Evolving Agricultural Labor Markets

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Abstract

Agricultural employment is critical to the lives of hundreds of millions of men and women across the globe as well as to the farms that employ them and the communities in which they live. However, as the agricultural transformation unfolds, workers move off the farm to jobs in an expanding food services sector, in urban areas, and abroad, with far-reaching ramifications for agricultural producers and labor markets. This chapter examines the changing role of agricultural employment in developing and developed economies. It draws from two decades of research using a wide diversity of analytical approaches to document how agricultural labor markets evolve and the impact this evolution has on workers, farmers, and rural economies. We highlight new empirical findings, emerging themes, and policy implications, including the growing concentration of off-farm agri-food employment, migration, changing gender roles, and the legacy of the COVID-19 pandemic.

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 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 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, as countries in these regions rely upon farm workers 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.

[1] The term "low-skilled" is a 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.

This 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.

Part 2 provides a discussion of labor demand in the context of agricultural households, which have historically comprised the majority of farms in today's high-income countries and continue remain the primary type of household unit in the developing world. As the agricultural transformation unfolds, farms shift from relying primarily on family workers to employing more hired labor. Part 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. These 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. Part 4 focuses on research efforts to estimate impacts of agricultural labor supply shocks; Part 5, on efforts to identify impacts of immigration policies; Part 6 on climate-induced migration; Part 7 on farm worker welfare; and Part 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. Part 9 discusses labor-saving technological change and the prospect of robots in the field. We conclude in Part 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 worldwide come from rural households, including agricultural households that both produce crops and consume what they produce and landless households that merely provide labor to other farms and consume what they can purchase in the market (Hill et al., 2020). Distinguishing household types has important implications for labor supply decisions. Taylor and Charlton (2018) present a textbook model of farm labor supply from both household types.

In an economy with perfect consumer and labor market access, where agriculture is the only labor sector available, the farm labor supply decision reduces to the standard labor supply decision. Each household has a given time endowment, and the variables shaping leisure demand, including the agricultural wage (which serves as the opportunity cost of leisure in an economy where only agricultural wage work is possible) and the prices of other goods in the utility function determine farm labor supply. Other things being equal, the impact of a change in the agricultural wage in this simple model is ambiguous. An increase in the wage increases the opportunity cost of leisure, which has the effect of increasing labor supply. However, it also increases household income for any level of labor supplied, which has the effect of decreasing labor supply as long as leisure is a normal good.

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. The demand for labor, like other inputs, is set by standard first-order conditions for profit maximization. The household's consumption demand for the crop is determined by setting its marginal rate of substitution between leisure and consumption equal to the wage-to-crop price ratio, as in a consumer model. Unlike the consumer

model, however, the agricultural household's budget constraint (or full income) includes farm profits. This results in a recursive model, in which changes in the crop output price and/or wage affect consumption both directly and indirectly via the profit effect.

A price shock to the agricultural good could either benefit or harm a household that is both a producer and consumer of the good. As a producer, an increase in prices raises household income, but as a consumer, it makes consumption of the good more expensive, thereby reducing the real value of household income. Generally, if the household is a net seller of the good (e.g. the household does not consume as much of the good as it produces and sells the excess in the market), it will benefit from a positive price shock. If the household is a net buyer, it will be worse off. The income effects of the price change could potentially lead the household to alter its labor supply.

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, the agricultural household's production decisions affect its labor supply decisions and vice-versa. Farm profits, time endowments, and consumer preferences influence labor supply. In this sense, economists say that production decisions and consumer preferences are non-recursive or inseparable. A household's preferences, or equivalently its shadow values, for leisure and consumer goods determine how much labor the household provides and how much leisure the household consumes.

An agricultural household model (Singh et al., 1986) would add one new determinant of farm labor supply: farm capital, which appears in the household crop production function. If there are other variable (fixed) inputs in the crop production function, their prices (quantities) also would potentially affect farm labor supply. If capital and labor are complements, then

increased capital investment will increase the marginal product of labor and vice versa. If they are substitutes, capital investment would depress farm wages (reduce the marginal value product of labor on the farm) and induce migration off of the farm (Lele and Mellor, 1981). Beaman et al. (2013) find that women who received free fertilizer in a randomized experiment in Mali also increased complementary inputs of hired labor and herbicides, thus making it more difficult to study the returns to a single given input to production. Learning, or accumulation of human capital, can also be an important complementary input to new capital and technologies in agricultural production. Social networks, which can sometimes be gender specific, often play an important role in the decision to adopt a new technology (Conley and Udry, 2001, 2010; Vasilaky and Leonard, 2018).

2.1 Gender Considerations

Heterogeneous returns to labor along with preferences 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 within 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 and labor on women's plots. Andrews et al. (2014) find a similar result in Uganda. In Tanzania, Slavchevska (2015) finds lower returns to factors including male labor on female-managed plots and concluded 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. 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 greater consequences in the presence of such shocks.

Numerous variables may affect the returns to labor and other factors 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). Estimated substitutability of male and female labor on farms often vary within countries. Oseni et al. (2015) find that in Southern Nigeria women would be as productive in managing agricultural plots as men if they received equal inputs. In Northern Nigeria, however, women still produced an estimated 28% less than men, on average, after controlling for observable factors of production.

Division of tasks between men and women may be important in some contexts. 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 et al. (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 et al., 1996). 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 as 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 farm workers 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 non-agricultural wages accounted for 44% (Aslan and Taylor, 2012).[2]

An examination of nearly 100 studies by Reardon et al. (1998) find 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 households in northern China finds that nonfarm income (including remittances from rural-to-urban migrants) accounted for 45% of rural total income there (add citation here).

[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.

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 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 technologies and shifting from familial to commercial production. In this process, family migrants can play the role of financial intermediaries by providing capital and income insurance to their families' farms (Taylor and 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 in 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 et al. (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 et al. (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 selecting individuals to migrate from Tonga to New Zealand, Gibson et al. (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. Poorer households more frequently experienced net gains from labor migration.

Incentives for migrants to send remittances also 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 Brere et al., 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 and Taylor, 1991). This suggests that a number of factors within households or in households' nearby surroundings can potentially influence the decision to engage in labor migration or remit, and thus patterns of investment and agricultural productivity growth.

2.3 Seasonality of Agricultural Employment

The seasonality of farm production, and thus farm labor demand, can have dire implications in rural economies with few other occupational prospects. Migration to urban centers often plays a critical role in household survival through the lean season. Income and consumption in agricultural households often is lowest just prior to harvest because work opportunities are few and grain prices are high (Khandker and Mahmud, 2012). In Northern Bangladesh, the season

just prior to harvest is called the Monga and is frequently characterized by famine (Bryan et al. 2014; Khandker, 2012). Similarly, lean seasons are frequently observed in sub-Saharan Africa and South Asia. 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 more rural workers to migrate seasonally to urban centers where non-farm jobs are more plentiful. Bryan et al. (2014) investigated 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 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 projects (Deninger and Liu, 2013).

