10. Economic and Societal Aspects

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10.1 Introduction

In 1984, a group of small farmers and community activists, together with 19 farm workers, sued the University of California (U.C.) for developing a new harvesting technology that revolutionized the production of processing tomatoes. The plaintiffs argued that the University's agricultural research program "displaces farm workers, eliminates small farmers, hurts consumers, impairs the quality of rural life, and impedes collective bargaining."[1] The case eventually settled, but it cost the University of California dearly and put a damper on labor-saving agricultural research and development for more than two decades. The United States (U.S.) Secretary of Agriculture Robert Bergland famously stated: "I will not put federal money into any project that reduces the need for farm labor" (Sarig et al., 2000).

The U.C. tomato harvester case was the product of an era in which farm labor was abundant and wages for farm workers were stagnant or decreasing. Today, U.S. farmers face a different world in which the number of people willing to work in orchards and fields is diminishing and real farm wages are on the rise. Nevertheless, the case highlighted the potentially far-reaching social implications of labor-saving technological change, and it left behind a legacy of suspicion that mechanization might be antithetical to the welfare of workers, consumers, and the communities in which they live.

This chapter explores economic and social aspects of advanced automation in tree fruit orchards and vineyards. It begins by explaining economists' views on the social welfare effects of automation under different labor market scenarios, in particular, when agricul-

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[1] See California Agrarian Action Project, Inc. v. Regents of the University of California, (1989).

tural workers are abundant and when they are scarce. Next, it traces the evolution of a farm labor market going through the transition from labor abundance to labor scarcity by examining the case of California and sharing new research findings on how farmers are adapting to a diminishing farm labor supply. When agricultural labor is abundant, automation may be detrimental to agricultural workers and small farmers who cannot afford to invest in new technologies, even if the total benefits to society are positive. On the other hand, in the current era of labor scarcity, labor-saving automation is more likely to create benefits for workers and consumers as well as for agricultural producers and society as a whole. We conclude by imagining a future with robots in the fields and what this is likely to portend for workers, consumers, and rural communities.

10.2 Economic Views on Automation and Social Welfare

Broadly speaking, the widely held view among economists is that producers adopt new technologies when the expected cost savings from doing so exceed the investment cost. Adoption is only one part of technology change, however, because new technologies need to be developed before adoption can take place.

There is some disagreement about the determinants of technology development. The induced innovation hypothesis posits that changes in relative factor (input) prices determine technology development. This hypothesis was first advanced by economist John Hicks in his classic work The Theory of Wages (1932). Hicks wrote:

A change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind—directed to economizing the use of a factor which has become relatively expensive.

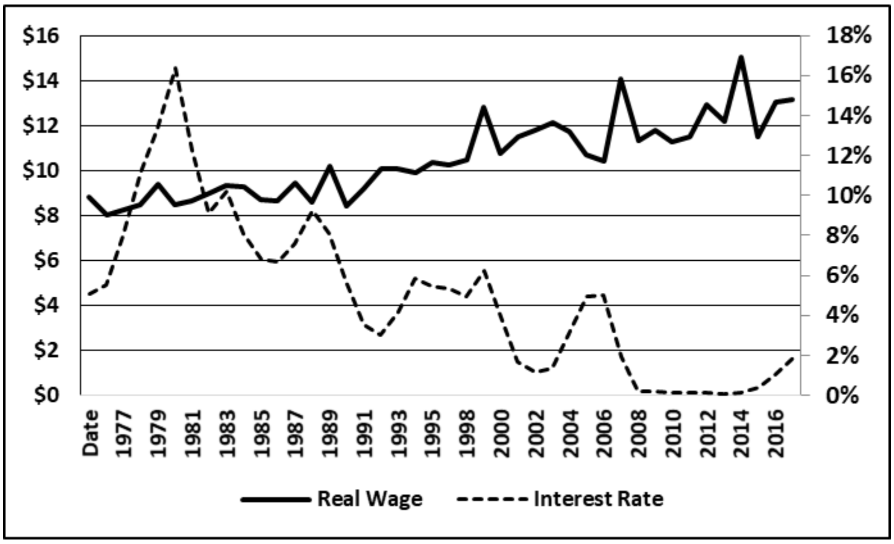
For example, in a labor-abundant environment, wages are low relative to capital and land rents, so there is little incentive for public and private entities to invest their resources in developing labor-saving technologies. In a labor-scarce environment, rising wages relative to rents create incentives to develop labor-saving technologies as well as for farmers to adopt those technologies once they are "on the shelf."

