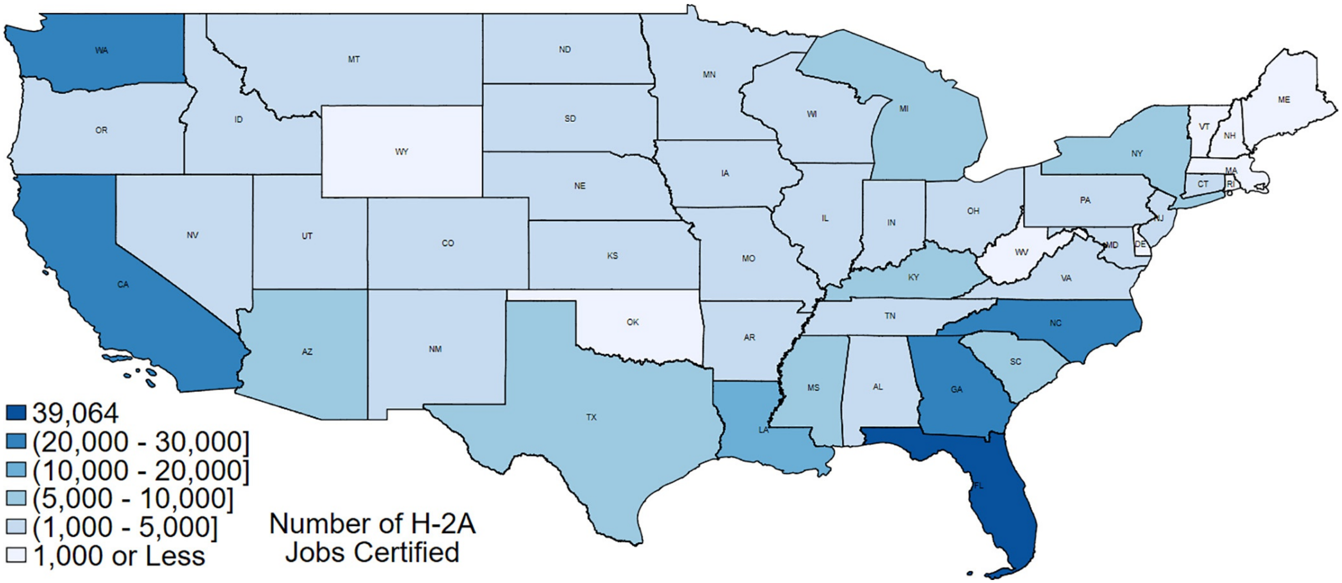

FIG. 1

Number of H-2A jobs certified in FY 2020, by worksite state. Note: US Department of Labor H-2A disclosure data processed by authors.

Source: https://www.dol.gov/agencies/eta/foreign-labor/performance.

In a perfectly competitive labor market, workers are paid their marginal revenue product. However, relatively recent developments in labor market theory have challenged this assumption, countering that some degree of market power is present in the labor market; thus, labor markets are actually in a state of monopsonistic competition. Manning (2003) argues that perfectly competitive labor markets represent "one point at the edge of the parameter space and every other point in the parameter space gives employers some monopsony power." Monopsonistic labor market theory argues that the relevant factor limiting the capacity of a firm to offer wages below its workers' marginal revenue product is the workers' ability to quit the firm for work elsewhere. Although the number of employers in the labor market is traditionally viewed as the sole factor determining the degree of labor market competition, this recent theory suggests that labor market power can exist in the presence of many firms if there are frictions that merely reduce the ability of workers to switch employers (Bhaskar, Manning, & To, 2002; Staiger, Douglas, & Phibbs, 2010). Examples of labor market frictions include heterogeneous preferences for work with a particular type of employer, mobility costs, non-transferable human capital, and a lack of legal work authorization, all of which have characterized farm workforces to some degree across the globe.

In the static model of monopsony, the firm-level labor supply is modeled as a function of the wage. As a result, the optimal equilibrium outcome enables the employer to pay a wage that is below the workers' marginal revenue product in some cases. This "surplus" that employers extract from workers was originally coined by Pigou (1924) and Hicks (1932) as the "exploitation rate," defined as the relative difference between the marginal revenue product and the wage paid. In a static model, the exploitation rate can be expressed as the inverse of the firm-level labor supply elasticity (see Manning, 2003, Chapter 2). Under a perfectly competitive labor market scenario, the labor supply facing the firm is perfectly elastic; thus, the exploitation rate collapses to zero (i.e., workers are paid their marginal revenue product of labor).

In a dynamic monopsony model, the firm's equilibrium employment level in the current period is a function of the job separation rate and the number of recruits in the current period. In the steady state, equilibrium employment is equal to the ratio of the number of new recruits to the job separation rate. It can be shown that the labor supply elasticity facing the firm is equal to the recruitment elasticity minus the separation elasticity (Manning, 2003, Chapter 4). If the researcher can estimate these two elasticities, then inference can be made about the extent to which farm employers are able to exercise market power over workers.

In an award-winning article in the *American Journal of Agricultural Economics*, Richards (2018) finds that if all undocumented Mexican workers were to leave the state of California, wages would rise by 42% (Richards, 2018). Richards argues that, although frictions in California's farm labor market allow farm employers to extract some surplus from farmworkers by paying wages below workers' marginal revenue product, a 42% increase in wages is too large for farm employers to absorb. As a result, a wage increase of that magnitude is unlikely to occur, and production of labor-intensive crops could decline if other adjustments are not made to offset the negative production effects of the declining farm labor supply (Rutledge & Mérel, 2020).

If farm labor markets are actually in a state of monopsonistic competition, then economic theory suggests that higher minimum wages should tend to increase both the market clearing wage and the number of workers employed. Econometric studies that examine the impact of minimum wages date back at least to the seminal work of Grossman (1983), who modeled the supply of labor in terms of efficiency units wherein the amount of effort exerted by skilled workers relies dually upon their wage as well as their wage relative to the minimum wage. In this sense, an increase in the minimum wage can lead to discontentment among high-skilled workers, who perceive the minimum wage as inequitable. As a result, when the minimum wage is increased, high-skilled workers may reduce the amount of effort they exert. Under these circumstances, in order for the firm to maintain a given level of production, it must increase skilled workers' wages because of two factors: (i) a higher minimum wage induces a substitution effect, which increases the demand for skilled workers and (ii) the efficiency units decrease as a result of the reduction in the effort of high-skilled workers, requiring an increase in the efficiency wage to restore equilibrium. Other pivotal minimum wage studies include Card and Krueger (1994)'s fast food study, which finds evidence that higher minimum wages led to higher levels of employment. The evidence they present is consistent with some degree of monopsonistic competition in the fast food labor market. However, studies that examine the impact of minimum wages in the agricultural sector are relatively few.

Among the minimum wage studies that focus on the agricultural sector are Dickens et al. (1995) who examine the impact of minimum wage increases in the United Kingdom, Bhorat, Kanbur, and Stanwix (2014) who study the impact in South Africa, and both Moretti and Perloff (2000) and Kandilov and Kandilov (2020), who analyze effects in the United States. Dickens et al. (1995) find that a 10% increase in the agricultural minimum wage raised the average earnings of agricultural workers in the United Kingdom by 4–5%. Bhorat et al. (2014) find that the sectoral minimum wage law in South African agriculture increased farmworker wages by about 30%. In South Africa, wage increases were more pronounced in districts that had a higher gap between the initial wage and the new minimum wage, which is perhaps not surprising. However, they find that 50% of the farmworkers still received sub-minimum wages after the law was implemented. Their analysis concludes that farm employment fell as a result of the law and that the negative employment effects were particularly pronounced for part-time workers. Moretti and Perloff (2000) find that a one dollar increase in the federal minimum wage raises the average wage of crop farmworkers by $0.14, but a dollar increase in the minimum wage causes the real hourly earnings of piece-rate workers to fall by $0.26. They claim that the negative piece-rate effects were caused by a net inflow of workers into the agricultural sector from minimum wage-induced unemployment in other sectors of the economy, who disproportionately went into piece rate work. However, Kandilov and Kandilov (2020) estimate a long-run elasticity of total agricultural employment with respect to the minimum wage in the United States of about −0.40, and they suggest that increasing the minimum wage leads to higher capital investment and consolidation of agricultural operations.

3.2.2 Declining farmworker mobility in the United States

Specialty crop producers rely heavily upon seasonal labor inputs. If there is an inadequate supply of labor to meet crop and livestock demands, a nation's food supply, particularly of fresh fruits and vegetables, could be at risk. Several studies that examine data aggregated at the national level have determined that there is no shortage of farm labor in the United States (Levine, 2009; Martin, 2007). However, farmers continue to report labor shortages, and some research confirms that farm labor shortages exist and can be costly to farmers (Horner, 2011; Richards, 2018; Rosson, 2012).

An explanation for this apparent paradox is that farm labor markets are localized. For a given total farm labor supply, follow-the-crop migration is critical in redistributing workers across space to ensure that farmers have access to them when and where they are demanded. Without follow-the-crop migration, a much larger total farm labor supply would be necessary to meet seasonally changing farm labor demands, just as a smaller total money supply is needed if the velocity of money in an economy is high.

Fisher and Knutson (2012) explain that farm labor markets are becoming more localized due, in part, to the declining mobility of workers who are settling down in the United States. As a result, labor shortages can materialize when there is an insufficient supply of properly skilled workers in the local labor market at times when the demand for labor spikes due, for example, to weather shocks affecting the timing of harvest activities. Aggregate studies may mask heterogeneity at the local level, suggesting future research and data collection efforts should focus on local farm labor markets.

Using county level data from the Quarterly Census of Employment and Wages, which provides information about employment and earnings at the county and NAICS industry code levels, Hertz and Zahniser (2012) identify local labor markets that are experiencing market conditions consistent with a serious decline in farm labor supply. Their findings reinforce anecdotal evidence from farmers that labor shortages exist, and they bolster Fisher and Knutson's (2012) argument that labor shortages can materialize in local labor markets as a result of reduced labor mobility across regions.

Fan, Gabbard, Pena, and Perloff (2015) use data from the NAWS to estimate a mover-stayer follow-the-crop migration model. They find that workers' willingness to engage in follow-the-crop migration is decreasing over time, which compounds the impact of a declining total farm labor supply on farm wages and local labor shortages. This study also finds that farmworker mobility is negatively related to income and is lower for women, unauthorized immigrants, farmworkers who are English proficient, African American farmworkers, and those who are married or have children. The authors find that the share of U.S. agricultural workers who participate in follow-the-crop migration has fallen by more than 60% since the late 1990s. Decreasing farmworker mobility, combined with a declining total supply of agricultural workers, increases the likelihood of localized seasonal labor shortages.

4 Examining the effects of farm labor supply shocks on agricultural production

A handful of different approaches have been deployed to examine the effects of farm labor supply shocks, particularly in the U.S. In the mid-20th century, researchers used summary statistics to map trends in labor demand and production and make predictions about how labor supply shocks would affect agricultural production. An example is the Bracero program, an agricultural guest worker program established by the U.S. and Mexican governments during the Second World War to recruit Mexican workers to alleviate labor shortages on U.S. farms. The Bracero Program continued until 1964, when a fatal accident involving a train and flatbed truck transporting Bracero workers provoked the U.S. Congress to reevaluate the program. Congress voted to terminate the program, citing claims that the program depressed U.S. wages and took jobs from U.S. workers Clemens et al., 2018. Research in the years immediately following the Bracero program found evidence of short-term negative effects on the production of several major crops due to a lack of workers, which prevented crops from being harvested (Hirsch, 1967).

A sudden decline in the Bracero farm labor supply was accompanied by higher labor costs and increased reliance upon imports from Mexico. Some observers claimed that aggregate production was not in jeopardy, because domestic workers replaced part of the Bracero workforce and the amount of production affected comprised only a small share of the U.S. total (Martin, 1966). However, Martin (1966) argues that there was no benefit from terminating the program, because it severely harmed farmers who could not find workers to harvest their crops, and only a small number of domestic workers were employed on farms. Furthermore, increased labor costs reduced the profit margins of U.S. farmers.

Toward the end of the twentieth century, researchers started using econometrics to estimate farm labor supply and demand elasticities and predict impacts of market shocks. For example, Duffield (1990) finds that the farm labor demand elasticity increased over the past century, and major farm labor supply shocks (e.g., as a result of the 1986 Immigration Reform and Control Act, IRCA) would cause a dramatic reduction in the amount of labor employed, while inducing farmers to adopt labor saving technologies or switch crops.

More recent studies use equilibrium displacement models similar to the one developed by Muth (1964), who employed a two-input, single-output structural model to derive a set of reduced form equations for the equilibrium outcome variables. These equations consider equilibrium adjustments in input and output markets. For example, a negative shock to the farm labor supply would not only decrease the equilibrium quantity of labor employed for specialty crop production but also drive up farm wages, induce substitution and output effects, increase the marginal cost of production, and reduce the crop supply. The Muth model accounts for these adjustments and allows the researcher to simulate shocks to the initial equilibrium. Studies that use this approach typically take structural parameter estimates from the literature, often from multiple sources, and substitute them into reduced form equations to estimate shifts in demand, input supplies, or production technology.

Gunter, Jarett, and Duffield (1992) use a Muth model to estimate the effects of labor supply shocks on aggregate fruit and vegetable production as well as individual fruit and vegetable crops. Their results imply that a 10% decrease in the supply of farmworkers would cause a 1.7–3.9% decrease in the aggregate production of fruits and vegetables in the U.S. Brady, Gallardo, Badruddozza, and Jiang (2016) use an approach similar to Gunter et al. (1992) to examine the effects of supply shocks on tree fruit production in the state of Washington, extending the model to incorporate the effects of substitution across commodities (through cross-price elasticities). Their results imply that a 10% decrease in the farm labor supply would cause a 2.1–5.4% decrease in aggregate tree fruit production. Cassey, Lee, Sage, and Tozer (2018) follow the work of Brady et al. (2016) but examine the effect of pre-harvest labor supply shocks on production and farmer welfare in the pome and prunus industries. They find that a reduced labor supply coupled with an increased demand for labor (driven by population expansion) would lead to lower production but increased welfare for farmers due to an increase in tree fruit prices.

Davis and Espinoza (1998) offer a critique of this traditional equilibrium displacement approach and argue that even when researchers use a variety of parameter estimates to provide a range of potential effects, equilibrium displacement simulations often fail to capture the central tendency of the potential range of estimates. They propose an alternative simulation approach using a distribution of parameter values based on known priors to identify the mean, median, and mode of the entire set of results. Rutledge and Mérel (2020) develop an extension to the Muth (1964) model that uses the equilibrium displacement framework to gain insight into the likely direction of bias in a set of reduced-form regressions, which does not rely upon structural parameter values taken from the literature. Their approach finds an upper bound for the elasticity of hand-harvested specialty crops of 0.42 for the state of California. They conclude that a moderate decrease in the farm labor supply could generate economically meaningful reductions in the production of hand-harvested fruit and vegetable crops, but it would likely not devastate aggregate production.