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, Impbert 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 since 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 and Abiona, 2019; Foster and Gehrke, 2017). However, Ajefu and Abiona (2019) find that NREGS generally leads to less schooling and increased hours

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

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 fruits, vegetables, and horticultural (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 and Charlton, 2018, Chapter 4). 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]

The seasonality of labor demand creates challenges for workers. 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 farm workers, who are mostly unauthorized immigrants from rural Mexico, the world's largest country of farm labor emigration, to fill a

[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).

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 to1980, 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 1980-1990. Beginning in the 1980s, both farm employment and immigration increased rural poverty rates, as immigrant farm workers 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.

In the early part of the 20th century, Southern plantation owners 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, 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 and Naidu, 2014). These findings, combined with those of Martin and Taylor (2003), illustrate how agricultural employment can sometimes keep workers in poverty and discourage the adoption of labor-saving technologies (see also Anad and Kanbur, 1993; Kuznets, 1955). However, 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). 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. Lewis assumed that at the early stages of development, the marginal product of labor on farms is negligible (i.e., labor is abundant). As a result, the manufacturing sector can pull workers off farms without raising wages and without having any effect on total agricultural production. However, at a certain point in the agricultural transformation, labor becomes scarcer and the marginal product of labor on farms begins to rise. This is the "Lewis Turning Point" beyond which the manufacturing sector cannot draw additional workers from the agricultural sector without increasing wages. This is a critical concept in economic development, because it illustrates how capital investment combined with labor mobility can increase standards of living over time.

The importance of industrial employment in economic development led some countries to pursue major policy reforms that promote growing employment in the industrial sector. However, investment in industrial employment without complementary investments in agricultural productivity can lead to food price inflation, which can stall economic development (Johnston and Nielson, 1966; Lele and Mellor, 1981). Many economists emphasize the fundamental importance of simultaneously raising agricultural productivity as an economy's industrial sector expands (Johnston and Mellor, 1961; Ohkawa, 1961; Timmer, 1988). Increased

productivity can raise rural wages and the demand for manufactured goods as the urban demand for food rises, and it frees up labor from food production to work in sectors with greater labor productivity (Gollin et al., 2002).

There are numerous examples around the world wherein technological improvements in agricultural production led to higher per capita incomes. Restuccia et al. (2008) emphasize the importance in economic development of removing barriers impeding the adoption of modern agricultural inputs in poor countries. Johnson (2000) argues that higher incomes would have been impossible without the increased knowledge and technological advancements that accompanied the industrial revolution. However, comparative advantage in agricultural production could also lead to situations commonly known as Dutch Disease, in which the economy invests primarily in agriculture and becomes dependent on commodities with low profit margins (Corden and Neary, 1982; Field, 1978; Krugman, 1987; Matsuyama, 1992; Mokyr 1976; Wright, 1979). Foster and Rosenzweig (2004) find no evidence that improved agricultural productivity positively affected local industrialization in India. Rather, technological advancements in agriculture put upward pressure on local wages, inducing manufacturers to seek out locations with lower wages. These findings illustrate how the effects of agricultural productivity growth on income may be smaller in an open economy. In the context of their study, Foster and Rosenzweig (2004) concluded that agricultural development and nonfarm activities were substitutes rather than complements. McMillan et al. (2014) suggest that structural change led to poorer economic performance in Latin America and Sub-Saharan Africa under trade liberalization from 1990-2000 because there were few opportunities for workers to move into more productive sectors as they were laid off from jobs in sectors unable to compete in a global market place.

The distributive bias of technological change is critical in determining changes in agricultural and non-farm employment (Lele and Mellor, 1981). Bustos et al. (2016) demonstrate empirically that factor bias of technological change affected industrial employment growth and wages in rural Brazil. In the case of improved maize, the technology increased labor demand per acre, and the introduction of the improved maize technology was not associated with increases in industrial employment. However, in the case of improved soy, the technology reduced labor per unit of land; thus, the technology was accompanied by downward pressure on farm wages and increased local industrial employment and out-migration of labor. Their findings, combined with those of Foster and Rosenzweig (2004) in India, illustrate that differences in factor bias of technological change can shape the course of the agricultural transformation.

Schultz (1956) argues that investment in humans as productive agents in agricultural production is critical to economic growth. Foster and Rozenzweig (2008) find that the development of new agricultural technologies can boost investment in human capital through increased education. However, raising rural education can have myriad effects on rural economies. In some cases, increased rural education can potentially improve expected earnings in the non-farm sector and thus increase rural-urban migration. Charlton and Taylor (2020) find that secondary school construction in rural Southern Mexico led to an increased probability that non-indigenous individuals grew up to work in the non-farm sector. Their findings illustrate that rural school construction may not 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 and Fox,

[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.

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 et al., 2006; de Janvry et al., 2006). Thus, social safety nets may be critical to maintain investments in human capital in agrarian societies where households are highly exposed to risk.

In highly developed countries, few people work in agriculture. In the United States, less than 1% 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 and Charlton, 2018). Labor-intensive agricultural production in California expanded through the employment of Chinese, Japanese, Hindu, Armenian, and Mexican immigrants (Taylor and Charlton, 2018). About two-thirds of crop workers in the United States in 2016, excluding H-2A guest workers, were born in Mexico.[7] 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). The case of Mexico is particularly well-documented, thanks to the availability of farmworker data from both sides of the border. 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. Taylor et al. (2012), using data from the 2003, 2008, and 2011

[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 and Martin, 2020).

[7] 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.

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 (most of whom previously had worked on farms in Mexico or the United States) 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.

Because Mexican immigrants are transitioning 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 to address the declining farm labor supply, which he dubs the **4 S**'s: **S**tretch, **S**upplement, **S**atisfy and **S**ubstitute. First of all, farmers can **S**tretch the existing workforce by increasing worker productivity through the use of improved time management practices or mechanical harvest aids. Second, the domestic workforce can be **S**upplemented by using foreign guest workers, such as those that can be hired through the U.S. H-2A visa program. Third, employers can retain

workers by **S**atisfying them with higher wages, benefits, and better working conditions. And last, **S**ubstitution includes the development of new technologies to replace workers and/or increased reliance upon imports to meet consumer demand.

Evidence suggests that once farm workers 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.

Charlton and 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. When expanding the model to include explanatory variables related to the agricultural transformation, they find 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. This evidence indicates that the days of farm labor abundance, when the labor supply was relatively elastic, is coming to an end.

Hanson et al. (2017) show that declining birth rates in Mexico caused total Mexico-U.S. immigration to decline during the Great Recession and in the following years. However, their

study does not investigate sector-specific impacts. Since decreasing birth rates are also a factor in the agricultural transformation, U.S. farms could suffer disproportionately from reduced labor supply. 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 Taylor (2016)'s findings that the agricultural transformation was well underway in rural Mexico during this time period.