Advocates of induced innovation point to so called "Green Revolution" high-yielding grain varieties that gained wide acceptance in Japan, where land was relatively scarce. Growth in agricultural output in continental Europe, which increased at twice the rate of the U.S., was also driven by rising grain yields (Binswanger, 1986). Early improvements in wheat and rice varieties were developed by the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines, which eventually led to the inception of the Consultative Group on International Agricultural Research (CGIAR) (Pingali, 2012). Rising world food demand, fed by population and income growth, induced institutions like the CGIAR and the Rockefeller Foundation to invest in R&D to increase yields per acre of land. In contrast, mechanical innovations were central to the history of grain production in the United States, where land was relatively abundant and the cost of capital was low.

An opposing view is that research and development is largely an exogenous, self-perpetuating process, as new breakthroughs lead to others that, in turn, lower the costs of developing new technologies over time. U.C. researchers developed the tomato harvester in an environment of labor abundance and low agricultural wages, exploiting new developments in mechanical and agronomic engineering. It is difficult to argue that relative prices of labor and capital led to Jobs' and Wozniak's invention of the personal computer or the i-phone, which would not have been possible without prior advances in transistor and wireless technology. Once they became available, though, adoption was explosive.

Some economists have attempted to test whether relative factor prices explain the development of new technologies, consistent with induced innovation, with mixed results. Figure 10.1 depicts the factor prices for labor and capital inputs (real wages and interest rates), revealing a pattern (i.e., a rising wage to interest rate ratio) that is consistent with the induced innovation of labor-saving technologies.

Examples that find support of induced innovation include Thirtle et al. (1995) in South Africa, Bidabadi and Hashmitabar (2009) in Iran, and Hyami and Ruttan (1971) in the U.S. However, examining data at a more granular geographical level in the U.S., Olmstead and Rhode (1993) only found evidence of induced innovation in certain regions of the U.S. but not in others. This led them to argue that the induced innovation hypothesis was insufficient to fully explain the development of American agriculture and that other factors must have also played a role. Others argue fervently that technological determinism is the main driver of R&D and that it is becoming more important over time (e.g., Arrow, 1962; Levin, 1988).



Note: Wage data were obtained from the Current Population Survey (https://ipums.org/). Interest rate data were obtained from the St. Louis Federal Reserve Economic Research Database (https://fred.stlouisfed.org/).

Figure 10.1: Real U.S. Farm Worker Wages vs. Federal Funds Interest Rate (1976-2017)

It is likely—to the point of being almost tautological—that a mixture of these two theories is needed to explain the development and adoption of advanced automation in tree fruit orchards and vineyards. Creating labor-saving solutions for delicate, difficult-to-pick fruits is complex and would not be possible without recent advancements in mechanical engineering, machine learning, artificial intelligence, wireless technology, agronomics, and other fields. Farmers will not adopt new labor-saving technologies unless it is economically feasible and optimal to do so. The economic cost-benefit analysis for adopting new labor-saving technologies obviously depends upon factor prices, including wages. Even if a robot can pick a fresh peach crop as well as a human farm worker, farmers will be unlikely to purchase the robot unless wages are high (and expected to keep on rising) and capital costs (i.e., interest rates on loans to invest in robots) are low.

Asking whether induced innovation or technological determinism drives the creation and adoption of new technologies might seem like an academic exercise, but the answer has potentially far-reaching social ramifications. Take the U.C. tomato harvester. It was launched into an environment of abundant farm labor and low farm wages. Even though the end of the U.S.-Mexico Bracero program (1942-1964) created some expectations of labor shortages, for the most part they did not materialize. It would seem that an induced innovation model is ill-suited to explain why the U.C. tomato harvester appeared when it did. It is difficult to argue that rising relative wages led U.C. researchers to develop the tomato harvester, as induced innovation theory would posit.