Zahniser, Hertz, Dixon, and Rimmer (2011) construct a computable general equilibrium model with national-level data to simulate how changes in immigration policy could affect agricultural production and other outcomes.[10] They find that that a policy increasing immigration enforcement would lead to a 3.4% reduction in farm employment and a 2.0% (2.9%) reduction in fruit (vegetable) production. Since the

[10]The first policy they consider simulates increases in the use of the H-2A visa program, and the second policy simulates increased immigration enforcement across the entire U.S. economy.

reduction in farm employment is an equilibrium value, this implies an upper bound for the nationwide elasticity of fruit (vegetable) production with respect to the farm labor supply of 0.58 (0.85).

Interestingly, all of these studies uncover elasticities of production with respect to the farm labor supply that are less than unit elastic. Rutledge and Mérel (2020) explain that this result implies that, to some extent, non-labor inputs can substitute for farm labor. In the U.S., farmers are becoming increasingly reliant upon labor-saving technologies, which allows them to continue producing what traditionally were labor-intensive crops with fewer workers. Options to mechanize certain labor-intensive tasks, such as the thinning and weeding vegetable crops, are becoming increasingly viable as manufacturers improve existing technologies and increase their reliability. In addition, overtime-pay laws (e.g., California's Assembly Bill 1066) and rising minimum wages for farmworkers can make it difficult to "stretch" the existing workforce. In the case of overtime laws, it may be more cost effective to stop employing workers once they have reached the overtime threshold on a given farm and, instead, hire new workers (including workers released from other farms that have reached the threshold). However, this becomes harder to do as the farm labor supply contracts, making labor-saving technology adoption a more attractive long-run solution.

5 Assessing the impacts of immigration policy

As domestic workers move out of farm work, farmers almost universally shift to a foreign-born workforce. Foreign workers constitute an increasing and, in many cases, predominant share of the total labor supply, which follow-the-crop migration continually redistributes across farms, in tandem with seasonally shifting labor demands. Traditionally, immigration policies in the United States and other countries have tended to facilitate immigration in response to farm labor demand as domestic workers withdraw from the workforce, either through agricultural exceptionalism or benign neglect. In the 2000s, this began to change, with growing political resistance to immigration in high-income countries, often fueled by nationalist sentiments. It is difficult to isolate impacts of restrictive immigration policies on farm labor supply and wages, but a few researchers have attempted to do so.

As mentioned previously, the agricultural sector anticipated widespread labor shortages following the termination of the Bracero Program, but these doomsday prophesies were not realized for two main reasons. First, the termination of the Bracero Program advanced the development and adoption of labor-saving technologies Clemens et al., 2018. Second, the Bracero Program set the stage for unauthorized immigration from rural Mexico to U.S. farms (Taylor & Charlton, 2018). Former Bracero workers had networks and job contacts in the United States, easily facilitating immigration directly to U.S. farms, and at the time there were no legal sanctions against employers who knowingly hired unauthorized immigrant workers.

Boucher, Smith, Taylor, and Yúnez-Naude (2007) use retrospective panel data from the first round of the Mexico National Rural Household Survey to model impacts of the 1986 Immigration Reform and Control Act (IRCA) as well as the North American Free Trade Agreement (NAFTA) on farm labor migration from West-central Mexico, traditionally the major source of immigrant farm labor. They find that both policies stimulated an increase in migration from rural Mexico to U.S. farm jobs. IRCA included the first efforts to fine employers for knowingly hiring unauthorized immigrant workers. However, it also included a liberal farmworker legalization program. The findings suggest that the latter, which granted visas to the family members of recently legalized workers, had a positive effect on the immigrant farm labor supply that more than offset any negative effect of employer sanctions.

Implementation of state- and county-level immigration enforcement policies beginning as early as 2005 provided opportunities for economists to evaluate the effects of individual policies using difference-in-differences econometric techniques. Arguably, the strictest immigration policies were implemented in Arizona. Luo et al. (2018) examine the effects of the 2008 Legal Arizona Workers Act (LAWA) on farm family labor decisions. They find that enactment of LAWA increased the supply of family labor to on-farm work, while reducing the probability that likely undocumented workers were employed in agriculture. This evidence suggests that to a certain extent domestic workers from farm families may substitute for low-skilled immigrant workers.

From 2005 to 2012, numerous state, county, and other local jurisdictions implemented Immigration and Nationality Act (INA) 287(g) policies that permitted local law enforcement officers to perform some of the duties of Immigration Customs Enforcement (ICE), including detaining and initiating deportation procedures for unauthorized immigrants.[11] Several studies show that implementation of these policies reduced immigrant populations, both directly through deportations and indirectly through fear of discrimination and possible deportation (Amuedo-Dorantes, Puttitanun, & Martinez-Donate, 2019).

Agricultural expenditures, farm incomes, and production of labor-intensive crops like vegetables also declined following 287(g) implementation (Kostandini et al., 2014). Ifft and Jodlowski (2016) find evidence that 287(g) policies lead to a reduction in the farm labor supply and total agricultural acreage within counties, along with limited evidence that farms substitute capital for labor as labor becomes scarcer in these counties.

[11]In 2013, ICE implemented a similar immigration enforcement program called Secure Communities. Secure Communities was implemented in all 3181 jurisdictions as of January 22, 2013. Some scholars contend that Secure Communities was not as effective as 287(g) in discouraging immigration, but it effectively replaced 287(g) as a local immigration enforcement strategy (Kostandini, Mykerezi, & Escalante, 2014). Thus, most studies on the effects of 287(g) on labor, immigration, and agricultural production focus on years prior to 2013.

Charlton and Kostandini (2020) show that dairy operations become more labor efficient following the implementation of county 287(g) policies. Dairies are more likely to use labor-saving technologies, like automatic take-offs, and dairy operators are more likely to hold off-farm jobs, potentially diversifying income risk. However, total milk production in the county, number of dairies in operation, and average dairy size all decline after 287(g) policies are implemented. Their findings suggest that either farms respond to inward shocks to the immigrant labor supply by investing in labor-saving technologies, or less labor-efficient farms cease operation. Nevertheless, any potential gains in productive efficiency following the enactment of 287 (g) policies were insufficient to fully offset the adverse labor supply shock on the dairy industry. These studies contribute to a growing literature showing that labor scarcity can induce labor-saving technology adoption (Acemoglu, 2010; Clemens, Lewis, & Postel, 2018; Hornbeck & Naidu, 2014).

An alternative to increased mechanization in the face of reduced farm labor immigration is for employers to find new means of attracting immigrant workers to their farms. Guest worker visa programs can potentially provide a positive opportunity for workers to legally migrate to an international location and save money to send home to their families. The guest worker solution corresponds to Martin (2021)'s suggested strategy to "Supplement" the farm labor supply through guest workers. Employers may view guest worker visas as an opportunity to legally recruit new workers and contract a workforce ahead of the crop season. An example, well known in the development economics and international migration literature, is New Zealand's Recognized Seasonal Employers (RSE) program. Farm employers are required to attempt to recruit local workers before obtaining approval to import guest workers from the Pacific Islands while adhering to strict regulations regarding wages, reimbursement for travel, housing, and other measures. Gibson and McKenzie (2014) examine the RSE program's impacts on staging areas in Tonga by using propensity-score prescreened difference-in-differences analysis with micro-survey data gathered before, during and after individuals' participation in this program. They find that the RSE had significant positive impacts on an array of development indicators, including household income, consumption and savings, ownership of durable goods, own perceptions of standard of living, and children's schooling. Australia's Pacific Seasonal Worker's Pilot (PSWP) program is modeled largely on RSE.

The RSE is unique in scope and design. Nevertheless, high-income, as well as some developing countries around the globe, depend on immigrant agricultural workers to fill the void left by domestic workers who eschew farm work (Taylor & Charlton, 2018). Canada's Seasonal Agricultural Worker Program (SAWP) recruits mostly rural Mexican workers. Mediterranean agriculture relies heavily on an immigrant hired farm workforce, largely undocumented (Corrado, de Castro, & Perrotta, 2016). Albanian workers, many unauthorized, harvest crops in Greece, whose policies reflect a more laissez-faire approach with occasional legalization schemes.[12] In Spain, farmers request guest workers from the *Dirección*

[12]See *Central Europe Review* Vol. 1, No. 21, 15 November 1999; http://www.ce-review.org/99/21/vidali21.html.

General de Inmigración (DGI), which establishes a quota for the following year. The lack of a cap on available permits and steep fines for each illegal hire appear to limit unauthorized farm labor migration.[13] Since the breakup of the Soviet Union, Western European countries have relied heavily on farmworkers from Poland and other A8 countries of Eastern Europe, whose movement across borders is facilitated by the Schengen Accord. Until Brexit, the United Kingdom (U.K.) allowed farmworkers from Eastern Europe to travel freely to the U.K. after registering with the Workers Registration Scheme.[14] However, post-Brexit, the U.K. potentially faces severe farmworker shortages, with calls for a return to a prior scheme to enable farmers to legally recruit foreign workers.[15] South African farmers recruit farmworkers from neighboring Zimbabwe.[16] Haitian workers constitute most of the seasonal sugar workforce in the neighboring Dominican Republic (Filipski, Taylor, & Msangi, 2011). Costa Rica imports farmworkers from Nicaragua while implementing occasional temporary immigration and legalization reforms.[17,18] Mexico is at a transitional phase, both exporting and importing farmworkers. Its immigrant farm workforce comes mostly from Guatemala.[19] Rigorous studies of the impacts of these programs are elusive, largely due to data limitations.

6 Climate-induced migration

According to the United Nations, between 2000 and 2019 the number of international migrants increased from 140 to 272 million people, with the largest concentrations in industrialized countries (United Nations, 2020; see Fig. 2). The scientific community generally agrees that the frequency of extreme weather events will increase in the

[13] "Spain: Strawberries, Migrants," *Rural Migration News*, Vol. 14 Number 2 (April 2008) and "Southern Europe," *Migration News*, Volume 15 Number 2 (April 2009).

[14] The A8 countries include the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia. "UK: Migrants," *Rural Migration News,* Volume 15 Number 1 (January 2009).

[15] Agerholm, Harriet. February 5, 2018. "UK Crops Let to Rot after Drop in EU Farm Workers in Britain after Brexit Referendum." *Independent*. http://www.independent.co.uk/news/uk/home-news/uk-crops-eu-farm-workers-brexit-referendum-rot-manpower-recruitment-numbers-a8194701.html

[16] "Africa: Land, Cotton," *Rural Migration News*, Volume 10 Number 1 (January 2004) and "Africa: Migrants, SA, USAID," *Migration News,* Volume 15 Number 4 (October 2009).

[17] Fouratt, C.E., 2016. Temporary Measures: The Production of Illegality in Costa Rican Immigration Law. *PoLAR: Political and Legal Anthropology Review*, *39*(1), pp. 144–160.

[18] International Organization for Migration. 2001. Binational Study: The State of Migration Flows between Nicaragua and Costa Rica. http://www.rcmvs.org/investigacion/BinationalStudyCR-Nic.pdf

[19] Instituto Nacional de Migración Circular No. CRE-47-97, "para trabajar temporalmente en las fincas cañeras, ganaderas y plataneras del Estado de Chiapas" (http://www.gobernacion.gob.mx/archnov/MANUALm.pdf). These workers are allowed multiple entries and exits into Mexico, but their movement is limited to within the state of Chiapas. See also Protection of Migrant Agricultural Workers in Canada, Mexico and the United States *Commission for Labor Cooperation,* Secretariat of the Commission for Labor Cooperation (International organization created under the North American Agreement for Labor Cooperation, http://www.naalc.org/english/pdf/study4.pdf).

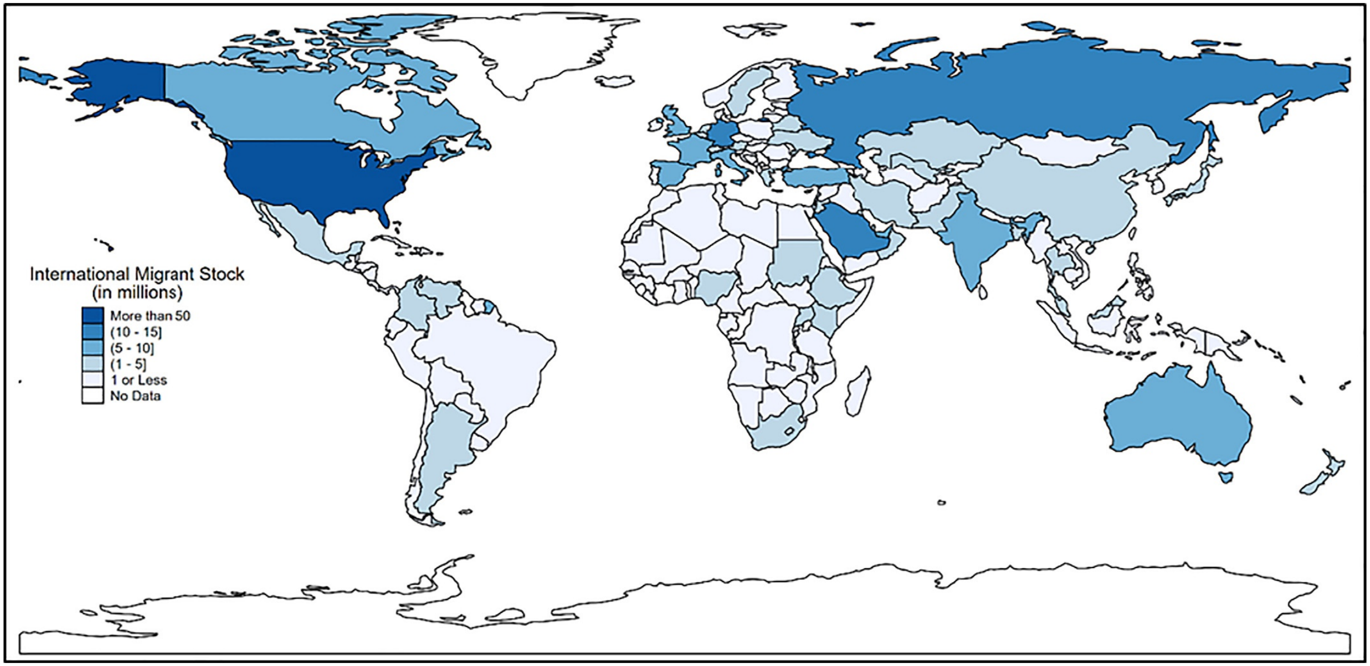

FIG. 2

International migrant stock estimates, mid-year 2019. Note: United Nations data processed by authors. These estimates include all international migrants, of which climate-induced migrants are a subset of.