Charlton and Taylor (2020), leveraging variation in the timing and location of secondary school construction, show that construction of secondary schools in rural Southern Mexico led to increases in both years of completed education and the probability of working in the non-farm sector. However, school construction only increased the probability of working in the non-farm sector for individuals from non-indigenous households, suggesting that there are heterogeneous returns to education; numerous societal factors could potentially impede the agricultural transformation among certain communities, races, or socio-economic groups.

One implication of a declining farm labor supply in Mexico is that the prospects for immigration to offer a solution to the U.S. farm labor problem 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 farm workers is rising—trends consistent with a diminishing farm labor supply from Mexico (Castillo 2020; Castillo and Simnitt, 2020; Zahniser et al., 2018). U.S. farmers are 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 Figure 1). 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. Despite these costs, H-2A demand more than tripled between 2007 and 2019 (Charlton and Castillo, 2020). In 2019, H-2A constituted an estimated 10% of the full-time equivalent farm workforce (Costa and Martin, 2020). Most H-2A workers, like the majority of U.S. hired farm workers, 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.

[Insert Figure 1 Here: Number of H-2A Jobs Certified in FY 2020, by Worksite State]

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., 2019a, 2019b; 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 (a 30% nominal wage increase) would be required to maintain the current farm labor supply from Mexico over ten years. Several recent studies also find evidence that indicates the aggregate farm labor supply elasticity is inelastic, suggesting that farm wage increases could possibly slow the agricultural transformation but will likely not halt it (Hill, 2019; Li and Reimer, 2020). Other research, however, finds evidence of a highly elastic supply of labor for some subsectors of U.S. agriculture in particular locales (Buccola et al., 2012). These contrasted

findings, however, may be a result of differences in the level of aggregation, as economic theory suggests that the supply of labor is much more elastic at the local level.

Historically, labor economists have argued that 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). In a perfectly competitive labor market, workers are paid their marginal revenue product of labor. However, relatively recent developments in labor market theory have challenged this assumption, countering that employers exercise at least some degree of market power over workers; 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 of labor is the workers' ability to quit the firm for work elsewhere. Although the number of employers in the labor market has been traditionally viewed as the sole factor that determines the degree of labor market competition, this recent theory suggests that employers can exercise labor market power in the presence of many firms if there are labor market frictions that merely reduce the ability of workers to switch employers. 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 of labor in some cases. This "surplus" that employers extract from workers was originally coined by Pigou (1924) and Hicks (1932) as the "exploitation rate," which is defined as the relative difference between the marginal revenue product and the wage paid. In the 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 exist in California's farm labor market that allow farm employers to extract some surplus from farmworkers by paying wages that are 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 and Mérel, 2021).

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. Studies that examine the impact of minimum wages date back to the seminal work of Grossman (1933), who modeled the supply of labor in terms of efficiency units where 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 the 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 the equilibrium. Other pivotal minimum wage studies include Card and Krueger (1995)'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 appear to be few and far between.

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 U.K., Bhorat et al. (2014) who study the impact in South Africa, and Moretti and Perloff (2000), who analyze the impact

on piece-rate workers in the U.S. Dickens et al. (1995) find that a 10 percent increase in the agricultural minimum wage raised the average earnings of agricultural workers in the U.K. by four to five percent. Bhorat et al. (2014) find that the sectoral minimum wage law in South African agriculture increased farmworker wages by about 30%. In South Africa, wages 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 farm workers 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 that 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.

3.3 Declining Farm Worker Mobility

Specialty crop producers rely heavily upon 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 (Levin, 2009; Martin, 2007). However, farmers continue to report labor shortages, and other 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 (2012)'s argument that labor shortages can materialize in local labor markets as a result of reduced labor mobility across regions.

Fan et al. (2015) used 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. This compounds the impact of a declining total farm labor supply on farm

wages and local labor shortages. This study also finds that farm worker mobility is negatively related to income and lower for women, unauthorized immigrants, farm workers who are English proficient, African American farm workers, and those who are married or have children. It calculates 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 to examine the effects of farm labor supply shocks have been developed over the past century. 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 Mexican 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) argued 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.

Towards 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 used 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 et al. (1992) use this approach 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 farm workers would cause a 1.7% to 3.9% decrease in the aggregate production of fruits and vegetables in the U.S. Brady et al. (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% to 5.4% decrease in aggregate tree fruit production. Cassey et al. (2018) follows the work of Brady et al. (2016) but examines 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 Espinosa (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 (2021) 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-from 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 et al. (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.[8] They find that that a policy that increases 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 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 (2021) explain that this result implies that, to some extent, farm labor can be substituted for non-labor inputs. 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 farm workers can make it difficult to "stretch" the existing workforce. In the

[8] 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.

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 movements. 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.

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 and 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 et al. (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 farm worker 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 the employer sanctions.

Implementation of state- and county-level immigration enforcement policies beginning as early as 2005 has 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 shifted the family farm labor supply outward, while reducing the probability that likely undocumented workers were employed in agriculture. This evidence suggests that domestic workers enter the farm workforce when immigration policies become more restrictive, and contrary to common belief, that domestic workers in some circumstances may substitute for low-skilled immigrant workers.

From 2005-2012, 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.[9] 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 et al., 2019).

Due to the policy's negative effect on the immigrant labor supply, 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.

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

[9] In 2013, ICE implemented a similar immigration enforcement program called Secure Communities. Secure Communities was implemented in all 3,181 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 et al., 2014). Thus, most studies on the effects of 287(g) on labor, immigration, and agricultural production focus on years prior to 2013.

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 that shows that labor scarcity can induce labor-saving technology adoption (Acemoglu 2010; Clemens et al., 2018; Hornbeck and 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. 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 and 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 et al. eds., 2016). Albanian workers, many unauthorized, harvest crops in Greece, whose policies reflect a more laissez-faire approach with occasional legalization schemes.[10] In Spain, farmers request guest workers from the *Dirección 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.[11] Since the breakup of the Soviet Union, Western European countries have relied heavily on farm workers 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 farm workers from Eastern Europe to travel freely to the U.K. after registering with the Workers Registration Scheme.[12] However, post-Brexit, the U.K. potentially faces severe farm worker shortages, with calls for a return to a prior scheme to enable farmers to legally recruit foreign workers.[13] South African farmers recruit farm workers from neighboring Zimbabwe.[14] Haitian workers constitute most of the seasonal sugar workforce in the neighboring Dominican Republic (Filipski and Taylor, 2009; Martin et al., 2002). Costa Rica imports farm workers from Nicaragua while implementing occasional temporary

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

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

[12] 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).