Nevertheless, a stunning drop in labor requirements to harvest processing tomatoes resulted in the almost complete adoption of the tomato harvester in a very short period of time: within five years, nearly 100 percent of processing tomato farmers had adopted (Taylor and Charlton, 2019). Despite the high cost of adopting the new technology, the dramatic decrease in labor costs made the tomato harvester a feasible investment for farmers who could afford it. There is no question that the technology displaced large numbers of field workers in this low-wage, labor-abundant environment. This explains the backlash against the U.C. tomato harvester, which was led by farm worker advocates and small farmers who could not afford to invest in the new technology. There is mixed evidence about whether the adoption of agricultural technologies generates harmful impacts for agricultural workers in developing countries, where a large proportion of the workforce is still engaged in agricultural work. The impacts differ by region and depend on factors such as land availability for farmland expansion and how well markets are integrated. For example, in Bangladesh, mechanization has been linked to higher wages in both the short and long run and does not appear to reduce employment (Hassan and Kornher, 2019). This has been attributed to scale effects, which have led to an increase in the demand for labor. However, in other regions, such as in Ethiopia, Senegal, and Kenya, the adoption of tractor-powered machines has been shown to displace labor (Kirui, 2019).

Technological determinism can result in the development and introduction of labor-saving automation in a labor-abundant environment. Induced innovation, on the other hand, posits that new labor-saving technologies will not be developed unless labor becomes scarce (and expensive) relative to the cost of other factors. It would seem, then, that social disruptions from new technologies are less likely in a world where induced innovation guides technology change compared to the situation where “innovation accidents” lead to the sudden and unexpected appearance of automation, like tomato harvesters and peach-picking robots.

10.3 California Agriculture: From Worker Abundance to Labor Scarcity

Concerned about farm labor shortages during WWII, President Roosevelt signed an executive order that launched the Bracero program, authorizing Mexican laborers (Braceros) to enter the U.S. to perform contract work on farms (Bracero History Archive, 2019). Over the 22-year duration of the program, roughly 1.5 million Braceros came to work on U.S. farms, many of them returning year after year from poor villages in rural Mexico under different contracts (Martin, 2006b). In addition to this large influx of Braceros, over five million unauthorized Mexicans were apprehended over the same period, suggesting that a significant number of unauthorized workers had also entered the farm labor force (Martin, 2001). This massive inflow of immigrants depressed the wages of native-born workers, which helped opponents of the Bracero program (including President Kennedy) successfully argue for its termination. After the Bracero program was ended by Congress in 1964, Mexicans continued to make the trek north into the U.S. The relatively high wages in the U.S., coupled with lax immigration enforcement across the southern border and laws that allowed U.S. employers to hire unauthorized workers, enabled undocumented Mexicans to flood the U.S. farm labor market, which led to decades of reliance upon low-wage Mexican workers for tree fruit production and vineyard work.

Attempting to end the massive inflow of undocumented immigrants from Mexico, the U.S. government passed the Immigration Reform and Control Act (IRCA) in 1986, which legalized 1.3 million unauthorized farm workers, established the current H-2A agricultural guestworker visa program, and imposed legal punishments (e.g., fines and jail time) for farmers who knowingly hire undocumented workers. The H-2A visa program allows U.S. farm employers to employ temporary foreign workers when a sufficient number of domestic workers are unavailable. Although its use has increased substantially over the past 10 years, historically it had not been widely used due to the higher cost of employing workers through the program, as well as the complicated nature of the approval process. Nevertheless, the passage of IRCA caused farmers and policymakers to become concerned about the potential for farm labor shortages, prompting the emergence of a body of academic literature. However, farm labor shortages did not materialize after the passage of IRCA, and researchers found that it may have even led to a temporary boost in the farm labor supply, resulting from family reunification policies that granted visas to the family members of unauthorized farm workers who had been recently legalized (Boucher et al., 2007). Despite these previous "false alarms," recent research reveals that the era of farm labor abundance *is* coming to an end.