Source: https://www.un.org/en/development/desa/population/migration/data/estimates2/estimates19.asp.

future (IPCC, 2014; Millock, 2015). Climate change is expected to create major negative impacts on the global economy, particularly for those employed in the agricultural sectors of developing countries since these countries typically have few safety nets to help rural populations cope with environmental shocks that reduce agricultural production (Falco, Donzelli, & Olper, 2018; Lobell, Schlenker, & Costa-Roberts, 2011; Schlenker & Roberts, 2009). Estimates indicate that there were as many as 30 million climate migrants in the mid-1980s (El Hinnawi, 1985), and projections suggest that the number could reach between 200 million (Stern, 2007) and 1 billion (Aid, 2007) by the year 2050. Although some analysts argue that the 2050 projections are unreliable, these critics nevertheless concede that a significant amount of migration is likely to occur as a result of climate change (IPCC, 2014; Millock, 2015).

A handful of papers provide excellent surveys of the climate migration literature. These papers include Obokata, Veronis, and McLeman (2014), who survey the literature on international climate migration; Millock (2015), who surveys the literature on both internal (i.e., domestic) and international climate migration; Falco et al. (2018), who survey the literature on migration resulting from climate-induced shocks to agriculture; Lilleør and Van den Broeck (2011), who survey the literature on climate migration in LDCs; and Piguet (2010) and McLeman (2012), who provide overviews of methodological approaches that have been used to examine climate migration.

Migration can be viewed as an adaptation strategy to climate change along with off-farm labor force participation, changes in crop choice, and the use of credit (Barrett, Reardon, & Webb, 2001). Yang and Choi (2007) find that remittances sent by migrants insure against income shocks in the Philippines. Increased temperature and irregular precipitation (either too little or too much) can affect agricultural productivity and reduce profits and food security, which in turn can induce migration (Mendelsohn & Massetti, 2017; Porter, Dessai, & Tompkins, 2014). Cattaneo and Peri (2016) and Cai, Feng, and Oppenheimer (2016) find a link between temperature and migration in the countries that are most dependent upon agriculture.

Many other studies uncover links between climate change and migration, though not always with a focus on agriculture. They include Bohra-Mishra, Oppenheimer, and Hsiang (2014), who find a link between higher temperatures and outmigration in Indonesia; Dun (2011), between flooding and migration in Vietnam; Gray and Mueller (2012a), between drought and migration in Ethiopia; and Hassani-Mahmooei and Parris (2012), between cyclones and migration in Bangladesh (see Table 1, for a list of climate-induced migration studies). Climate change may lead to suboptimal input use, which can lower the marginal productivity of labor and perpetuate poverty in vulnerable regions. Alem, Bezabih, Kassie, and Zikhali (2010) provide evidence that increased rainfall variability caused farmers to reduce their fertilizer use in Ethiopia.

The statistical associations found in the literature are heterogeneous across regions and fail to paint a consensual picture. For example, individuals who are

Table 1 List of climate-induced migration studies.

Author	Climate variable	Country of origin	Type of migration	Study finds link between climate and migration
Afifi, Liwenga, and Kwezi (2014)	Precipitation	Tanzania	Internal	Yes
Alem, Maurel, and Millock (2016)	Temperature and precipitation	Ethiopia	International	Yes
Alscher (2011)	Natural disasters, flooding	Nigeria	International	Yes
Beine and Parsons (2015)	Natural disasters	Multinational	International	Yes
Bohra-Mishra et al. (2014)	Temperature	Indonesia	Internal	Yes
Bohra-Mishra, Oppenheimer, Cai, Feng, and Licker (2017)	Temperature	Philippines	Internal	Yes
Cattaneo and Massetti (2015)	Temperature and precipitation	Nigeria	International	Yes
Dillon, Mueller, and Salau (2011)	Temperature	Nigeria	International	Yes
Dun (2011)	Flooding	Vietnam	Not Specified	Yes
Farbotko and Lazrus (2012)	Sea-level rise	Tuvalu	International	No
Feng et al. (2013)	Temperature	US	Internal	Yes
Findley (1994)	Drought	Mali	Internal	Yes
Gray (2009)	Harvest variability	Ecuador	International	Yes
Gray and Bilsborrow (2013)	Precipitation and drought	Ecuador	International	Yes
Gray and Mueller (2012a)	Drought	Ethiopia	Internal	Yes
Gray and Mueller (2012b)	Flooding and crop failure	Bangladesh	Internal	Yes
Gray and Wise (2016)	Temperature	Uganda	International	Yes
Halliday (2006)	Crop and livestock losses	El Salvador	International	Yes
Hassani-Mahmooei and Parris (2012)	Drought and cyclone	Bangladesh	Internal	Yes
Henry, Schoumaker, and Beauchemin (2004)	Precipitation	Burkina Faso	Internal	Yes

Table 1 List of climate-induced migration studies.—cont'd

Author	Climate variable	Country of origin	Type of migration	Study finds link between climate and migration
Iqbal and Roy (2015)	Temperature and precipitation	Bangladesh	International	Yes
Kubik and Maurel (2016)	Precipitation and temperature	Tanzania	Internal	Yes
Massey et al. (2010)	Agricultural productivity	Nepal	International	Yes
Mastrorillo et al. (2016)	Temperature and precipitation	South Africa	International	Yes
McLeman and Ploeger (2012)	Soil quality	Canada	Internal	Yes
McNamara and Gibson (2009)	Sea-level rise	Pacific Islands	Not Specified	No
Missirian and Schlenker (2017)	Temperature	Multinational	International	Yes
Mortreux and Barnett (2009)	Sea-level rise	Tuvalu	Not Specified	No
Mueller, Gray, and Kosec (2014)	Temperature	Pakistan	Internal	Yes
Nawrotzki, Riosmena, and Hunter (2013)	Drought	Mexico	International	Yes
Poston, Zhang, Gotcher, and Gu (2009)	Temperature	US	Internal	Yes
Radel et al. (2010)	Drought	Mexico	International	Yes
Salauddin and Zaman (2012)	Cyclone, storm surge, and erosion	Bangladesh	Internal	Yes
Shen and Binns (2012)	Sea-level rise	Tuvalu	International	No
Shen and Gemenne (2011)	Sea-level rise, flooding	Tuvalu	International	No
Warner et al. (2010)	Flooding	Vietnam	International	Yes
Wrathall (2012)	Flooding	Honduras	International	Yes

Note: This list is not intended to be exhaustive. For a survey of the climate migration literature, see Obokata et al. (2014), Millock (2015), Falco et al. (2018), and Lilleør and Van den Broeck (2011).

subject to liquidity constraints, defined by the destruction of capital as a result of environmental shocks, may actually experience a decline in their propensity to migrate (Cattaneo & Peri, 2016). Falco et al. (2018) argue that the economic literature supports the idea that climate change induces migration, but it consists mainly of statistical associations that fail to provide convincing causal evidence.

They point out that some climate migration studies attempt to use causal identification strategies (such as instrumental variables) but fail to include common control variables such as time fixed effects (e.g., Feng, Krueger, & Oppenheimer, 2010; Feng, Oppenheimer, & Schlenker, 2013). In some cases, the findings of these studies have been overturned by simply including commonly used fixed effects, revealing that at least some of the estimated effects are likely confounded by other factors such as war, crime, or political instability, making it difficult to isolate the true impact that climate has on the migration decision (Auffhammer & Vincent, 2012).

Jessoe, Manning, and Taylor (2018) use employment data from a random sample of rural Mexicans, together with village-level weather data, to estimate the impact of weather shocks on rural labor allocations between 1980 and 2007. They find that extreme heat reduces the likelihood of local work. The impact is particularly acute for wage workers, and negative impacts reverberate from farm to non-agricultural employment. In response to extreme heat, migration to urban areas or to the United States increases, and the migration impact is larger if the extreme-heat events occur at the height of the maize growing season.

Obokata et al. (2014)'s survey of the literature includes 23 empirical studies that find a statistically significant relationship between climate change and migration and five that do not. Like Falco et al. (2018), Obokata et al. (2014) argue that the heterogeneity across regions and the diverse array of empirical approaches make it difficult to ascertain which environmental factors have the largest influence on migration. Of the studies they examine that look at both internal and international migration, internal migration was found to be much more prominent, and international migration was typically found to be dependent on non-environmental factors, such as government assistance programs, underscoring the important role that policymakers can play as a provider in times of disaster (Dun, 2011; Findley, 1994; Gray, 2009; Henry, Piche, Ouedraogo, & Lambin, 2004).

It is also important to distinguish between climate migrants who are forcibly displaced and those for whom climate is one of many factors in the decision to migrate. The Environmental Justice Foundation (2021) identifies individuals who are forcibly displaced as "climate refugees," defined as "persons or groups of persons who, for reasons of sudden or progressive climate-related change in the environment that adversely affects their lives or living conditions, are obliged to leave their habitual homes either temporarily or permanently, and who move either within their country or abroad." According the UN Secretary-General, Antonio Guterres, these climate refugees are "not truly migrants, in the sense that they did not move voluntarily" (Environmental Justice Foundation, 2021). Forced migration in this context refers to a situation where a set of realistic alternatives to migration does not exist (CMSNY, 2021).

In many circumstances, climate may be just one of several reasons someone might leave their home (Sohn, 2020). According to a report put out by the United Kingdom (Foresight, 2011), factors that contribute to the decision to migrate can be broken down into five broad categories: political, demographic, economic, social, and environmental. Although environment factors only comprise a single category, they are considered “threat multipliers” because they can exacerbate other factors that contribute to migration. For example, climate disasters may affect market infrastructure, which can affect the ability to find a job and generate income. Environmental factors may also influence political factors by degrading governments’ ability to keep the peace (Weerasinghe, 2021).

A lack of adaptation options, such as social support systems, may be just as important as environmental shocks (Alscher, 2011; Wrathall, 2012). In some cases, the presence of social support systems, such as those aimed at relocating victims, can actually facilitate migration (Dun, 2011; Henry, Piche, et al., 2004; Henry, Schoumaker, & Beauchemin, 2004; Massey, Axinn, & Ghimire, 2010; Warner, 2010; Warner, Hamza, Oliver-Smith, Renaud, & Julca, 2010; Wrathall, 2012). The role of social capital, including migration networks, has been found to interact with environmental shocks to induce migration (Findley, 1994; Massey et al., 2010; Wrathall, 2012). In sum, for many climate-migrants, it may be difficult to disentangle the effect of climate change from other factors that contribute to the migration decision.

In the developing world, younger men tend to be the main household members engaging in migration as an income diversification strategy (Findley, 1994; Gray, 2009; Radel, Schmook, & McCanless, 2010). Male outmigration can make family members left behind (i.e., women, children, and the elderly) highly vulnerable, particularly if migrants fail to send sufficient remittances home. Some studies document that male outmigration leaves origin countries devoid of strong physical labor, which can inhibit the rebuilding of communities after environmentally-related disasters (Afifi, 2011). Male outmigration can also cause children in the origin country to drop out of school to participate in subsistence farming activities (Alscher, 2011). Lower educational attainment has the potential to trap individuals in agricultural or other low paying work, and this can slow the transformation process.

The outmigration of agricultural workers has important implications for both the sending and receiving regions. An inward shift in the rural labor supply is expected to raise rural wages, benefiting local workers but increasing labor costs for landowners and nonfarm employers in rural communities. Filipski, Lee, Hein, and Nischan (2019) find evidence that rural-urban migration in Myanmar benefited the landless poor who gained access to more job opportunities in the cities, but it negatively affected farmers who had to pay higher wages. Productivity gains from farm mechanization accompanying rural-urban migration were insufficient to offset the negative effects of rising wages on farm profits.

The consequence of lower farm profits due to higher farm wages may be offset if households receive sufficient remittances from international migrants. Remittances can stimulate the local economy and increase the demand for services, such as construction, which can create new off-farm job opportunities for local workers. Although an influx of new climate migrants could be beneficial to farmers in the receiving regions by lowering production costs and reducing the probability that local labor shortages will occur, it can also induce wage stagnation in the receiving region and lead to worse economic outcomes.

7 Farmworker welfare

The seasonality of farm employment, high mobility of agricultural workers, and lack of legal protections hamper efforts to improve wages and working conditions for agricultural workers through union activity in high as well as low-income countries. The United Farm Workers (UFW) movement in the United States, under the leadership of César Chávez, famously achieved victories for farmworkers in the 1960s. However, the UFW subsequently lost most of its support over a relatively short period. Perhaps its greatest victory was in leading a consumer boycott on table grapes in 1968 to demand higher wages and improved working conditions. Many farm employers offered workers increased wages and benefits in exchange for not joining the UFW, and growers throughout California and Arizona came to recognize the UFW as the union representative of approximately 50,000 farmworkers (Taylor & Charlton, 2018).

In 1975, California Governor Brown signed the California Agricultural Labor Relations Act (ALRA) into law, which established the right to collective bargaining for agricultural workers. Embedded in California's ALRA is a provision that requires "…making employees whole…for the loss of pay resulting from the employer's refusal to bargain [with the union]…," a protection that is unique to California's agricultural workers and is not found anywhere else in U.S. labor law (California Legislative Information, 2021). However, the implementation of this "make-whole" provision has led to a considerable amount of litigation regarding the methodology used to calculate the amount of compensation to which workers are entitled (Martin, Egan, & Luce, 1988; Martin, Vaupel, & Egan, 1988). Martin and Egan (1989) develop a contract-averaging methodology, which estimates the value of the average wage increase and fringe benefits that would have been negotiated had good-faith bargaining actually taken place. Their approach uses data from the union contracts that were in effect during the bad-faith bargaining period and is aimed at simplifying the make-whole remedy calculation to ensure that workers are paid in a timely manner. However, despite union protections afforded to California farmworkers, by 2006 the UFW had fewer than 25 contracts (Pawel, 2006). Taylor and Charlton (2018) offer three explanations for why the UFW lost its influence in short time: first, farmworkers are difficult to organize given their migratory nature and seasonality; second, many farmworkers did not see long-term gains to union membership; and third, the elastic supply of undocumented farmworkers who migrated from Mexico following the UFW's prime reduced workers' bargaining power.

Since the UFW's rise and fall, consumer activists have championed most of the major victories for farmworker rights in the United States. Several farmworkers were discovered chained in slave-like conditions on a tomato farm in Immokalee, Florida in 2001, and the Coalition of Immokalee Workers (CIW) was formed in response. Chavez's work with the UFW illustrated that consumer boycotts were more effective in farm labor bargaining than workers' strikes. The CIW led a boycott on Taco Bell, a major tomato buyer, demanding that it take corporate responsibility for ensuring better treatment of farmworkers in its supply chain. In 2005, Taco Bell agreed to include a payment to farmworkers in its tomato purchases, purchase tomatoes only from farmers who abide by an enforceable "Code of Conduct," and complete transparency of all tomato purchases in Florida. In 2010, CIW grew its campaign to include numerous tomato buyers by launching the Fair Foods Program (FFP), the effects of which are illustrated in Taylor and Charlton (2018). The FFP includes a label for all tomatoes purchased under the conditions to which Taco Bell agreed, in addition to implementing worker-to-worker education sessions and a Fair Food Code of Conduct with third-party monitoring. This example demonstrates how consumers can influence labor markets in upstream stages of production.