[13] 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

[14] "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).

immigration and legalization reforms.[15,16] Mexico is at a transitional phase, both exporting and importing farm workers. Its immigrant farm workforce comes mostly from Guatemala.[17] 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, largely concentrated in industrialized countries (United Nations, 2020; see Figure 2). The scientific community generally agrees that the frequency of extreme weather events will likely increase in the 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 sector in developing countries as a result of environmental shocks that disturb crop production (Falco et al., 2018; Lobell et al., 2011; Schlenker and 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 (Christian 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).

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[15] 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.

[16] 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

[17] Instituto Nacional de Migración Circular No. CRE – 247-97, "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).

[Insert Figure 2 Here: Figure 2: International Migrant Stock Estimates, Mid-Year 2019]

A handful of papers provide excellent surveys of the climate migration literature. These papers include Obokata et al. (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 der 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.

In addition to off-farm labor force participation, changes in crop choice, and the use of credit, migration can be viewed as an adaptation strategy to climate change (Barrett et al., 2001; Fafchamps et al., 2007). For example, Yang and Choi (2007) find that remittances sent by migrants are able to 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 and Massetti, 2017; Porter et al., 2014). Evidence of this has been brought forth by Cattaneo and Peri (2016) and Cai et al. (2016), who find a link between temperature and migration only 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 et al. (2014) who find a link between higher temperatures and outmigration in Indonensia, 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 also lead to suboptimal input use, which can lower the marginal productivity of labor and perpetuate poverty in vulnerable regions. For example, increased rainfall variability has caused farmers to reduce their fertilizer use in Ethiopia (Alem et al., 2010).

[Insert Table 1 Here: List of Climate-Induced Migration Studies]

The statistical associations found in the literature are heterogeneous across regions and fail to paint a consensual picture. For example, individuals who are subject to liquidity constraints, defined by the destruction of capital as a result of environmental shocks, may actually experience a decline in the propensity to migrate (Catteneo and 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. The authors also 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 et al., 2010, 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, which makes it difficult to isolate the true impact that climate has on the migration decision (Auffhammer and Vincent, 2012).

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; Findley1994; Gray, 2009; Henry et al., 2004a).

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," which they define 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 U.K. (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 the need to migration decision. 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 the political factors by degrading the government's 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 et al., 2004a, 2004b; Massey et al., 2010; Warner, 2010; Warner et al., 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 to effect of climate change and the other factors to 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 et al., 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. For example, Gupta et al. (2020) find that during the COVID-19 shock, some rural households in India had to send money to family members who had migrated the city, because urban employers were laying off workers and migrants were unable to travel 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. Belton and Filipski (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 farm workers 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 farm workers (Taylor and 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 that workers are entitled to (Martin et al., 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 these 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; second, many farmworkers did not see long-term gains to

union membership; and third, the elastic supply of undocumented farm workers 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 farm worker 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 and Staiger, 2001; Hur and 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," whereby 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 and 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.[18] This system generates a space for contractors who cut costs by mistreating, underpaying, or otherwise abusing workers to hide within the trade network, because monitoring and regulating labor practices is costly.

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

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 and 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 during 2020, countries throughout the world implemented mandatory quarantine or "shelter-in place" orders and restricted internal as well as cross-border migration (Cortignani et al., 2020). Government mandated shutdowns triggered a number of supply and demand

responses across agri-food systems, with important ramifications for agricultural labor. At the time of writing this chapter, research on impacts of COVID-19 on agricultural labor is nascent but provides useful insights into how labor markets are impacted by global economic shocks. For example, Cho et al. (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 farm workers, 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 the developed world, there has historically been a high demand for foreign agricultural workers even during times of economic crises that lead to anti-immigration sentiment. In addition, many seasonal migrant workers develop relationships with specific employers over time and return to work for them year after year (Mitaratonna and Ragot, 2020). Employers value these "circular migrants" because they develop specific skills that help increase operational efficiency and lead to higher profits.

In developing countries, COVID-19 restrictions have sometimes prevented the return migration of urban migrants to their homes in rural locations. Gupta et al. (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.

8.1 Migration Restrictions and Labor Supply

The agricultural sector faced widespread fears of labor shortages following temporary restrictions on international migration intended to mitigate the spread of COVID-19. Although the Mexico-U.S. border was open to essential migration, including farm labor migration, many feared that an insufficient number of workers would migrate to the United States during the pandemic, or that workforce outbreaks of COVID-19 would cause major labor shortages during critical seasons of agricultural production or during the harvest of perishable crops.

The restriction of movement across international borders due to COVID-19 caused temporary labor shortages of harvest workers. Labor shortages were reported worldwide, including in Columbia (Rueda, 2020), Canada (Larue, 2020), Malaysia (Bloomberg, 2020), Thailand (Saokaew, 2020), Ethiopia (Orchardson, 2020), Zimbabwe (Orchardson, 2020), India (Orchardson, 2020), Germany, Italy, Spain, the U.K., and France, (Cretan and Light, 2020), and China (ADB, 2020; Zhou et al., 2020). After realizing that the food supply could be drastically disrupted by policies restricting the movement of labor, 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 guestworker program, allowing foreign guest workers already in the country to extend their work visas and start working on other farms (Beatty et al., 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. 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 et al., 2003). Only an estimated 4.6% of the U.S. labor force is undocumented and therefore ineligible for unemployment benefits (Krogstad et al., 2019).

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 2007-2019, a one percentage point increase in the state unemployment rate was associated with a five percent 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, unemployment benefits were temporarily expanded in 2020 and

there was increased risk of exposure to COVID-19 for those who went to work, particularly in the close working conditions in fields and food processing plants. Although the number of H-2A visas issued in April 2020 dropped considerably in comparison to previous years (Charlton and Castillo, 2020), the total number of H-2A positions certified by the DOL for FY20 increased by 7% (or by 17,764 certifications) relative to FY19.[19]

France, Germany, Spain, the U.K., and Italy set up 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 (Mitaratonna and 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; Rogozann and Gabor, 2020). Eastern European migrants were authorized to take specially chartered flights and busses 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.

Aggregate and general-equilibrium effects of the coronavirus pandemic on farm labor supply are hitherto unknown. Ridley and Devadoss (2020) use crop-county-level data from the 2017 U.S. Census of Agriculture and simulate a potential loss in U.S. agricultural production worth millions of dollars due to disruptions in the labor supply to fruit and vegetable farms. Their analysis involves the estimation of crop-specific output-employment elasticities to simulate

[19] 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.

the effects of labor supply shocks under two hypothetical scenarios. They conclude that COVID-19-induced labor supply constraints could have generated non-trivial impacts on fruit and vegetable production, but that these effects would not have been "cataclysmic." 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.

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 cases (e.g., France and the Netherlands), food prices increased due to higher labor and transport costs (Mitaratonna and Ragot, 2020; Ragasa and Lambrecht, 2020). Farm labor costs also rose as a result of government mandates for quarantine, housing, and preventative measures for seasonal agricultural workers.