For at least 10 years, media outlets have provided anecdotal evidence of farm labor shortages in California (and throughout the U.S.), with some farmers claiming lost income due to an inability to find enough workers during harvest time (e.g., Plummer, 2013; Glaister, 2006; Good, 2017; della Cava and Lopez, 2019; Oatman, 2019). Subsequently, a new body of research has taken root exploring whether the anecdotal evidence can be corroborated with data or if these reports are being blown out of proportion by politically-motivated actors. Skeptics argue that farm labor shortages wouldn't occur if farmers simply raised wages. However, some economists argue that local farm labor shortages may occur even when wages rise because agricultural labor markets are local, farm labor is not always mobile, and factors such as weather can affect the timing of regional labor demand shocks when a sufficient number of properly-skilled workers are simply not available in the local labor market (Fisher and Knutson, 2012).

In a recent issue of the *American Journal of Agricultural Economics*, Richards (2018) used structural and econometric modeling to study whether there is evidence of farm labor shortages among different classes of farm employees in California, the state with the highest demand for agricultural labor. He found evidence consistent with persistent shortages among harvest workers in recent decades. Hertz and Zahniser (2012) provide evidence of labor shortages by identifying U.S. counties that have experienced extraordinary growth in farm worker earnings yet have had lower employment levels, consistent with a declining farm labor supply. Others have found that the farm workforce is aging and is not being replenished by young immigrant workers (Martin, 2019), immigrant farm workers are settling down in the U.S. and are less likely to travel to work on farms (Fan et al., 2015; Reyes, 2004), and as the Mexican economy continues to expand, workers are being drawn out of the farm labor pool into other sectors of the economy (Taylor et al., 2012; Charlton and Taylor, 2016; Rutledge and Taylor, 2019b).

Immigration policies are also playing a role. Increased security at the southern border has led to higher “coyote” (smuggler) fees, which can cost thousands of dollars and has reduced the number of Mexicans who can afford to cross the border (Orrenius, 2004; Dickerson and Medina, 2017). And those who pay the increased fees often have to take out loans from family members in the U.S. and end up seeking work in higher paying nonfarm occupations (such as construction) to pay them off. In parts of the U.S., local immigration enforcement policies have driven farm workers out of the local labor market suggesting that, in general, the threat of deportation may also lead to a smaller farm labor supply (Ifft and Jodlowski, 2016; Kostandini, 2013). And the current administration's stance on immigration has been felt by farmers who claim that it has impacted the number of workers who are available (Frank, 2017). These factors have induced farmers to raise wages, reducing the already tight profit margins that they operate on (Rutledge and Taylor, 2019a; Charlton et al., 2019b; Hertz and Zahniser, 2012). And even if farmers gave up all of the surplus (profit) they generate through employing farm workers, recent research has found that they would still not be able to raise wages high enough to put an end the shortages because the increase in wages that would be necessary to attract enough workers exceeds the profits that farmers have to spare (Richards, 2018). In addition, global and national market pressures make it difficult for local farmers to pass increased labor costs onto the wholesalers and retailers who purchase their fruits because commodity prices are not determined locally, and farmers generally do not dictate the price they receive for their crops.

Other frictions in the farm labor market arise from the fact that domestic workers are unwilling to perform farm work because of the non-pecuniary costs (Taylor et al., 2012). To highlight this fact, during the recent recession when unemployment rates were close to 10%, the United Farm Workers (a farm labor union based in California) launched the “Take Our Jobs" campaign, which offered farm employment to any American who wanted a job. However, even though unemployment rates were the highest they had been in decades, only a few dozen Americans took them up on their offer after realizing that the work entailed “back-breaking jobs in triple-digit temperatures that pay minimum wage, usually without benefits" (quoted from Smith, 2010). This means that the existing pool of workers who are willing to perform farm work is comprised of poor (mainly undocumented) Mexican immigrants who do not have better employment opportunities, of which there is a limited (and decreasing) supply.