Labor standards have been a major point of contention in international trade negotiations for many years. At the World Trade Organization (WTO) meetings in Singapore in 1996 and Seattle in 1999, the United States and France proposed a "social clause" that would specify a set of minimum labor standards and permit restrictions on imports from countries that do not comply (Bagwell & Staiger, 2001; Hur & Zhao, 2009). The European Union (E.U.) again brought up labor standards at the WTO conference in Doha in 2001.

Labor unions and humanitarian organizations often contend that international labor standards are necessary to prevent a "race to the bottom," wherein firms impoverish workers to improve their competitive edge in export markets. However, developing countries typically oppose international labor standards, arguing that increased labor costs would reduce their competitiveness in global trade (Hur & Zhao, 2009). Proposed strategies to protect labor conditions in international trade vary. Bagwell and Staiger (2001) suggest that tariffs can substitute for lower labor standards. They conclude that, by granting governments more sovereignty in trade negotiations, the WTO rule could enable governments to achieve efficient levels of labor and environmental standards while focusing trade negotiations specifically on trade policy rather than "social" or environmental standards. Most proposed strategies to enforce social standards in global trade remain contentious, but global trade also opens new avenues for labor exploitation.

Increasing trade among and within global production networks has created new opportunities for labor abuse, especially in labor contracting chains. Labor contracting, which may entail recruitment agents or labor intermediaries, is common in industries that require seasonal workers on short notice. Forms of labor contracting vary but often entail a "cascaded system" with multiple degrees of separation between producers and workers (Barrientos, 2013). There is no formal definition of labor contracting, but the International Labor Office (ILO) describes it as a "triangular employment relationship," in which the legal employer is distanced from the worker.[20] This system generates a space for contractors who cut costs by

[20]See for example, International Labour Office (2003) "The Scope of the Employment Relationship." International Labour Conference, 91st Session. Report V. Geneva, Switzerland.

mistreating, underpaying, or otherwise abusing workers to hide within the trade network because monitoring and regulating labor practices is costly.

Concentration of production and seasonality are two common factors often associated with rising shares of labor contractors. This makes agriculture a prime industry for labor contracting, which expanded rapidly in the U.S. in the 1990s (Thilmany & Martin, 1995). Undocumented immigrants typically are more vulnerable to abuse than domestic workers. Farm labor contractors have been known to charge workers high fees for transport, training, or the provision of false documents. Employment experiences with labor contractors vary widely, some workers reporting that they like the continuity of work that their contractor provides while others are trapped in abusive situations, even slavery (Barrientos, 2013). Global supply chains can exacerbate the economic returns to abusive labor relations, since global buyers can outsource higher-cost and higher-risk stages of production while continuing to specify essential standards, and many production activities may not be regulated through national laws.

Numerous organizations or countries have implemented unique legislation to help protect workers in industries, including agriculture, where supply chains span multiple countries. In 2002 the United Kingdom's Ethical Trading Initiative started the multi-stakeholder Temporary Labour Working Group (TLWG), which included trade unions, NGOs and supermarkets, to establish standards for labor contractors. The TLWG was a key player in lobbying the U.K. to enact the Gangmasters (Licensing) Act, which requires all labor contractors in the U.K. to register with the Gangmasters Licensing Authority. South Africa implemented the Basic Conditions of Employment Act, which gave joint liability to producers if contractors do not abide by labor legislation. The California Transparency in Supply Chains Act, effective in 2012, requires retailers and manufacturers with annual global revenue of more than $100 million that do business in California to disclose information regarding their provisions to eradicate slavery and human trafficking in their supply chain (Barrientos, 2013).

As the globalized economy has grown more integrated, private organizations have frequently imposed specific social standards into their global contracts, including provisions for unions and NGOs to monitor procedures, freedom of association, the right to collective bargaining, right-to-work contracts and regular employment (Riisgaard, 2009). One key activity that has been highly influenced by privately enforced labor regulations is the trade in cut flowers from countries including Kenya, Colombia, Israel, and Tanzania to private supermarkets and auction halls in Europe. The cut flower trade is highly seasonal, with peak demands during holidays and summer months, and retailers often adjust orders on the day of delivery. Consequently, suppliers depend on a highly elastic, difficult-to-monitor labor supply. The industry has adopted a range of private social and environmental standards to protect workers' rights since the mid-1990s, including standards set by private European buyers and initiatives in producer countries (Riisgaard, 2009). International unions can also be influential in upholding workers' rights. For example, major multinational banana distributor Chiquita signed an agreement with the

Latin-American Coordination of Banana Workers Unions (COLSIBA) in 2001 to ensure better working conditions on banana plantations throughout Latin America (Riisgaard, 2005). These international initiatives, combined with FFP-like consumer initiatives, offer models to improve farmworker protection in an integrated global economy.

8 The farm labor market and COVID-19

Concerned about the possibility of overloading health care systems and preventing the spread of COVID-19, in 2020 countries throughout the world implemented mandatory quarantine or "shelter-in place" orders and restricted internal as well as cross-border migration (Cortignani, Carulli, & Dono, 2020). Government mandated shutdowns triggered a number of supply and demand responses across agri-food systems, with important ramifications for agricultural labor. It also exacerbated some of the difficulties in developed countries of procuring an adequate immigrant farm workforce and difficulties in developing countries of producing and distributing adequate food throughout the urban and rural populations.

At the time of writing this chapter, research on impacts of COVID-19 on agricultural labor is nascent but provides useful insights into how global economic shocks can potentially affect labor markets along the food supply chain. For example, Cho, Lee, and Winters (2020) find that the pandemic caused a large decrease in restaurant employment in the U.S. and smaller, yet nontrivial, employment effects in food manufacturing and grocery stores. However, they find no effects on farm employment. This may be due in part to the relatively inelastic demand for food and the essential status of farmworkers, as well as the fact that a large share of the agricultural workforce in the United States is undocumented and therefore ineligible for unemployment benefits.

COVID-19 responses have generally been national in scope and have lacked multinational cooperation. As a result, the effects of COVID-19 on the food supply chain and on labor demand have differed by country. In developing countries, COVID-19 restrictions have sometimes prevented the return migration of urban migrants to their homes in rural locations. Gupta, Zhu, Doan, Michuda, and Majumder (2020) find that weekly household income in a relatively poor region of rural India with high out-migration declined by US$13.50 in the month immediately following India's lockdown. They estimate an 88% reduction in local income and 63% reduction in remittance income. In response to this income loss, rural households reduced their purchases of non-consumption items, consumed a smaller variety of foods, and reduced their meal portions. Most households consumed more foods from their own production, and many foraged for leafy vegetables and small freshwater fish. Most of the migrants in urban centers lost their jobs and survived on local aid distributed in the cities. Some households sent money to migrant family members in the city to help them through the lockdown. Filipski et al. (2020), using many local economy-wide impact evaluation (LEWIE) models, find that COVID-19 and policy responses to mitigate its spread negatively impact rural households at least as much as urban households in sub-Saharan Africa due to lower income from nonfarm wages, as well as household-farm crop production.

Although developed countries typically have relatively robust safety nets to help redistribute food and income during economic shocks, the coronavirus pandemic still led to major disruptions in the food supply chain. The closure of food service businesses and schools eliminated large produce orders for some producers, particularly in March and April. Although produce demand increased at grocery stores, friction in the supply chain emerged as some producers scrambled to adjust their packaging facilities in order to accommodate smaller individual-sized items intended for retail sale (Hobbs, 2020). In some countries, including France and the Netherlands, food prices increased due to higher labor and transport costs (Mitaritonna & Ragot, 2020; Ragasa & Lambrecht, 2020).

In addition to shocks to demand for food products in traditional restaurant and cafeteria markets, there were also shocks to labor input supplies in food supply chains. Developed countries have historically retained high demand for foreign agricultural workers even during times of economic crises that lead to anti-immigration sentiment. Often seasonal migrant workers develop relationships with specific employers over time and return to work for them year after year (Mitaritonna & Ragot, 2020). Employers value these “circular migrants” because they develop specific skills that help increase operational efficiency and lead to higher profits. However, the coronavirus pandemic placed increased stress on migration networks worldwide. The restriction of movement across international borders due to COVID-19 caused temporary labor shortages of harvest workers worldwide, including in Columbia (Rueda, 2020), Canada (Larue, 2020), Thailand (Saokaew, 2020), Ethiopia (Orchardson, 2020), Zimbabwe (Orchardson, 2020), India (Orchardson, 2020), Germany, Italy, Spain, the U.K., and France, (Cretan & Light, 2020), and China (ADB, 2020; Zhou, Han, Li, & Wang, 2020).

Many countries modified their orders to accommodate the agricultural sector. To “avoid disruptions in lawful agricultural-related employment, protect the nation’s food supply chain, and lessen impacts from the coronavirus (COVID-19) public health emergency,” the U.S. government temporarily modified the foreign agricultural guest worker program, allowing foreign guest workers already in the country to extend their work visas and start working on other farms (Beatty, Hill, Martin, & Rutledge, 2020; USCIS, 2020). Within the E.U., travel restrictions imposed at the individual country level forced authorized seasonal migrants from Eastern Europe to return to their home countries (Cretan & Light, 2020). Migrant destination countries (e.g., Austria, Germany, France, Italy, Spain, and the U.K.) implemented a number of different approaches in an attempt to prevent labor shortages in the food supply chain. These approaches included attempts to replace migrant workers with domestic workers, tweaking labor laws to induce existing workers to work longer (e.g., tax exemptions for overtime work), regularizing unauthorized migrants, and providing wage compensation to employers.

There was some speculation that historically high unemployment rates during the pandemic might reduce the incidence of farm labor shortages if workers laid off from other industries sought work in agriculture. Charlton and Castillo (2020) investigate whether rising unemployment rates in the non-farm sectors affected H-2A agricultural guest worker demand in years prior to the coronavirus pandemic. They find that from 2007 to 2019, a 1 percentage point increase in the state unemployment rate was associated with a 5% decline in demand for H-2A agricultural guest workers. This amounts to an estimated half a percent of the total crop workforce in 2019 and suggests that rising unemployment in non-farm sectors does in fact reduce farmers' need to recruit guest workers. However, governments provided temporary increases in unemployment benefits and other benefits, and past research suggests that these may limit the potential of agricultural labor markets to absorb workers who have been laid off (e.g., Green, Martin, & Taylor, 2003). Only an estimated 4.6% of the U.S. labor force is undocumented and therefore ineligible for unemployment benefits (Krogstad & Gonzalez-Barrera, 2019). Nevertheless, the total number of H-2A positions certified by the Department of Labor (DOL) in Fiscal Year 2020 increased by 7% (or by 17,764 certifications) relative to Fiscal Year 2019,[21] thus suggesting that U.S. agricultural production remained highly dependent on non-domestic labor sources during the pandemic despite high unemployment in other sectors.

France, Germany, Spain, the U.K., and Italy created websites to connect part-time and unemployed domestic workers with agricultural employers. Except for Italy, each of these countries also implemented rules permitting domestic agricultural workers to continue collecting unemployment benefits while working on farms in an effort to help secure national food supplies (Mitaritonna & Ragot, 2020). However, none of these countries were able to secure an adequate domestic agricultural workforce, so, instead, they exempted seasonal AFS migrants from border restrictions (Cortignani et al., 2020; Haley et al., 2020; Rogozanu & Gabor, 2020). Eastern European migrants were authorized to take specially chartered flights and buses to various locations throughout Western Europe to work on farms and in food processing plants (Mutler, 2020). Following Portugal's lead, Italy's minister of agriculture eventually asked for the temporary regularization of unauthorized immigrants to help secure an adequate farm work force.

Preventative measures to reduce the spread of COVID-19 on farms in 2020, including provision of personal protective equipment, sometimes providing additional workers housing, accommodating worker distancing in fields, and paying for additional sick leave, increased labor costs substantially on many farms, possibly leading some producers to reconsider their production methods. Charlton (2021) found that historical employment of 100 additional fruit, vegetable, and horticultural workers

[21]Based on authors' analysis of United States Department of Labor Employment and Training Administration H-2A Disclosure Data. These data are publicly available at: https://www.dol.gov/agencies/eta/foreign-labor/performance.

was associated with 4.5% more COVID-19 cases within U.S. counties in the corresponding month from April to August in 2020. Causal interpretation is beyond the scope of the analysis, but findings are indicative of increased health risks in the production of labor-intensive crops during the pandemic. In Germany, an outbreak at a slaughterhouse caused more than 200 Romanian workers to become infected with the COVID-19 virus, at least one of whom eventually died (Mutler, 2020). Malone, Shaefer, and Wu (2020) argue that, at a minimum, during a health crisis such as the COVID-19 pandemic, essential workers in the agricultural food supply chain should be compensated for the potential of increased exposure to the disease. If producer strategies to prevent the spread of COVID-19 among farmworkers are sufficiently costly or risks associated with worksite virus outbreaks sufficiently large, the coronavirus pandemic might incentivize some producers to invest in labor-saving technologies or transition away from labor-intensive agricultural production.

9 Replacing farmworkers with robots

Labor-saving technological change takes center stage in U.S. agricultural history related to grain crops. In the early 21st Century, the same can be said for difficult-to-mechanize fruit, vegetable and horticultural crops.

Technological change has been viewed by some (most prominently, Hyami & Ruttan, 1971; Hicks, 1932) and as an endogenous process, driven by relative factor prices, and by others (e.g., Arrow, 1962; Levin, 1988) as a largely exogenous process, with new advances laying the foundation for future ones by lowering research and development (R&D) costs. In practice, it is likely that both are important in shaping the development path of labor-saving agricultural technologies over time. The agricultural and food revolutions, including a declining farm labor supply and rising wages throughout the AFS, no doubt play a key role in shaping this process (see for example, Acemoglu, 2010; Charlton & Kostandini, 2020; Clemens et al., 2018; Hornbeck & Naidu, 2014).

Charlton et al. (2019b) discusses the theoretical link between technology change and a declining farm labor supply and provide examples of new labor-saving agricultural technologies. Taylor and Charlton (2018) provide a framework for cost-benefit analysis of labor-saving technology adoption, with an example from California raisin grape production. Recent farmer surveys reveal that rising labor costs and labor-availability problems are causing U.S. farmers to adopt labor-saving technologies (Rutledge & Taylor, 2019; Fig. 3). Fig. 4 shows that some of these technologies include, in particular, mechanized equipment to reduce labor demand during harvest.