The COVID-19 pandemic introduced a new element of cost and uncertainty for the production of labor-intensive crops. Worker safety during the coronavirus pandemic is of primary concern, particularly in essential industries where working remotely is not possible. A recent PBS documentary (Frontline, 2020) highlights a lack of protections for agricultural workers who often rideshare and/or live together in large groups and work in close proximity to each other. The PBS film documents a lack of access to employer-provided PPE, exposing one employer who threatened to terminate workers who refused to work without adequate protections against the disease. A survey of low-skilled domestic workers in the United States revealed that

many had increased empathy for H-2A agricultural guest workers, though their views on immigration policy were unchanged (Luckstead et al., 2020).

Even though employers have taken precautions, there have been numerous worksite outbreaks of COVID-19. Charlton (2020) examines the relationship between month-to-month changes in fruit, vegetable, and horticultural (FVH) employment within counties and new COVID-19 cases. The study shows that the employment of 100 additional FVH workers within a county is associated with 21 new COVID-19 cases. These findings have important implications for assessing differences in production risk due to potential worker sickness across various crops. In the model of Charlton et al. (2019b), an increase in labor supply uncertainty due to COVID-19 would logically reinforce incentives for farmers to adopt labor-saving technologies and practices. In the long run, investments in the development and adoption of labor-saving technologies are expected to increase most rapidly among crops that experience the greatest risk of farm labor shortages. Labor-saving technologies, including the use of robotics, could potentially improve worker safety and create higher-skill, better paying jobs while mitigating the risk of farm labor shortages.

Digital platforms for extension, marketing, and logistics have the potential to reduce the risks associated with disease outbreaks in the developing world. Digital technologies such as online banking, mobile internet, digital training systems, and online sale portals can generate benefits for rural communities. Many of these technologies are already available, but their adoption has not been uniform (Mitaratonna and Ragot, 2020). The lack of digital technology adoption is determined by a number of factors, including whether the proper infrastructure is in place, whether individuals are aware of the technologies, whether individuals have access to the

training required to use them, and the reliability of the technology. Women in developing countries, for example, often have lower digital literacy and thus reduced digital access.

8.2 Trade Restrictions

Lockdowns and trade restrictions affected the supply of agricultural inputs and the distribution of food in certain areas. The level of disruption varied depending on the type of product being traded and who the primary trading partners were (Kurtz, 2020). Trade restrictions have affected the transportation industry and reduced exports of agricultural goods. The pandemic caused significant delays in shipping containers being returned to major exporting ports in countries like China, which slowed down a significant amount of global trade (Qiu et al., 2020). Chinese export cargo volumes dropped by at least 20%, while some countries, including Russia, Vietnam, Kazakhstan, and Thailand barred exports of food products, including rice, grains, and potatoes (Deloitte 2020). In Africa, a significant decline in GDP has been projected as a result of declining staple crop exports, which will likely lead to increased poverty rates. Examples of other types of food-related shortages include feed for (and exports of) Chinese poultry (Martin 2020), lower beef exports in the U.S. (McCarthy, 2020), reduced access to wheat and rice in Africa (Kurtz 2020), and halted cocoa exports from Ghana (Quayson et al., 2020). Declining (or halted) exports created spillover effects for smallholder farmers, some of whom sold their products at abnormally low prices to generate income due to decreased market access as a result of export restrictions (Quayson et al., 2020). To prevent commodity shortages, North American and European countries opened up “green lanes,” which allowed freight vehicles to cross their borders despite bans on passenger travel.

Modern food systems are built around the “just-in-time” approach, in which there are relatively low stocks of goods and continuous product flows (Hobbs, 2020). These systems are generally efficient under normal circumstances, with retailers entering into contracts with key suppliers to bump up supply during specific times of the year (e.g., holidays). However, this system has shown vulnerability with respect to exogenous shocks, such as panic buying during the pandemic. In addition, food supply chains reliant upon a few large suppliers are more susceptible to shocks, inasmuch as the closure of one facility can lead to large reductions in supply.

Although panic buying created demand shocks that strained transportation and distribution chains, supply problems were generally short-lived in developed countries. However, lower incomes due to the subsequent global recession may have long lasting implications on consumer behavior, as consumers with less disposable income become more sensitive to price fluctuations. Long term changes in consumer demand have the potential to influence the crop mix over time, while changing what is available in grocery stores. The global recession will almost certainly lead to increased poverty rates, particularly in developing countries. Pandemic-induced recessions (and high domestic unemployment rates) have the potential to create a new wave of international migrant workers seeking out employment opportunities in wealthier nations. A new wave of international migration could reinforce nationalist political ideologies and leave household members left behind by migrants highly vulnerable if they become increasingly reliant upon remittances.

8.3 Essential Workers

In the wake of the COVID-19 pandemic, governments classified businesses as either essential or non-essential, which effectively dictated who was legally entitled to work. In many cases, seasonal migrants, who are generally subject to negative stereotypes and are often thought of as outsiders, were suddenly recognized as essential workers, particularly when countries were faced with food insecurity during lockdown and could not get domestic workers to perform farm work (Cretan and Light, 2020). However, the issue of national food security appears to have taken priority over the health and safety of migrant workers, as many AFS workers were subject to long work days, poor pay, and substandard working and living conditions. 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).

In the U.S. and many other countries, primary agricultural production activities were deemed essential during the pandemic, but businesses in the food service sector, such as restaurants, were not. The categorization of "essential" businesses and workers has important ramifications. This decision has the potential to induce the collapse of some businesses, leading to long-term unemployment, lower incomes, and slower economic growth. In the wake of such closures, workers may encounter difficulties meeting their financial obligations, which can strain social welfare systems and lead to increased national debt. Government determinations of essentiality have the potential to affect the well-being of those deemed to be non-essential if they are unable to generate income.

Workers who are deemed essential can continue working, but they face an increased risk of exposure to COVID-19, particularly if provisions are not taken to mitigate risk of virus transfer at the workplace. Malone et al. (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.

9. Replacing Farm Workers 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, Hayami and Ruttan (1971) and 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 and Kostandini, 2020; Clemens et al., 2018; Hornbeck and Naidu, 2014).

Charlton et al. (2019) discuss 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 and Taylor, 2019 and Figure 3). Figure 4 shows that

some of these technologies include, in particular, mechanized equipment to reduce labor demand during harvest.

[Insert Figure 3 Here: Reasons Farmers Are Adopting Labor Saving Technologies in California]

[Insert Figure 4 Here: Most Common Types of Labor-Saving Technologies Recently Adopted in California]

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 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 raisin 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 et al., 2016). When a technology has large economies of scale, this generates incentives for technology adopters to acquire land from those who do not adopt and reduces 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 1930-1970, but this trend reversed from 1970-1976. Consequently, they conclude that farm consolidation would have stabilized in the following years. However, Macdonald (2020) finds that farmland shifted to larger operations from 1987-2017, 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 et al., 2015). Engineers are also developing fruit-catching mechanisms that use air suspension to cushion the fruit as it falls, thereby reducing bruising (Ma et al., 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 Kohrner (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. And 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 et al., 2009; World Bank, 2020; Zhang et al., 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).