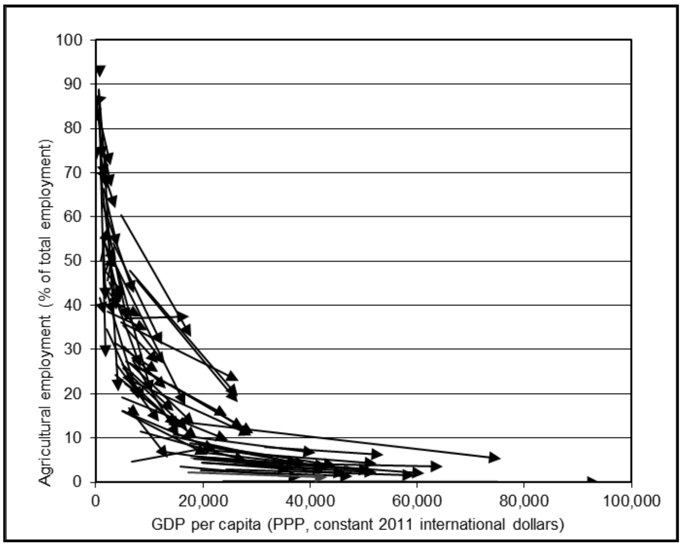
The fact that few U.S.-born workers are willing to do farm work underscores this country's relatively advanced position in the economic development process. In fact, the transition out of farm work is common among most countries that have gone through the development process. The response to labor shortages tends to involve importing farm labor from poorer nations.

Figure 10.2-A shows a scatterplot of the proportion of each country's labor force in agriculture against the per-capita Gross Domestic Product (a commonly used measure of economic development). The beginning of each arrow marks the position that each country was at in 1991, while the arrowheads show the position of each country in 2017. Nearly all of the arrows point to the southeast, indicating that as countries develop and become richer, their workforce tends to transition out of farm work. Figure 10.2-B shows the same graph (rescaled) isolating Mexico and the U.S. Clearly the U.S. is further along in the development process. However, Mexico is clearly transitioning out of farm work, too, and it is beginning to import farm workers from Central America (Martin, 2013; Taylor and Charlton, 2019).

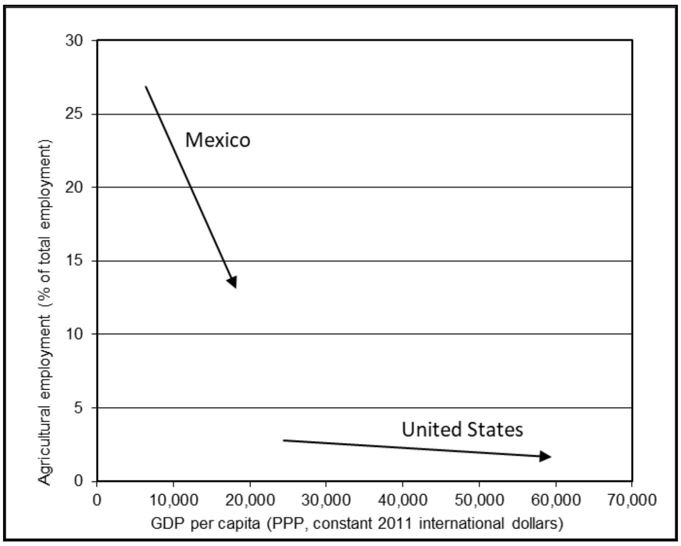
This process has been examined by two studies that explore the trend in farm work among rural Mexicans (the primary source of labor to U.S. farms). Using panel data from the Mexico National Rural Household Survey (Spanish acronym ENHRUM), Taylor et al. (2012) found evidence that a negative trend in the supply of rural Mexican labor to U.S. farms has been underway for years. In a follow-up study using a more recent version of the ENHRUM data, Charlton and Taylor (2012) quantify the negative trend in the farm labor supply from Mexico and conclude that lower fertility rates, increased educational attainment, and an expanding non-farm economy in Mexico have contributed to a decline in the pool of workers willing to work on U.S. farms.