The adoption and diffusion of new agricultural technologies can be slow and difficult to predict. For example, mechanized raisin harvesting technologies have been available since prior to the 1960s, but their diffusion has only begun to spread in the past two decades. Mechanized harvest with continuous tray systems reduces labor inputs from 19.2 person-hours per ton of dry raisins using manual raisin harvesting techniques to only 4.4 person-hours per dry ton. An even more labor

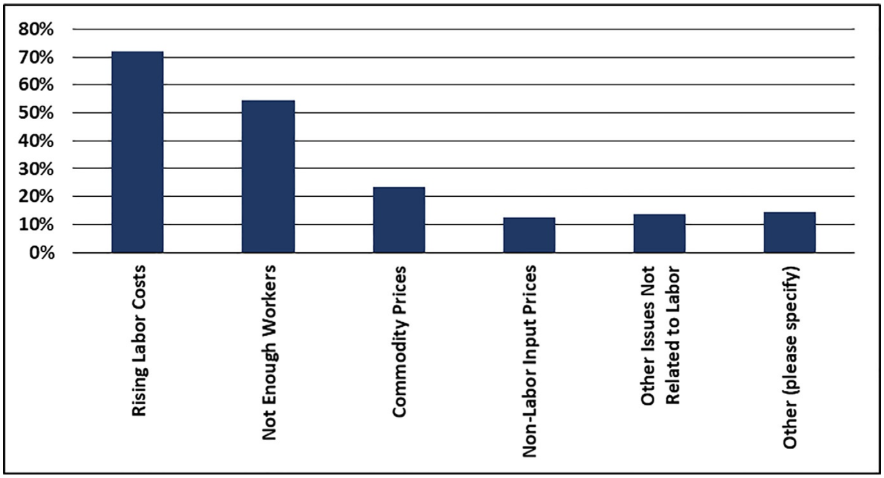

FIG. 3

Reasons farmers are adopting labor saving technologies in California.

Source: Data from the CFBF-UC Davis "Adapting to Farm Labor Scarcity Survey" processed by authors.

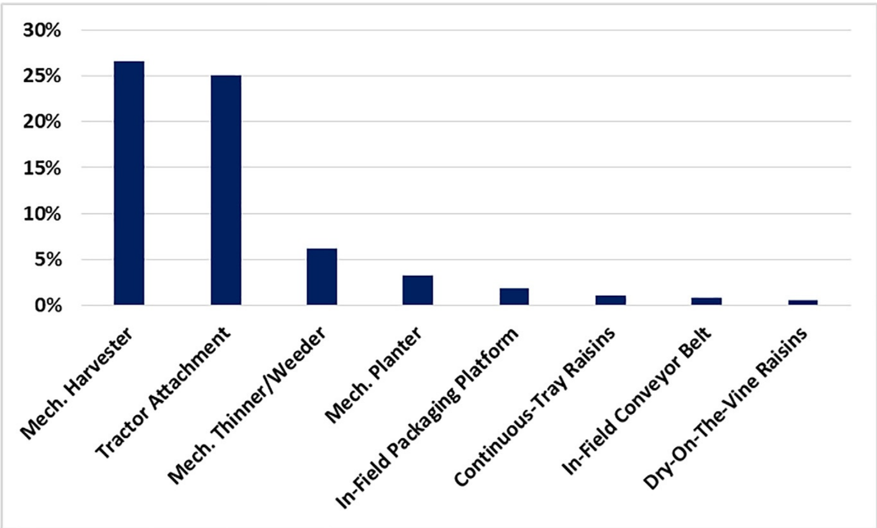

FIG. 4

Most common types of labor-saving technologies recently adopted in California. Note: "Other" responses are not included in this graph.

Source: Data from the CFBF-UC Davis "Adapting to Farm Labor Scarcity Survey" processed by authors.

efficient technology called “dry-on-vine” (DOV) was first developed in the 1960s. DOV produced higher yields and reduced labor inputs to just 3.2 person-hours per dry ton.

Nevertheless, almost all of California’s 270,000 acres of raisin grapes were harvested manually and dried on trays between rows until 2000. Adoption rates of mechanized raisin harvesting techniques remained low for many years because labor was inexpensive and readily available. There were high up-front costs to adopting DOV technology, including building a new trellis system to accommodate the harvester, planting a new grape variety, and purchasing the harvester. However, growth in real farm wages and a drop in raising prices gradually induced growers to adopt mechanical technologies. In 2017, an estimated 20% of raisin acreage in California was harvested using mechanized continuous tray systems and 9% with DOV (Charlton et al., 2019b).

Numerous variables factor into a producer’s decision to adopt a new technology. One of the earliest works in this area, by Just and Zilberman (1988), finds that the joint distribution of risk preferences, farm size, access to credit, and the stochastic structure of alternative production activities determine the adoption of new technologies across farms. Economies of scale associated with new technologies that emerge as a result of labor shortages could accelerate the consolidation of agricultural production and benefit larger farms, possibly at the cost of small farms.

When there are no economies of scale, no constraints on land acquisition, and entrepreneurs can access credit, custom machine services or rental markets for harvesting machinery are expected to emerge (Lu, Reardon, & Zilberman, 2016). When a technology has large economies of scale, this generates incentives for technology adopters to acquire land from those who do not adopt, thus reducing the incentives for entrepreneurs to contract out machine services. Kislev and Peterson (1982) suggest that economies of scale were mostly irrelevant in U.S. agricultural development prior to the 1970s, because most farms were small businesses and small farms benefited from new technologies by renting equipment or custom services. They claim that long-term upward trends in the ratio of the opportunity cost of farm labor to machine costs caused farms to consolidate from 1930 to 1970, but this trend reversed from 1970 to 1976. Consequently, they conclude that farm consolidation would have stabilized in the following years. However, MacDonald (2020) finds that farmland shifted to larger operations from 1987 to 2017, negating Kislev and Peterson (1982)’s predictions. MacDonald (2020) concludes that broad-based technological innovations and associated economies of scale play a vital role, even though economies of scale can be divided through rental and custom service markets.

Both consolidation of land and the emergence of custom harvesters are visible in the nut industry. Nuts are mechanically harvested using machines that surround the trunks of the trees and shake the trunks until the nuts fall, either into a catching frame or onto the ground where they can be swept together and picked up by machine. Processing fruit can sometimes be harvested mechanically by shaking the fruit from trees or bushes, since bruising is not so harmful in the production of juices or jams.

However, it is much more difficult to mechanically harvest fruit for fresh-to-market sale, because fresh fruit typically is delicate and bruising destroys the finished product. Despite this difficulty and the one of replacing hand pickers with mechanical solutions, there is emerging research on the use of robotics to harvest delicate fruits and vegetables. For example, engineers are developing sensors and algorithms to improve fruit perception efficiency for use in robotic harvesters. Some of these sensors will have to detect which fruit are ripe and which are not, inasmuch as fruit often does not ripen uniformly (Gongal, Amatya, Karkee, Zhang, & Lewis, 2015). Engineers are also developing fruit-catching mechanisms that use air suspension to cushion the fruit as it falls, thereby reducing bruising (Ma, Karkee, Fu, Sun, & Zhang, 2016). Although not yet commercially available, these technologies may become more viable for some operations if labor becomes sufficiently costly or uncertain.

Recent studies have found mixed evidence on the effects of technology adoption on labor market outcomes. For example, Hassan and Kornher (2019) report that machine rental services for tilling, threshing, and irrigation pumping in Bangladesh had positive wage effects in the short, medium, and long run. Although mechanization can lead to an increase in the demand for labor when accompanied by scale effects, it can also displace labor when not (Kirui, 2019). Mechanization can be beneficial to workers when economies of scale are not present in some circumstances. Take for example the case of China, which has had limited economies of scale due to a lack of land ownership rights. One quarter of China's workforce (200 million people) remains employed in the agricultural sector, but mechanized planting and harvesting services allow staple crop producing households to allocate labor more efficiently (Lohmar, Gale, Tuan, & Hansen, 2009; World Bank, 2020; Zhang, Yang, & Reardon, 2017). The provision of mechanical services has provided many of China's estimated 140 million rural-to-urban migrants with an opportunity to stay engaged in higher-paying work off the farm during the planting and harvesting seasons, when historically they have been expected to return home to work on the farm. There is evidence that migrant remittances have mitigated lost-labor effects of migration on crop production (Rozelle et al., 1999).

Labor migration and remittances can increase technology adoption, particularly in rural regions of developing countries, by reducing risk and liquidity constraints. For example, in Kenya, migration and remittances were shown to increase the adoption of improved seeds, and migration had a larger effect than remittances (Tshikala, Kostandini, & Fonsah, 2019). Similarly, in Uganda, Veljanoska (2021) found that remittances increased investment in livestock, which might be considered a risky investment, and use of organic fertilizer in farming. These studies show that off-farm labor opportunities, available through labor migration, can make important contributions to agricultural productivity.

Studies show that risk and uncertainty are critical in the timing of technology adoption. Koundouri et al. (2006) find that farms with greater production risk related to droughts were more likely to adopt water-saving technologies, and farmers with better information about the water-saving technologies typically placed lower option value on waiting to adopt the technology. By extension, one would expect that farms with greater risk of labor shortages would be some of the first adopters of labor-saving technologies as new technologies become available and more profitable.

Returns to technologies are not homogeneous across growers. Some producers will benefit more from technological change than others, and technological developments may be more suitable to specific terrains or climates (Just & Zilberman, 1988). That is why Griliches (1957) distinguished between lags in availability of a new technology and lags in acceptance. He argued that acceptance is a function of the profitability of shifting to the new technology, but technologies may not become available in all regions at once. For example, in the case of hybrid corn, plant breeders had to develop numerous breeds suitable to specific growing conditions around the United States. Resources were first allocated to the regions with the highest returns to hybrid seeds, and then the technology was gradually modified and made available to other regions. Both public and private investments were critical in the diffusion of hybrid corn (Griliches, 1957). Sunding and Zilberman (2001) provide a similar argument and explain that, although larger farms are more likely to adopt a technology at first, adoption becomes increasingly more feasible for smaller farms over time as more information is diffused, thus lowering the cost of adoption and learning.

Labor-saving mechanization in FVH production, although complex and costly to develop, may provide more universal solutions to the farm labor problem in the long run. In the meantime, as producers face increasing challenges in procuring seasonal farmworkers, the incentives to develop and adopt labor-saving technologies, including harvesting aids and mechanized or robotic harvesters, thinners, and weeders, are increasing as well.

10 Conclusion

Agriculture is the most universal, and arguably most essential, production sector in the global economy. Yet, as economies become more industrialized, fewer people supply their labor to agricultural work. Throughout much of the 20th century, today's developed countries expanded their agricultural production, particularly labor-intensive fruits and vegetables, by hiring immigrant farmworkers from less developed countries. Today, the United States hires guest workers from Mexico, Mexico hires guest workers from Guatemala, New Zealand from other Pacific Island countries, South Africa from Zimbabwe, England from Poland, and the list goes on. Nevertheless, agricultural producers throughout much of the world are beginning to feel the pinch of a tightening farm labor supply, as economic development pushes and pulls workers out of agriculture in migrant-source countries, as well.

Historically, we often observe that disruptions in the labor supply induce technological change (Charlton & Kostandini, 2020; Clemens et al., 2018; Hornbeck & Naidu, 2014). Many of these disruptions were mostly temporary in nature or confined to a localized region or jurisdiction. However, we may be entering a new era wherein workers worldwide are more educated and less willing to work in agriculture (Charlton & Taylor, 2020). Arguably, this era already is underway, incentivizing agricultural industries to invest in labor-saving technologies that complement the primary skills of the new workforce.

Around the world, many workers who leave the farm end up in downstream sectors of the agri-food system (AFS), and there is a compelling case to situate new research on agricultural labor demand within the context of shifting employment within the AFS (Christiaensen, 2020). Despite a prolific literature on agricultural labor, few researchers have broadened their scope to include employment along the AFS chain. Agriculture's share of national employment declines as countries develop, but the broader agri-food system expands, fueled by rising demand for more protein and nutrient rich, processed foods and what Reardon, Timmer, and Minten (2012) call the "supermarket revolution" (i.e., the proliferation of retail food markets). Today, in high-income countries, most agriculture-related employment is not on farms, but rather, in food processing and marketing activities that, like agriculture, employ a largely immigrant workforce. The speed of the agri-food value chain transformation in lower- and middle-income countries today is occurring remarkably quickly. It took about a century for North America and Western Europe to transition from local spot markets with little to no food processing to longer value-added agricultural chains. However, countries today are undergoing this transformation in just a few decades (Barrett et al., 2020).

Transformation of the AFS occurs in three general stages: First, the economy is primarily composed of small, semi-subsistent farms and short AFS chains since most of the population resides in poorly connected rural locations. Second, is a transitional phase during which AFS chains lengthen to serve a growing urban population. The third stage is the formation of a modern, organized system with long supply chains that include major investments in cold storage, preservation, packing, bulk storage and transport, and other logistics. The growth in urban demand for diverse foods during this stage provides numerous opportunities for product differentiation, monopolistic competition, and expanding markets to provide food away from home (Barrett et al., 2020). Improved collection of microdata on employment and income in the AFS will be critical for ongoing research into this growing sector of developing economies.

Hired and family farm work will continue to be a major employer in poor countries for the foreseeable future. However, labor productivity on farms will continue to rise, young people will leave farms, and societies will become increasingly dependent on downstream employment in AFS activities, including food processing, marketing, logistics, food retail, and food services. The shift from farm to off-farm employment in agri-food systems has been most pronounced in countries that have transitioned from state-run to market-based systems (Barrett, Reardon, Swinnen, & Zilberman, 2019). Dorosh and Thurlow (2018) underline the importance of agricultural growth for poverty reduction in sub-Saharan Africa; however, this effect sometimes is exceeded by growth in agri-food processing and trade.

The transfer of benefits from increased agricultural activity to non-farm economic growth is not automatic. Hornbeck and Keskin (2015) find no evidence of long-term economic spillovers from increased agricultural production above the Ogallala Aquifer in the United States as irrigation technologies improved. Their study, although not focused specifically on labor, reinforces the notion proposed by Timmer (1988) that economic linkages between agricultural and non-agricultural sectors are critical to economic development; however, they may not form without appropriate institutions or government policies.

In high-income countries, the future of agriculture, as well as other nodes in the AFS, likely will include the expanded use of robotic solutions to grow, harvest, process, and market crops as well as a complementary demand for engineers and technicians. It is possible that the main source of labor for this technologically-advanced workforce will shift back to domestic workers, if educational systems are able to create the AFS workforce of the future. Otherwise, the demand for high-skilled immigrant workers is bound to increase, as labor-saving solutions become more complex on farms and elsewhere within the AFS.

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References

Acemoglu, D. (2010). When does labor scarcity encourage innovation? *Journal of Political Economy*, *118*(6), 1037–1078.