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 and 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. 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 due to the relaxation of feasibility constraints as from the diffusion of information, which lowers the cost of adoption.

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, modified, gradually became available to other regions. Both public and private investments were critical in the diffusion of hybrid corn. Labor-saving mechanization in FVH production, although far more complex and costlier to develop, may provide more universal solutions to the farm labor problem.

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 farm workers 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 and Kostandini, 2020; Clemens et al., 2018; Hornbeck and Naidu, 2014). Most of these disruptions were mostly temporary in nature. However, we may be entering a new era wherein workers worldwide are more educated and less willing to work in agriculture (Charlton and 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 et al. (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.

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 et al., 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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11.Tables

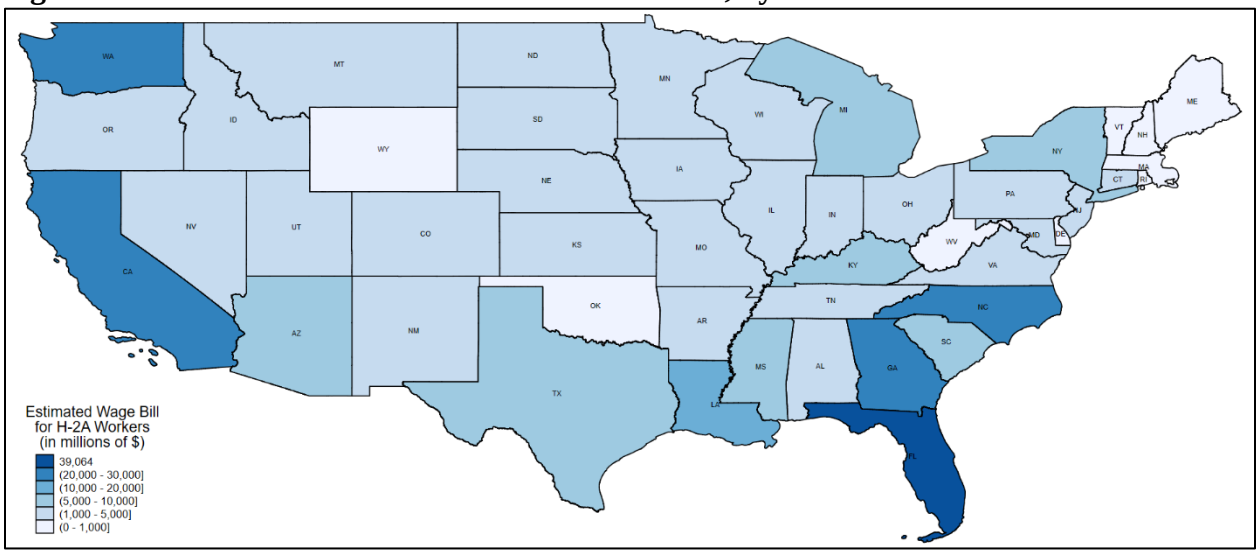
Table 1: List of Climate-Induced Migration Studies

Author	Climate Variable	Country of Origin	Type of Migration	Study Finds Link Between Climate and Migration
Afifi et al. (2014)	Precipitation	Tanzania	Internal	Yes
Alem et al. (2016)	Temperature and Precipitation	Ethiopia	International	Yes
Alscher (2011)	Natural Disasters, Flooding	Nigeria	Internatioanal	Yes
Beine and Parsons (2014)	Natural Disasters	Multinational	International	Yes
Bohra-Mishra et al. (2014)	Temperature	Indonesia	Internal	Yes
Bohra-Mishra et al. (2017)	Temperature	Phillipines	Internal	Yes
Cattaneo and Masseti (2015)	Temperature and Precipitation	Nigeria	International	Yes
Dillon et al. (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 & Livestock Losses	El Salvador	International	Yes
Hassani-Mahmooei and Parris (2012	Drought and Cyclone	Bangladesh	Internal	Yes
Henry et al. (2004b)	Precipitation	Burkina Faso	Internal	Yes
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 et al. (2014)	Temperature	Pakistan	Internal	Yes
Nawrotzki et al. (2013)	Drought	Mexico	International	Yes
Poston et al. (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 der Broeck (2011).