ADB. (2020). *Food security in Asia and the Pacific amid the COVID-19 pandemic*. Retrieved December 18, 2020 from https://www.adb.org/sites/default/files/publication/611671/adb-brief-139-food-security-asia-pacific-covid-19.pdf.

Afifi, T. (2011). Economic or environmental migration? The push factors in Niger. *International Migration*, *49*(S1), e95–e124.

Afifi, T., Liwenga, E., & Kwezi, L. (2014). Rainfall-induced crop failure, food insecurity and out-migration in same-Kilimanjaro, Tanzania. *Climate and Development*, *6*, 53–60.

Aid, C. (2007). *Human tide: The real migration crisis*. London: Christian Aid.

Ajefu, J., & Abiona, O. (2019). Impact of shocks on labour and schooling outcomes and the role of public work programmes in rural India. *The Journal of Development Studies*, *55*(6), 1140–1157.

Akresh, R. (2005). *Understanding pareto inefficient intrahousehold allocations*. IZA Discussion Paper No. 1858.

Alem, Y., Bezabih, M., Kassie, M., & Zikhali, P. (2010). Does fertilizer use respond to rainfall variability? Panel data evidence from Ethiopia. *Agricultural Economics*, *41*(2), 165–175.

Alem, Y., Maurel, M., & Millock, K. (2016). *Migration as an adaptation strategy to weather variability: An instrumental variable probit analysis: Working paper in economics n. 665*. Göteborg, Sweden: University of Gothenburg.

Alscher, S. (2011). Environmental degradation and migration on Hispaniola Island. *International Migration*, *49*(S1), e164–e188.

Amuedo-Dorantes, C., Puttitanun, T., & Martinez-Donate, A. P. (2019). Deporting "Bad Hombres"? The profile of deportees under widespread versus prioritized enforcement. *International Migration Review*, *53*(2), 518–547.

Anand, S., & Kanbur, S. M. R. (1993). The Kuznets process and the inequality-development relationship. *Journal of Development Economics*, *40*(1), 25–52.

Andrews, M. J., Golan, J., & Lay, J. (2015). Inefficiency of male and female labor supply in agricultural households: Evidence from Uganda. *American Journal of Agricultural Economics*, *97*(3), 998–1019.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity and social factors*. Princeton University Press (Chapter 23).

Arslan, A., & Edward Taylor, J. (2012). Transforming rural economies: Migration, income generation and inequality in rural Mexico. *Journal of Development Studies*, *48*(8), 1156–1176.

Arthur Lewis, W. (1954). Economic development with unlimited supplies of labour. *The Manchester School*, *22*(2), 139–191.

Auffhammer, M., & Vincent, J. R. (2012). Unobserved time effects confound the identification of climate change impacts. *Proceedings of the National Academy of Sciences*, *109*, 11973–11974.

Bagwell, K., & Staiger, R. W. (2001). Domestic policies, national sovereignty, and international economic institutions. *The Quarterly Journal of Economics*, *116*(2), 519–562.

Barrett, C. B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy*, *33*, 299–317.

Barrett, C., Reardon, T., Swinnen, J., & Zilberman, D. (2019). *Structural transformation and economic development: Insights from the agri-food value chain revolution*. Mimeo: Cornell University.

Barrett, C. B., Reardon, T., Swinnen, J., & Zilberman, D. (2020). Agri-food value chain revolutions in low-and middle-income countries. *Journal of Economic Literature*, *58*, 1–67.

Barrett, C. B., Reardon, T., & Webb, P. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Policy*, *26*(4), 315–331.

Barrientos, S. W. (2013). 'Labour chains': Analyzing the role of labour contractors in global production networks. *Journal of Development Studies*, *49*(8), 1058–1071.

Basu, A. K. (2013). Impact of rural employment guarantee schemes on seasonal labor markets: Optimum compensation and workers' welfare. *Journal of Economic Inequality*, *11*, 1–34.

Basu, A. K., & Chau, N. H. (2004). Exploitation of child labor and the dynamics of debt bondage. *Journal of Economic Growth*, *9*, 209–238.

Beaman, L., Karlan, D., Thuysbaert, B., & Udry, C. (2013). Profitability of fertilizer: Experimental evidence from female rice farmers in Mali. *American Economic Review: Papers & Proceedings*, *103*(3), 381–386.

Beatty, T., Hill, A., Martin, P., & Rutledge, Z. (2020). COVID-19 and farm workers: Challenges facing California agriculture. *ARE Update*, *23*(5), 2–4.

Beegle, K., Dejejia, R. H., & Gatti, R. (2006). Child labor and agricultural shocks. *Journal of Development Economics*, *81*, 80–96.

Beine, M., & Parsons, C. (2015). Climatic factors as determinants of international migration. *Scandinavian Journal of Economics*, *117*, 723–767.

Belton, B., & Filipski, M. (2019). Rural transformation in central Myanmar: By how much, and for whom? *Journal of Rural Studies*, *67*, 166–176.
Benjamin, D. (1992). Household composition, labor markets, and labor demand: Testing for separation in agricultural household models. *Econometrica*, *60*(2), 287–322.
Bhaskar, V., Manning, A., & To, T. (2002). Oligopsony and monopsonistic competition in labor markets. *Journal of Economic Perspectives*, *16*(2), 155–174.
Bhorat, H., Kanbur, R., & Stanwix, B. (2014). Estimating the impact of minimum wages on employment, wages, and non-wage benefits: The case of agriculture in South Africa. *American Journal of Agricultural Economics*, *96*(5), 1402–1419.
Böhme, M. H. (2015). Does migration raise agricultural investment? An empirical analysis for rural Mexico. *Agricultural Economics*, *46*(2), 211–225. https://doi.org/10.1111/agec.12152.
Bohra-Mishra, P., Oppenheimer, M., Cai, R., Feng, S., & Licker, R. (2017). Climate variability and migration in the Philippines. *Population and Environment*, *38*, 286–308.
Bohra-Mishra, P., Oppenheimer, M., & Hsiang, S. M. (2014). Nonlinear permanent migration response to climatic variations but minimal response to disasters. *Proceedings of the National Academy of Science USA*, *111*, 9780–9785.
Boucher, S. R., Smith, A., Taylor, J. E., & Yúnez-Naude, A. (2007). Impacts of policy reforms on the supply of Mexican labor to US farms: New evidence from Mexico. *Review of Agricultural Economics*, *29*(1), 4–16.
Brady, M. P., Gallardo, R. K., Badruddozza, S., & Jiang, X. (2016). Regional equilibrium wage rate for hired farm workers in the tree fruit industry. *Western Economics Forum*, *15*(1), 1–12.
Bryan, G., Chowdhury, S., & Mushfiq Mobarak, A. (2014). Underinvestment in a profitable technology: The chase of seasonal migration in Bangladesh. *Econometrica*, *82*(5), 1671–1748.
Buccola, S., Li, C., & Reimer, J. (2012). Minimum wages, immigration control, and agricultural labor supply. *American Journal of Agricultural Economics*, *94*(2), 464–470.
Bustos, P., Caprettini, B., & Ponticelli, J. (2016). Agricultural productivity and structural transformation. *American Economic Review*, *106*(6), 1320–1365.
Cai, R., Feng, S., & Oppenheimer, M. (2016). Climate variability and international migration: The importance of the agricultural linkage. *Journal of Environmental Economics and Management*, *79*, 135–151.
California Legislative Information. (2021). *Labor code, division 2, part 3.5, chapter 6, section 1160.3*. Retrieved May 17, 2021 from: https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=LAB&sectionNum=1160.3.
Card, D., & Krueger, A. B. (1994). Minimum wages and employment: A case study of the fast food industry in New Jersey and Pennsylvania. *The American Economic Review*, *84*(4), 772–793.
Card, D., & Lewis, E. G. (2005). *The diffusion of Mexican immigrants during the 1990s: Explanations and impacts*. National Bureau of Economic Research Working Paper 11552.
Cassey, A. J., Lee, K., Sage, J., & Tozer, P. R. (2018). Assessing post harvest labor shortages, wages, and welfare. *Agricultural and Food Economics*, *6*(17).
Castillo, M., & Charlton, D. (2021). *Housing booms and H-2A Agricultural guest worker employment*. (Working Paper).
Castillo, M., & Simnitt, S. (2020). *Farm labor*. USDA, Economic Research Service. April. Retrieved May 20, 2021 from: https://www.ers.usda.gov/amber-waves/2019/may/us-hired-farm-workforce-is-aging/.

Cattaneo, C., & Massetti, E. (2015). *Migration and climate change in rural Africa*. Milano, Italy: Fondazione Eni Enrico Mattei.
Cattaneo, C., & Peri, G. (2016). The migration response to increasing temperatures. *Journal of Development Economics*, *122*, 127–146.
Champlin, D., & Hake, E. (2006). Immigration as industrial strategy in American meatpacking. *Review of Political Economy.*, *18*(1), 49–70.
Charlton, D., & Castillo, M. (2020). Potential impacts of a pandemic on the U.S. Farm Labor Market. *Applied Economic Perspectives & Policy*, *43*(1), 39–58. https://doi.org/10.1002/aepp.13105.
Charlton, D., & Edward Taylor, J. (2016). A declining farm workforce: Analysis of panel data from rural Mexico. *American Journal of Agricultural Economics*, *984*, 1158–1180.
Charlton, D., & Kostandini, G. (2020). Can technology compensate for a labor shortage? Effects of 287(g) immigration policies on the U.S. dairy industry. *American Journal of Agricultural Economics*, *103*(1), 70–89.
Charlton, D., & Taylor, J. E. (2020). Rural school access and the agricultural transformation. *Agricultural Economics*, *51*(5), 641–654.
Charlton, D., Taylor, J. E., Vougioukas, S., & Rutledge, Z. (2019a). Can wages rise quickly enough to keep workers in the fields? *Choices*, *34*(2), 1–7.
Charlton, D., Taylor, J. E., Vougioukas, S., & Rutledge, Z. (2019b). Innovations for a shrinking agricultural workforce. *Choices*, *34*(2), 1–8.
Cho, S. J., Lee, J. Y., & Winters, J. V. (2020). *COVID-19 employment status impacts on food sector workers*. Iowa State University. Economics working paper no. 20013.
Christiaensen, L. (2020). *Agriculture, jobs, and value chains in Africa*. World Bank Group, Open Knowledge Repository. https://openknowledge.worldbank.org/handle/10986/33693.
Christiaensen, L., Rutledge, Z., & Taylor, J. E. (2020). Viewpoint: The future of work in agri-food. *Food Policy*, *99*.
Clemens, M. A., Lewis, E. G., & Postel, H. M. (2018). Immigration restrictions as active labor market policy: Evidence from the Mexican Bracero exclusion. *American Economic Review*, *108*(6), 1468–1487.
Conley, T., & Udry, C. (2001). Social learning through networks: The adoption of new agricultural technologies in Ghana. *American Journal of Agricultural Economics*, *83*(3), 668–732.
Conley, T., & Udry, C. (2010). Learning about new technology: Pineapple in Ghana. *American Economic Review*, *100*(1), 35–69.
Corrado, A., de Castro, C., & Perrotta, D. (Eds.). (2016). *Migration and agriculture: Mobility and change in the Mediterranean area* Routledge.
Cortignani, R., Carulli, G., & Dono, G. (2020). COVID-19 and labour in agriculture: Economic and productive impacts in an agricultural area of the Mediterranean. *Italian Journal of Agronomy*, *15*(2), 172–181.
Costa, D., & Martin, P. (2020). *Coronavirus and farmworkers. Working paper*. Economic Policy Institute.
Cretan, R., & Light, D. (2020). COVID-19 in Romania: Transnational labour, geopolitics, and the ROMA 'outsiders'. *Eurasian Geography and Economics*.
Das, U. (2015). Can the rural employment guarantee scheme reduce rural out-migration: Evidence from West Bengal, India. *The Journal of Development Studies*, *51*(6), 621–641.
Davis, B., Handa, S., Hypher, N., Rossi, N. W., Winters, P., & Yablonski, J. (Eds.). (2016). *From evidence to action: The story of cash transfers and impact evaluation in Sub Saharan Africa*. Oxford: Oxford University Press.

Davis, G. C., & Espinoza, M. C. (1998). A unified approach to sensitivity analysis in equilibrium displacement models. *Southern Journal of Agricultural Economics*, *80*, 868–879.

De Janvry, A., Finan, F., Sadoulet, E., & Vakis, R. (2006). Can conditional cash transfer programs serve as safety nets in keeping children at school and from working when exposed to shocks? *Journal of Development Economics*, *79*, 349–373.

De la Briere, B., Sadoulet, E., de Janvry, A., & Lambert, S. (2002). The roles of destination, gender, and household composition in explaining remittances: An analysis for the Dominican sierra. *Journal of Development Economics*, *68*(2), 309–328.

Deninger, K., & Liu, Y. (2019). Heterogeneous welfare impacts of National Rural Employment Guarantee Scheme: Evidence from Andhra Pradesh, India. *World Development*, *117*, 98–111.

Dickens, R., Machin, S., Manning, A., Metcalf, D., Wadsworth, J., & Woodland, S. (1995). The effect of minimum wages on UK agriculture. *Journal of Agricultural Economics*, *46*(1), 1–19.

Dillon, A., Mueller, V., & Salau, S. (2011). Migratory responses to agricultural risk in northern Nigeria. *American Journal of Agricultural Economics*, *93*, 1048–1061.

Dorosh, P., & Thurlow, J. (2018). Beyond agriculture versus non-agriculture: Decomposing sectoral growth-poverty linkages in five African countries. *World Development*, *109*, 440–451.

Duffield, J. A. (1990). *Estimating farm labor elasticities to analyze the effects ff immigration reform*. USDA, Economic Research Service, agriculture and rural economy division. Staff report no. AGES 9013.

Dun, O. (2011). Migration and displacement triggered by floods in the Mekong delta. *International Migration*, *49*(S1), e200–e223.

Edward Taylor, J., Charlton, D., & Yúnez-Naude, A. (2012). The end of farm labor abundance. *Applied Economic Perspectives and Policy*, *344*, 587–598.

Elad, R. L., & Houston, J. E. (2002). Seasonal labor constraints and intra-household dynamics in the female fields of southern Cameroon. *Agricultural Economics*, *27*, 23–32.

El Hinnawi, E. (1985). *Environmental* refugees. Rep., U. N. Environment Programme.

Environmental Justice Foundation. (2021). *Protecting climate refugees*. Retrieved May 12, 2021 from: https://ejfoundation.org/what-we-do/climate/protecting-climate-refugees?.

Escobar, A., Martin, P., & Stabridis, O. (2019). *Farm labor and Mexico's export produce industry*. Washington, DC: Wilson Center. https://www.wilsoncenter.org/sites/default/files/media/uploads/documents/mexico%20farm%20book_V2.pdf.

Falco, C., Donzelli, F., & Olper, A. (2018). Climate change, agriculture, and migration: A survey. *Sustainability*, *10*(5).

Fan, M., Gabbard, S., Pena, A. A., & Perloff, J. M. (2015). Why do fewer agricultural workers migrate now? *American Journal of Agricultural Economics*, *97*(3), 665–679.

Farbotko, C., & Lazrus, H. (2012). The first climate refugees? Contesting global narratives of climate change in Tuvalu. *Global Environmental Change*, *22*, 382–390.

Feng, S., Krueger, A. B., & Oppenheimer, M. (2010). Linkages among climate change, crop yields, and Mexico-US cross-border migration. *Proceedings of the National Academy of Sciences*, *107*, 14257–14262.

Feng, S., Oppenheimer, M., & Schlenker, W. (2013). *Weather anomalies, crop yields and migration in the US Corn Belt; NBER working paper w17734*. National Bureau of Economic Research: Cambridge, MA, USA.

Fergusson, L., Ibáñez, A. M., & Riaño, J. F. (2020). Conflict, educational attainment, and structural transformation: La violencia in Colombia. *Economic Development and Cultural Change*, *69*(1), 335–371.

Filipski, M., Aboudrare, A., Lybbert, T. J., & Taylor, J. E. (2017). Spice price spikes: Simulating impacts of saffron price volatility in a gendered local economy-wide model. *World Development*, *91*, 84–99.

Filipski, M., Gupta, A., Kagin, J., Husain, A., Grinspun, A. O., Caccavale, M., et al. (2020). Are rural households immune to COVID-19? A meta local economy approach for sub-Saharan Africa. In *Presented at Socialprotection.org global E-conference: Turning the COVID-19 crisis into an opportunity: What's next for social protection? October 7, 2020*. https://www.youtube.com/watch?v=Y2B1Nu2Vw5c.

Filipski, M., Lee, H. L., Hein, A., & Nischan, U. (2019). Emigration and rising wages in Myanmar: Evidence from Mon State. *Journal of Development Studies*. https://doi.org/10.1080/00220388.2019.1626834.

Filipski, M., Taylor, J. E., & Msangi, S. (2011). Effects of free trade on women and immigrants: CAFTA and the Rural Dominican Republic. *World Development*, *39*(10), 1862–1877.

Filipski, M., Thome, K., Taylor, EdwardJ., & Davis, B. (2015). Effects of treatment beyond the treated: A general equilibrium impact evaluation of Lesotho's cash grants program. *Agricultural Economics*, *46*(2), 227–243.

Filmer, D., & Fox, L. (2014). *Youth employment in Sub-Saharan Africa*. *Africa development forum*. Washington, DC: World Bank and Agence Française de Développement. https://openknowledge.worldbank.org/handle/10986/16608 License: CC BY 3.0 IGO.

Findley, S. E. (1994). Does drought increase migration? A study of migration from rural Mali during the 1983–1985 drought. *International Migration Review*, *28*, 539–553.

Fisher, D. U., & Knutson, R. D. (2012). Uniqueness of agricultural labor markets. *American Journal of Agricultural Economics*, *95*(2), 463–469.

Foresight. (2011). *Migration and global environmental change: Future challenges and opportunities*. London: The Government Office for Science. Retrieved May 12, 2021 from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/287717/11-1116-migration-and-global-environmental-change.pdf.

Foster, A. D., & Gehrke, E. (2017). *Start what you finish! Ex ante risk and schooling investments in the presence of dynamic complementarities*. NBER working paper 24041.

Foster, A. D., & Rosenzweig, M. R. (1996). Technical change and human-capital returns and investments: Evidence from the Green revolution. *The American Economic Review*, *86*(4), 931–953.

Garip, F. (2014). The impact of migration and remittances on wealth accumulation and distribution in rural Thailand. *Demography*, *51*(2), 673–698.

Gibson, J., & McKenzie, D. (2014). The development impact of a best practice seasonal worker policy. *The Review of Economics and Statistics*, *96*(2), 229–243.

Gibson, J., McKenzie, D., & Stillman, S. (2011). The impacts of international migration on remaining household members: Omnibus results from a migration lottery program. *The Review of Economics and Statistics*, *93*(4), 1297–1318.

Gibson, J., McKenzie, D., & Stillman, S. (2013). Accounting for selectivity and duration-dependent heterogeneity when estimating the impact of emigration on incomes and poverty in sending areas. *Economic Development and Cultural Change*, *61*(2), 247–280.

Gollin, D., Parente, S., & Rogerson, R. (2002). The role of agriculture in development. *The American Economic Review*, *92*(2), 160–164.

Gongal, A., Amatya, S., Karkee, M., Zhang, Q., & Lewis, K. (2015). Sensors and systems for fruit detection and localization: A review. *Computers and Electronics in Agriculture*, *116*, 8–19.

Gray, C. (2009). Environment, land and rural out-migration in the southern Ecuadorian Andes. *World Development*, *37*, 457–468.
Gray, C., & Bilsborrow, R. (2013). Environmental influences on human migration in rural Ecuador. *Demography*, *50*, 1217–1241.
Gray, C., & Mueller, V. (2012a). Drought and population mobility in rural Ethiopia. *World Development*, *40*, 134–145.
Gray, C., & Mueller, V. (2012b). Natural disasters and population mobility in Bangladesh. *PNAS*, *109*(16), 6000–6005.
Gray, C., & Wise, E. (2016). Country-specific effects of climate variability on human migration. *Climate Change*, *135*, 555–568.
Green, R., Martin, P., & Taylor, J. E. (2003). Welfare reform in agricultural California. *Journal of Agricultural and Resource Economics*, *28*(1), 169–183.
Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica*, *25*(4), 501–522.
Grossman, J. B. (1983). The impact of the minimum wage on other wages. *The Journal of Human Resources*, *18*(3), 359–378.
Gunter, L. F., Jarett, J. C., & Duffield, J. A. (1992). Effect of U.S. immigration reform on labor intensive agricultural commodities. *American Journal of Agricultural Economics*, *74*(4), 897–906.
Gupta, A., Zhu, H., Doan, M. K., Michuda, A., & Majumder, B. (2020). Economic impacts of the COVID-19 lockdown in a remittance-dependent region. *American Journal of Agricultural Economics*, *103*(2), 466–485.
Haley, E., Caxaj, S., Glynis, G., Hennebry, J. L., Martell, E., & McLaughlin, J. (2020). Migrant farmworkers face heightened vulnerabilities during COVID-19. *Journal of Agriculture, Food Systems, and Community Development*, *9*(3), 35–39.
Halliday, T. (2006). Migration, risk, and liquidity constraints in El Salvador. *Economic Development and Cultural Change*, *54*(4), 893–925.
Hanson, G., Liu, C., & McIntosh, C. (2017). *The rise and fall of U.S. low-skilled immigration*. NBER Working Paper 23753.
Hassan, F., & Kornher, L. (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.
Hassani-Mahmooei, B., & Parris, B. W. (2012). Climate change and internal migration patterns in Bangladesh: An agent-based model. *Environment and Development Economics*, *17*, 763–780.
Henry, S., Piche, V., Ouedraogo, D., & Lambin, E. F. (2004). Descriptive analysis of the individual migratory pathways according to environmental typologies. *Population and Environment*, *25*(5), 397–422.
Henry, S., Schoumaker, B., & Beauchemin, C. (2004). The impact of rainfall on the first outmigration: A multi-level event-history analysis in Burkina Faso. *Population and Environment*, *25*, 423–460.
Hertz, T., & Zahniser, S. (2012). Is there a farm labor shortage? *American Journal of Agricultural Economics*, *95*(2), 476–481.
Hicks, J. R. (1932). *The theory of wages*. London: Macmillan.
Hill, A. (2019). *The labor supply of U.S. agricultural workers (working paper)*. Retrieved from the UC Davis farm labor website: https://farmlabor.ucdavis.edu/sites/g/files/dgvnsk5936/files/inline-files/Ali%20Hill%3B%20US%20Labor%20Supply.pdf.

Hill, A., & Burkardt, J. (2021). Peers in the field: The role of ability and gender in peer effects among agricultural workers. *The American Journal of Agricultural Economics*, *103*(3), 790–811.
Hirsch, H. G. (1967). *Effects of changes in use of seasonal workers on U.S.-Mexican agricultural trade and balance of payments*. Economic Research Service.
Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Canadian Journal of Agricultural Economics*, *68*, 171–176.
Hornbeck, R., & Keskin, P. (2015). Does agriculture generate local economic spillovers? Short-run and long-run evidence from the Ogallala Aquifer. *American Economic Journal: Economic Policy*, *7*(2), 192–213.
Hornbeck, R., & Naidu, S. (2014). When the levee breaks: Black migration and economic development in the American South. *American Economic Review*, *104*(3), 963–990.
Horner, C. (2011). Testimony. In *Hearing on America's agricultural labor crisis: Enacting a practical solution.* Subcommittee on Immigration, Refugees, and Border Security, U.S. Congress, Senate Committee on Judiciary (October 4).
Hur, J., & Zhao, L. (2009). Labor standards, labor-management bargaining and international rivalry. *Journal of Economic Behavior & Organization*, *71*(2), 259–272.
Hyami, Y., & Ruttan, V. (1971). *Agricultural development: An international perspective*. Baltimore, MD: The Johns Hopkins Press.
Ifft, J., & Jodlowski, M. (2016). *Is ICE freezing US agriculture? Impacts of local immigration enforcement on US farm profitability and structure*. (AAEA Conference Paper).
Imbert, C., & Papp, J. (2015). Labor market effects of social programs: Evidence from India's employment guarantee. *American Economic Journal: Applied Economics*, *7*(2), 233–263.
IPCC. (2014). *Climate change 2014: Impacts, adaptation, and vulnerability: The Working Group II contribution to the IPCC fifth assessment report (WGII AR5)*. (IPCC Report).
Iqbal, K., & Roy, P. K. (2015). Climate change, agriculture and migration: Evidence from Bangladesh. *Climate Change Economics*, *6*, 1550006.
Jacoby, H. (1992). Productivity of men and women and the sexual division of labor in peasant agriculture of the Peruvian sierra. *Journal of Development Economics*, *37*(1–2), 265–287.
Jessoe, K., Manning, D. T., & Taylor, J. E. (2018). To. Climate change and labour allocation in rural Mexico: Evidence from annual fluctuations in weather. *The Economic Journal*, *128*(608), 230–261.
Johnston, B. F., & Mellor, J. W. (1961). The role of agriculture in economic development. *The American Economic Review*, *51*(4), 566–593.
Johnston, B. F., & Nielsen, S. T. (1966). Agricultural and structural transformation in a developing economy. *Economic Development and Cultural Change*, *14*(3), 279–301.
Just, R., & Zilberman, D. (1988). The effects of agricultural development policies on income distribution and technological change in agriculture. *Journal of Development Economics*, *28*, 193–216.
Kandilov, A. M. G., & Kandilov, I. T. (2020). The minimum wage and seasonal employment: Evidence from the U.S. agricultural sector. *Journal of Regional Science*, *60*(4), 612–627.
Khandker, S. R. (2012). Seasonality of income and poverty in Bangladesh. *Journal of Development Economics*, *97*, 244–256.
Kirui, O. K. (2019). *The agricultural mechanization in Africa: Micro-level analysis of the state drivers and effects*. ZEF-Discussion Papers on Development Policy (No. 272).
Kislev, Y., & Peterson, W. (1982). Prices, technology, and farm size. *Journal of Political Economy*, *90*(3), 578–595.

Kostandini, G., Mykerezi, E., & Escalante, C. (2014). The impact of immigration enforcement on the U.S. farming sector. *American Journal of Agricultural Economics*, *96*(1), 172–192.

Krogstad, J. M., & Gonzalez-Barrera, A. (2019). *Key facts about US immigration policies and proposed changes*. Pew Research Center.

Kubik, Z., & Maurel, M. (2016). Weather shocks, agricultural production and migration: Evidence from Tanzania. *Journal of Development Studies*, *52*, 665–680.

Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review*, *65*(1), 1–28.

Larue, B. (2020). Labor issues and COVID-19. *Canadian Journal of Agricultural Economics*, *68*(2), 231–237. https://doi.org/10.1111/cjag.12233.

Lele, U., & Mellor, J. W. (1981). Technological change, distributive bias and labor transfer in a two sector economy. *Oxford Economic Papers New Series*, *33*(3), 426–441.

Levin, R. (1988). Appropriability, R&D spending, and technological performance. *The American Economic Review*, *78*(2), 424–428.

Levine, L. (2009). *Farm labor shortages and immigration policy*. Congressional Research Service Report RL30395.

Li, A., & Reimer, J. J. (2020). The US market for agricultural labor: Evidence from the national agricultural workers survey. *Applied Economic Perspectives and Policy*, *43*(3), 1–15.

Lilleør, H. B., & Van den Broeck, K. (2011). Economic drivers of migration and climate change in LDCs. *Global Environmental Change*.

Liu, Y., Barrett, C. B., Pham, T., & Violette, W. (2020). The intertemporal evolution of agriculture and labor over a rapid structural transformation: Lessons from Vietnam. *Food Policy*, *94*.

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, *333*(6042), 616–620.

Lohmar, B., Gale, F., Tuan, F., & Hansen, J. (2009). *China's ongoing agricultural modernization: Challenges remain after 30 years*. USDA ERS Economic Information Bulletin (No. 51).

Lu, L., Reardon, T., & Zilberman, D. (2016). Supply chain design and adoption of indivisible technology. *American Journal of Agricultural Economics*, *98*(5), 1419–1431.

Lucas, R. E. (1987). Emigration to South Africa's mines. *The American Economic Review*, *77*(3), 313–330.

Luo, T., Kostandini, G., & Jordan, J. L. (2018). The impact of LAWA on the family labor supply among farm households. *European Review of Agricultural Economics*, *45*(5), 857–878.

Lusk, J. L. (2016). *The evolving role of the USDA in the food and agricultural economy*. Arlington, VA: Mercatus Research, Mercatus Center at George Mason University (June).

Ma, M., Lin, J., & Sexton, R. J. (2021). The transition from small to large farms in developing economies: A welfare analysis. *American Journal of Agricultural Economics*.

Ma, S., Karkee, M., Fu, H., Sun, D., & Zhang, Q. (2016). Air suspension-based catching mechanism for mechanical harvesting of apples. *IFAC-PapersOnLine*, *49*, 353–358, (5th IFAC Conference on Sensing, Control and Automation Technologies for Agriculture. AGRICONTROL 2016.).

MacDonald, J. M. (2020). Tracking the consolidation of US agriculture. *Applied Economic Perspectives and Policy*, *42*(3), 361–379.