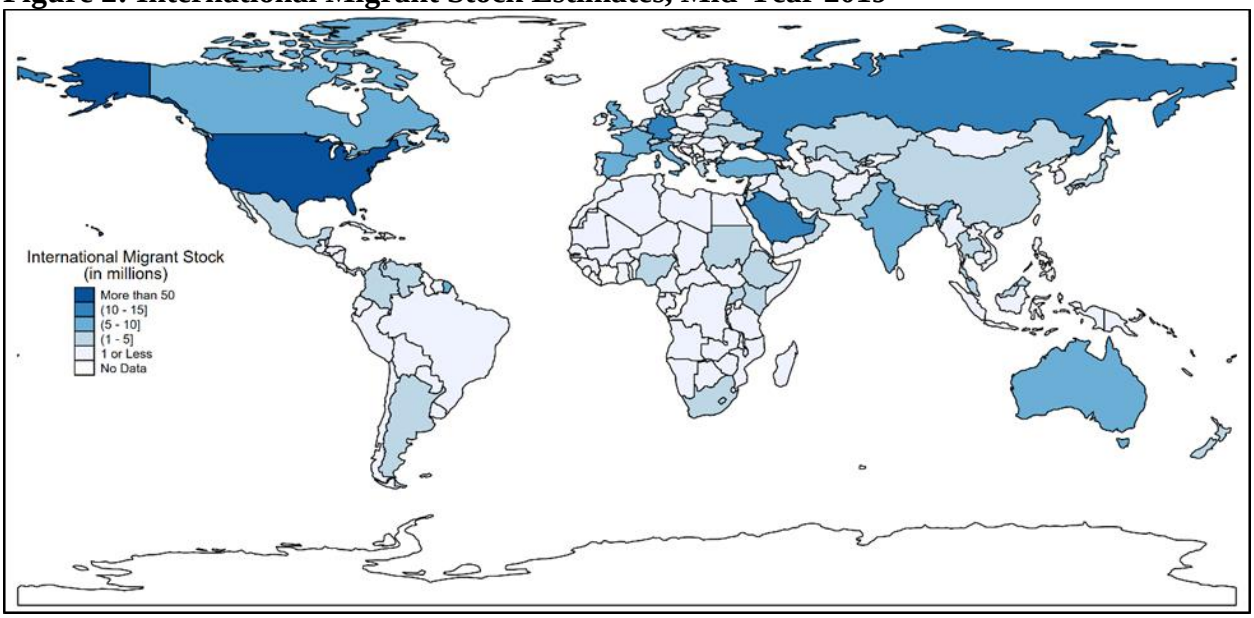
12. Color Figures

Figure 1: Number of H-2A Jobs Certified in FY 2020, by Worksite State



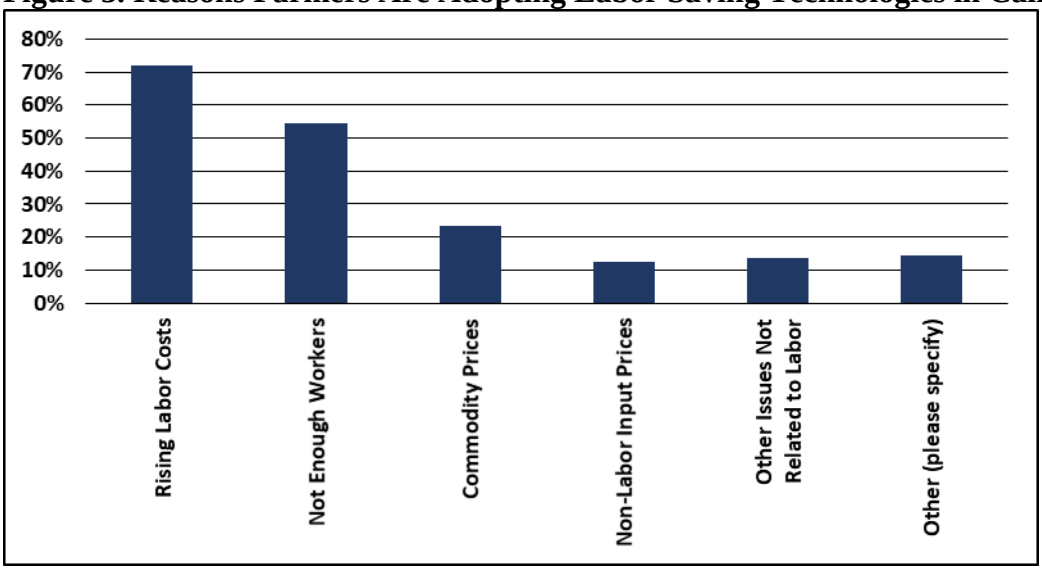
Note: US Department of Labor H-2A disclosure data processed by authors.
Source: https://www.dol.gov/agencies/eta/foreign-labor/performance.

Figure 2: International Migrant Stock Estimates, Mid-Year 2019



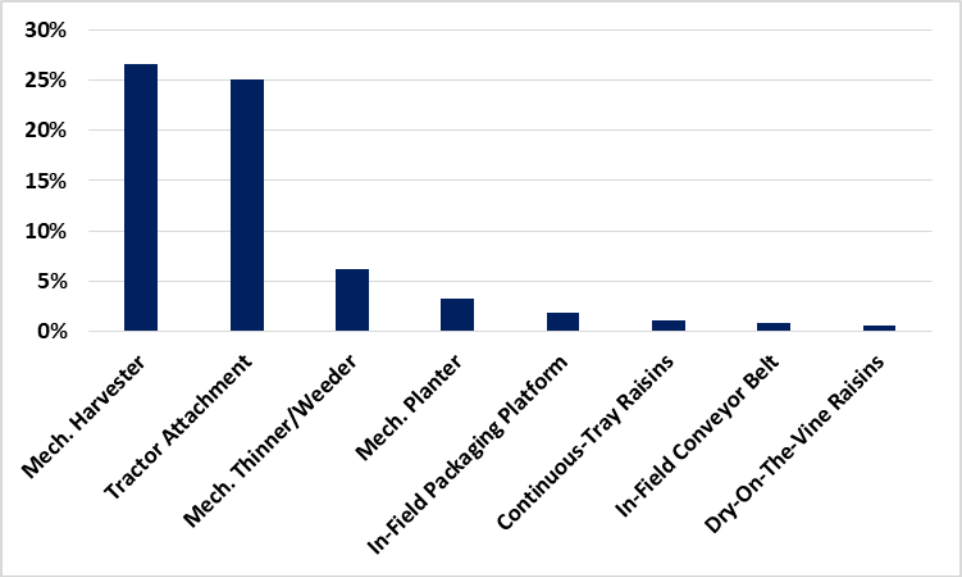
Note: United Nations data processed by authors. These estimates include all international migrants, of which climate-induced migrants are a subset of.
Source: https://www.un.org/en/development/desa/population/migration/data/estimates2/estimates19.asp.

Figure 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.

Figure 4. Most Common Types of Labor-Saving Technologies Recently Adopted in California

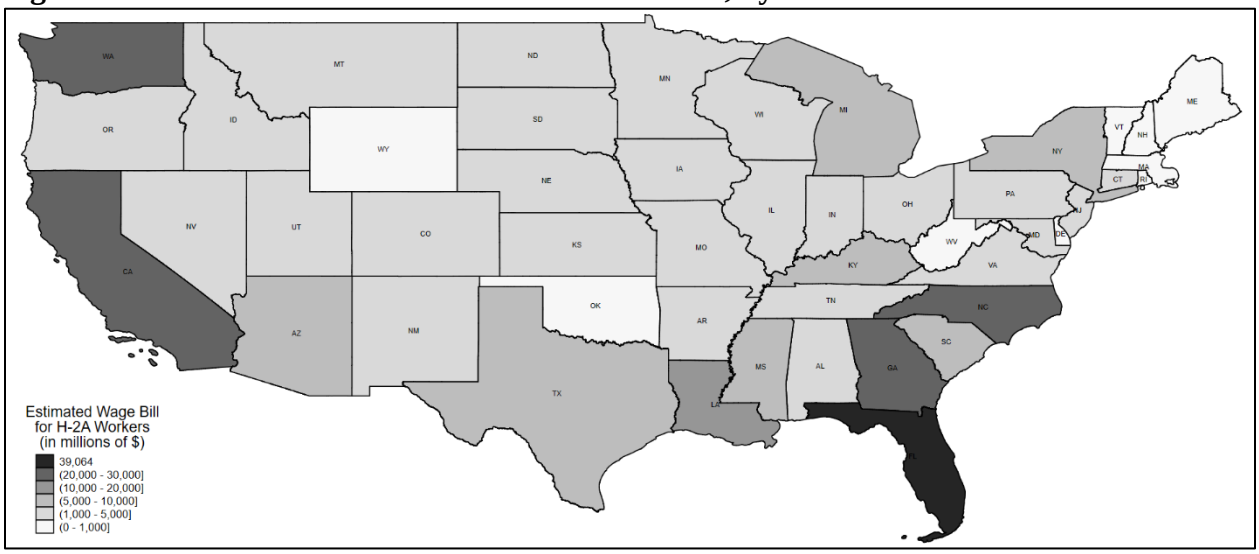


Note: "Other" responses are not included in this graph.