Malone, T., Shaefer, K. A., & Wu, F. (2020). The razor's edge of "essential" labor in food and agriculture. *Applied Economic Perspectives and Policy*, *43*(1), 368–381.

Manning, A. (2003). *Monopsony in motion: Imperfect competition in labor markets*. New Jersey: Princeton University Press.

Martin, W. E. (1966). Alien workers in United States agriculture: Impacts on production. *Journal of Farm Economics*, *48*(5), 1137–1145.

Martin, P. (2002). Mexican workers and US agriculture: The revolving door. *International Migration Review*, *36*, 1124–1142.

Martin, P. (2007). Farm labor shortages: How real, what response? *ARE Update*, *10*(5).

Martin, P. (2017). *Hired U.S. and California farm workers are aging and settling*. Rural Connections.

Martin, P. L., Egan, D., & Luce, S. (1988). *The wages and fringe benefits of unionized California farmworkers*. Giannini information series no. 88-4. Retrieved May 18, 2021 from: https://econpapers.repec.org/paper/agsdgiais/251904.htm.

Martin, P., & Egan, D. (1989). The makewhole remedy in California agriculture. *ILR Review*, *43*(1), 120–130.

Martin, P., & Taylor, J. E. (2003). Farm employment, immigration and poverty: A structural analysis. *Journal of Agricultural and Resource Economics*, *28*(2), 1–15.

Martin, P. L., Vaupel, S., & Egan, D. L. (1988). *Unfulfilled promise: Collective bargaining in California agriculture*. Boulder: Westview. Retrieved May 18, 2021 from: https://1lib.us/book/5409781/f5ec79.

Massey, D. S., Axinn, W. G., & Ghimire, D. J. (2010). Environmental change and outmigration: Evidence from Nepal. *Population and Environment*, *32*, 109–136.

Mastrorillo, M., Licker, R., Bohra-Mishra, P., Fagiolo, G., Estes, L. D., & Oppenheimer, M. (2016). The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, *39*, 155–169.

McLeman, R. (2012). Developments in modelling of climate change-related migration. *Climatic Change*, *117*, 599–611.

McLeman, R. A., & Ploeger, S. K. (2012). Soil and its influence on rural drought migration: Insights from depression-era southwestern Saskatchewan, Canada. *Population and Environment*, *33*, 304–332.

McNamara, K. E., & Gibson, C. (2009). We do not want to leave our land: Pacific ambassadors at the United Nations resist the category of 'climate refugees'. *Geoforum*, *40*, 475–483.

Mendelsohn, R. O., & Massetti, E. (2017). The use of cross-sectional analysis to measure climate impacts on agriculture: Theory and evidence. *Review of Environmental Economics and Policy*, *11*(2), 280–298.

Millock, K. (2015). Migration and environment. *Annual Review of Resource Economics*, *7*, 35–60.

Missirian, A., & Schlenker, W. (2017). Asylum applications respond to temperature fluctuations. *Science*, *358*, 1610–1614.

Mitaritonna, C., & Ragot, L. (2020). *After COVID-19, will seasonal migrant agricultural workers in Europe be replaced by robots?*. CEPII policy brief no. 33.

Moretti, E., & Perloff, J. M. (2000). *Minimum wage laws lower some agricultural wages*. CUDARE working paper no. 953.

Mortreux, C., & Barnett, J. (2009). Climate change, migration and adaptation in Funafuti, Tuvalu. *Global Environmental Change*, *19*, 105–112.

Mueller, V., Gray, C., & Kosec, K. (2014). Heat stress increases long-term human migration in rural Pakistan. *Nature Climate Change*, *4*, 182–185.

Muth, R. F. (1964). The derived demand curve for a productive factor and the industry supply curve. *Oxford Economic Papers, New Series*, *16*(2), 221–234.

Mutler, A. (2020). *Romanian migrants get COVID-19 as pandemic exposes bad conditions for East European workers*. (Radio Free Europe/Radio Liberty).
Nawrotzki, R. J., Riosmena, F., & Hunter, L. M. (2013). Do rainfall deficits predict U.S.-bound migration from rural Mexico? Evidence from the Mexican census. *Population Research and Policy Review*, *32*, 129–158.
Obokata, R., Veronis, L., & McLeman, R. (2014). Empirical research on international environmental migration: A systematic review. *Population and Environment*, *36*, 111–135.
Ohkawa, K. (1961). Balanced growth and the problem of agriculture. *Hitotsubashi Journal of Economics*, *2*(1), 13–25.
Orchardson, E. (2020). *Farm mechanization under COVID-19*. CIMMYT. Retrieved December 18, 2020 from: https://www.cimmyt.org/news/farm-mechanization-under-covid-19/.
Oseni, G., Corral, P., Goldstein, M., & Winters, P. (2015). Explaining gender differentials in agricultural production in Nigeria. *Agricultural Economics*, *46*, 285–310.
Pawel, M. (2006). *UFW: A broken contract*. (The Los Angeles Times).
Pigou, A. (1924). *The economics of welfare* (2nd ed.). London: Macmillan.
Piguet, E. (2010). Linking climate change, environmental degradation, and migration: A methodological overview. *Wiley Interdisciplinary Reviews: Climate Change*, *1*, 517–524. https://doi.org/10.1002/wcc.54.
Porter, J. J., Dessai, S., & Tompkins, E. L. (2014). What do we know about UK household adaptation to climate change? A systematic review. *Climate Change*, *127*, 371–379.
Poston, D. L., Zhang, L., Gotcher, D. J., & Gu, Y. (2009). The effect of climate on migration: United States, 1995–2000. *Social Science Research*, *38*, 743–753.
Preston, J. (2006). Pickers are few and growers blame congress, New York Times September 22. Retrieved April 24, 2018 from: http://www.nytimes.com/2006/09/22/washington/22growers.html?n¼Top%2FReference%2FTimes%20Topics%2FSubjects%2FF%2FFood&_r¼1.
Radel, C., Schmook, B., & McCanless, S. (2010). Environment, transnational labor migration, and gender. Case studies from southern Yucatan, Mexico and Vermont, USA. *Population and Environment*, *32*, 177–197.
Ragasa, C., & Lambrecht, I. (2020). COVID-19 and the food system: Setback or opportunity for gender equality. *Food Security*, *12*, 877–880.
Reardon, T. (1997). Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa. *World Development*, *25*(5), 735–747.
Reardon, T., Timmer, C. P., & Minten, B. (2012). Supermarket revolution in Asia and emerging development strategies to include small farmers. *Proceedings of the National Academy of Sciences*, *109*(31), 12332–12337.
Restuccia, D., Yang, D. T., & Zhu, Z. (2008). Agriculture and aggregate productivity: A quantitative cross-country analysis. *Journal of Monetary Economics*, *55*, 234–250.
Richards, T. (2018). Immigration reform and farm labor markets. *American Journal of Agricultural Economics*, *100*(4), 1050–1071.
Richards, T., & Patterson, P. (1998). Hysteresis and the shortage of agricultural labor. *American Journal of Agricultural Economics*, *80*, 683–695.
Riisgaard, L. (2005). International framework agreements: A new model for securing workers rights? *Industrial Relations*, *44*(4), 707–737.
Riisgaard, L. (2009). Global value chains, labor organization and private social standards: Lessons from east African cut flower industries. *World Development*, *37*(2), 326–340.

Rogozanu, C., & Gabor, D. (2020). *Are Western Europe's food supplies worth more than Eastern European workers' health?*. The Guardian.

Rosson, C. (2012). Regional views on the role of immigrant labor on U.S. and Southern dairies. *Journal of Agriculture and Applied Economics*, *44*(3), 269–277.

Rozelle, S., Taylor, J. E., & DeBrauw, A. (1999). Migration, remittances, and agricultural productivity in China. *American Economic Review*, *89*(2), 287–291.

Rueda, M. (2020). No pickers, no coffee: How COVID threatens Columbia's harvest. In *BBC News*. Retrieved December 18, 2020 from: https://www.bbc.com/news/world-latin-america-55172034.

Rutledge, Z., & Mérel, P. (2020). *Farm labor supply and food production (working paper)*. Retrieved May 19 from: https://www.zachrutledge.com/uploads/1/2/5/6/125679559/rutledge_jmp_current_version.pdf.

Rutledge, Z., & Taylor, J. E. (2019). California farmers change production practices as the farm labor supply declines. *ARE Update*, *22*(6), 5–8. Retrieved May 20, 2021 from: https://giannini.ucop.edu/filer/file/1565891668/19229/.

Salauddin, M., & Zaman, A. (2012). Nature and extent of population displacement due to climate change triggered disasters in south-western coastal region of Bangladesh. *International Journal of Climate Change Strategies and Management*, *4*, 54–65.

Saokaew, D. (2020). COVID-19: Labor shortage on Thai farms could threaten food supply. In *CGTN News*. Retrieved December 18, 2020 from: https://news.cgtn.com/news/2020-04-24/COVID-19-Labor-shortage-on-Thai-farms-could-threaten-food-supply-PWHjzzJ7SE/index.html.

Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate sever damages to US crop yields under climate change. *Proceedings of the National Academy of Science*, *106*(37), 15594–15598.

Schultz, T. W. (1956). Reflections on agricultural production, output and supply. *Journal of Farm Economics*, *38*(3), 748–762.

Shen, S., & Binns, T. (2012). Pathways, motivations and challenges: Contemporary Tuvaluan migration to New Zealand. *GeoJournal*, *77*, 63–82.

Shen, S., & Gemenne, F. (2011). Contrasted views on environmental change and migration: The case of Tuvaluan migration to New Zealand. *International Migration*, *49*(S1), e224–e242.

Singh, I., Squire, L., & Strauss, J. (1986). A survey of agricultural household models: Recent findings and policy implications. *The World Bank Economic Review*, *1*(1), 149–179.

Slavchevska, V. (2015). Gender differences in agricultural productivity: The case of Tanzania. *Agricultural Economics*, *46*, 334–355.

Sohn, R. (2020). *What is climate migration?*. Mashable. Retrieved May 12, 2021 from: https://mashable.com/article/what-is-climate-refugee-migration.

Staiger, J. S., Douglas, O., & Phibbs, C. S. (2010). Is there monopsony in the labor market? Evidence from a natural experiment. *Journal of Labor Economics*, *28*, 211–236.

Stark, O., & Taylor, J. E. (1989). Relative deprivation and international migration. *Demography*, *26*(1), 1–14.

Stark, O., & Taylor, J. E. (1991). Migration incentives, migration types: The role of relative deprivation. *The Economic Journal*, *101*(408), 1163–1178.

Stern, N. (2007). *The economics of climate change. The Stern review*. Cambridge, UK: Cambridge University Press.

Sunding, D., & Zilberman, D. (2001). The agricultural innovation process: Research and technology adoption in a changing agricultural sector. *Chapter 4 in The Handbook of Agricultural Economics: Vol. 1*. Elsevier Science B.V.

Taylor, J. E. (2010). Agricultural labor and migration policy. *Annual Review of Resource Economics*, *2*(1), 369–393.

Taylor, J. E., & Castelhano, M. (2016). Economic impacts of migrant remittances. In *International handbook of migration and population distribution* (pp. 525–541). Dordrecht: Springer.

Taylor, J. E., & Charlton, D. (2018). *The farm labor problem: A global perspective*. Amsterdam: Elsevier Academic Press.

Taylor, J. E., & Lopez-Feldman, A. (2010). Does migration make rural households more productive? Evidence from Mexico. *Journal of Development Studies*, *46*(1), 68–90.

Taylor, J. E., Rozelle, S., & De Brauw, A. (2003). Migration and incomes in source communities: A new economics of migration perspective from China. *Economic Development and Cultural Change*, *52*(1), 75–101.

Thilmany, D., & Martin, P. (1995). Farm labor contractors play new roles in agriculture. *California Agriculture*, *49*(5).

Timmer, C. P. (1988). The agricultural transformation. In *vol. 1*. *Handbook of development economics* (pp. 275–331).

Tshikala, S. K., Kostandini, G., & Fonsah, E. G. (2019). The impact of migration, remittances and public transfers on technology adoption: The case of cereal producers in rural Kenya. *Journal of Agricultural Economics*, *70*(2), 316–331.

Udry, C. (1996). Gender, agriculture production, and the theory of the household. *The Journal of Political Economy*, *104*(5), 1010–1046.

United Nations. (2020). *International migration stock [database]*. Retrieved December 23, 2020 from: https://www.un.org/en/development/desa/population/migration/data/estimates2/estimates19.asp.

USCIS. (2020). *USCIS response to coronavirus 2019 (COVID-19): H-2A temporary agricultural workers*. Retrieved July 7, 2020 from: https://www.uscis.gov/working-united-states/temporary-workers/h-2a-temporary-agricultural-workers.

Vasilaky, K. N., & Leonard, K. L. (2018). As good as the networks they keep? Improving outcomes through weak ties in rural Uganda. *Economic Development and Cultural Change*, *66*(4).

Veljanoska, S. (2021). Do remittances promote fertilizer use? The case of Ugandan farmers. *American Journal of Agricultural Economics* (In press).

Warner, K. (2010). Global environmental change and migration. Governance challenges. *Global Environmental Change*, *20*, 402–413.

Warner, K., Hamza, M., Oliver-Smith, A., Renaud, F., & Julca, A. (2010). Climate change, environmental degradation and migration. *Natural Hazards*, *55*, 689–715.

Weerasinghe, S. (2021). *What we know about climate change and migration*. Center for Migration Studies. Retrieved May 12, 2021 from: https://cmsny.org/publications/climate-change-migration-summary.

World Bank. (2020). World Bank open data [website]. https://data.worldbank.org.

Wrathall, D. J. (2012). Migration amidst social-ecological regime shift: The search for stability in Garifuna villages of northern Honduras. *Human Ecology*, *40*, 583–596.

Yang, D., & Choi, H. (2007). Are remittances insurance? Evidence from rainfall shocks in the Philippines. *World Bank Economic Review*, *21*(2), 219–248.

Zahniser, S., Hertz, T., Dixon, P., & Rimmer, M. (2011). U.S. agriculture and the market for hired farm labor: A simulation analysis. *American Journal of Agricultural Economics*, *94*(2), 477–482.

Zahniser, S., Taylor, J. E., Hertz, T., & Charlton, D. (2018). *Farm labor markets in the United States and Mexico pose challenges for U.S. agriculture*. U.S. Department of Agriculture, Economic Research Service. November. Retrieved May 20, 2021 from: https://www.ers.usda.gov/publications/pub-details/?pubid=90831.

Zhang, X., Yang, J., & Reardon, T. (2017). Mechanization outsourcing clusters and division of labor in Chinese agriculture. *China Economic Review*, *43*, 184–195.

Zhou, J., Han, F., Li, K., & Wang, Y. (2020). Vegetable production under COVID-19 pandemic in China: An analysis based on the data of 526 households. *Journal of Integrated Agriculture*, *19*(12), 2854–2865.