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

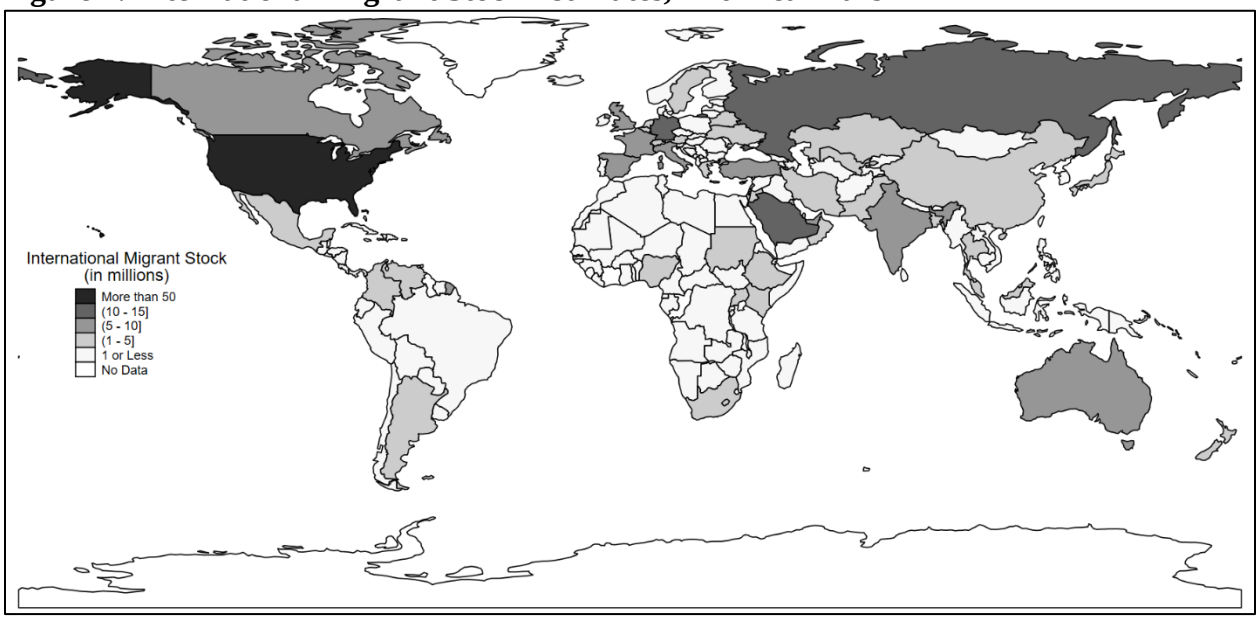
13.Black and White Figures

Figure 1: Number of H-2A Jobs Certified in FY 2020, by Worksite State



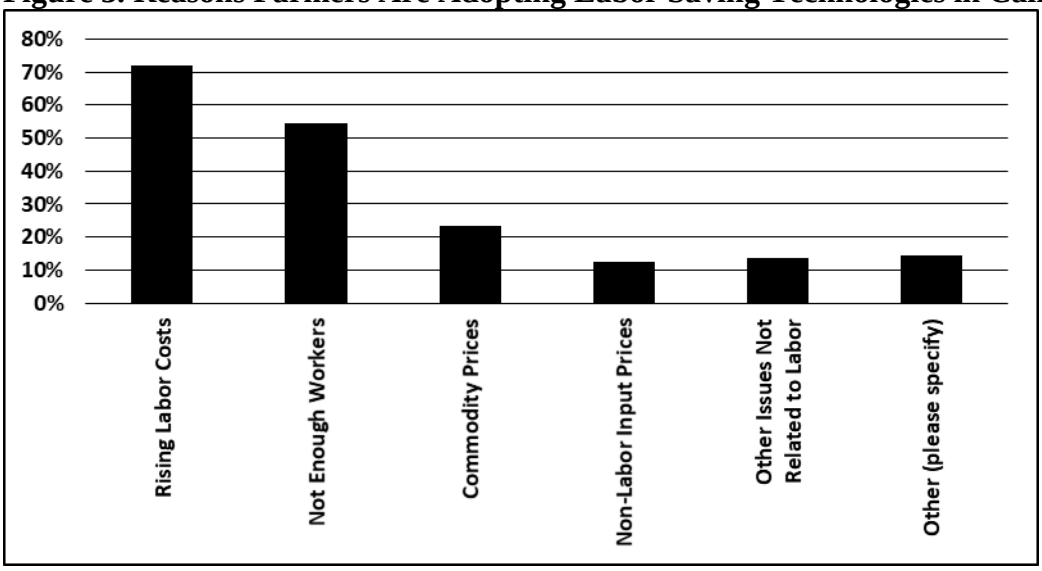
Note: US Department of Labor H-2A disclosure data processed by authors.
Source: https://www.dol.gov/agencies/eta/foreign-labor/performance.

Figure 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.

Figure 3. Reasons Farmers Are Adopting Labor Saving Technologies in California



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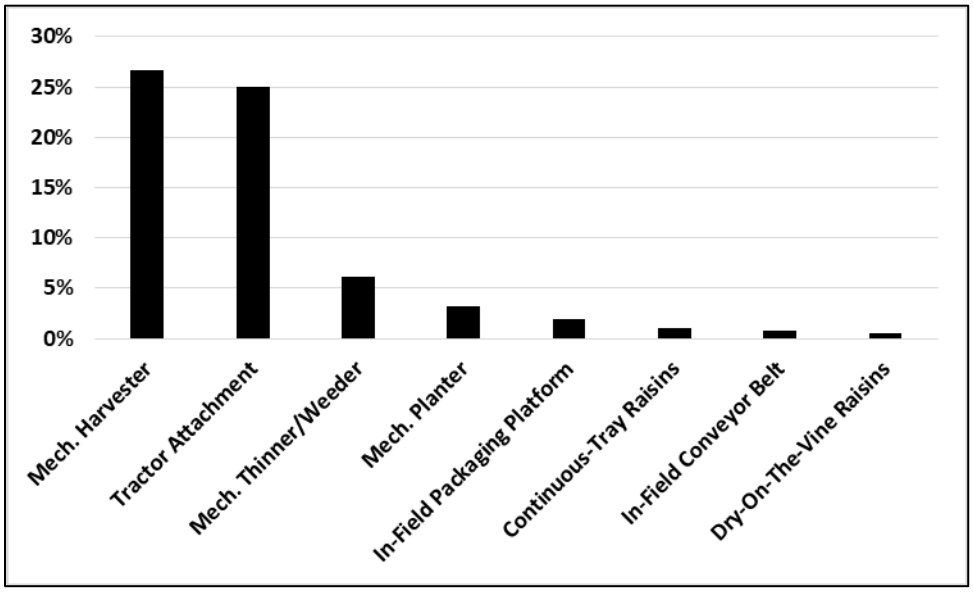

Note: "Other" responses are not included in this graph.

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