There is also evidence from the U.S. side of the border suggesting that farm workers are leaving farm work for other sectors of the economy. A 2009 congressional report explains that some farm workers want more stable employment than what is offered by farmers, leading to a search for non-farm jobs (Levine, 2009). A Pew Research Center report finds that there were only two occupations

A: Worldwide



B: Mexico and the U.S.



<u>Note:</u> Constructed by authors using data obtained from the World Bank at: https://data.worldbank.org.

Figure 10.2: Percentage of Individual Countries' Workforce in Agriculture vs. GDP per capita

where unauthorized immigrant workers outnumbered lawful immigrant workers (farm work and construction), indicating that the construction sector may serve as viable employment option for farm workers who want to get out of farm work (Pew Research Center, 2016). Card and Lewis (2007) find that there has been a shift in Latin American employment away from farm work into construction and retail. And data from the National Agricultural Workers Survey reveal that there has been an upward trend in the share of California farm workers who have recently engaged in non-farm work in the U.S. (Rutledge and Taylor, 2019b).[2] Taken together, this body of evidence points to a U.S. farm labor supply that is shifting inward, where fewer and fewer workers are going into the farm labor force and more and more workers are leaving it. This trend could be problematic for tree fruit farmers and vineyard owners if they are unable to adapt to the new reality that fewer and fewer Mexican farm workers are going to be available in the future.

10.4 Farmer Responses to a Diminishing Farm Labor Supply

Economic theory provides a framework from which we can gain understanding about how decreases in the farm labor supply affect employment and wages in the farm labor market. The theory of supply and demand suggests that a decreasing farm labor supply should lead to fewer workers employed and higher wages. This scenario best describes the U.S. farm labor market over the past two or three decades. Other countries that have experienced a sharp drop in the number of agricultural workers in recent decades include Japan, France, Spain, South Korea, and the United Kingdom (Roser, 2020). Figure 10.3 shows the inverse relationship between the number of hired U.S. farm workers and real (i.e., inflation-adjusted) farm worker wages since 1976, revealing a pattern that is consistent with what economists would expect.

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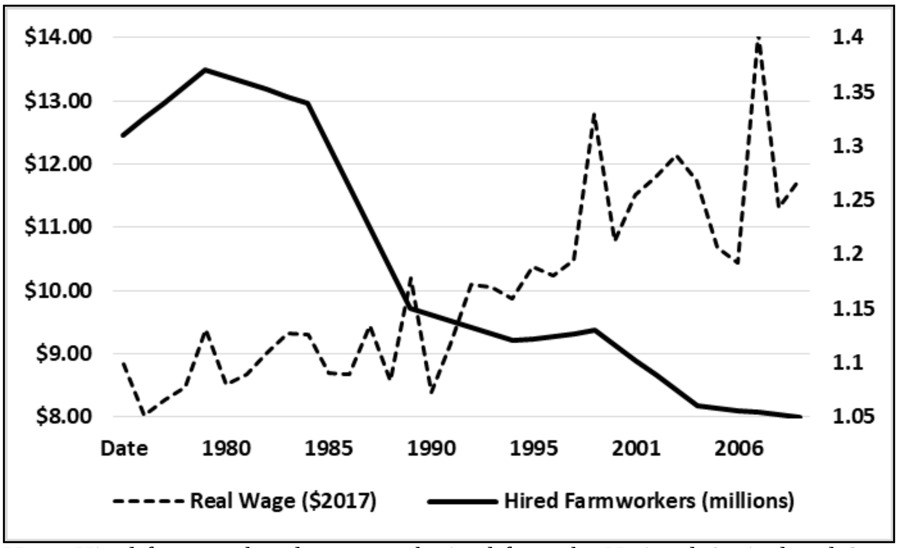
[2] The National Agricultural Workers Survey (NAWS) is a nationally representative annual survey of crop farm workers that is administered by the U.S. Department of Labor.

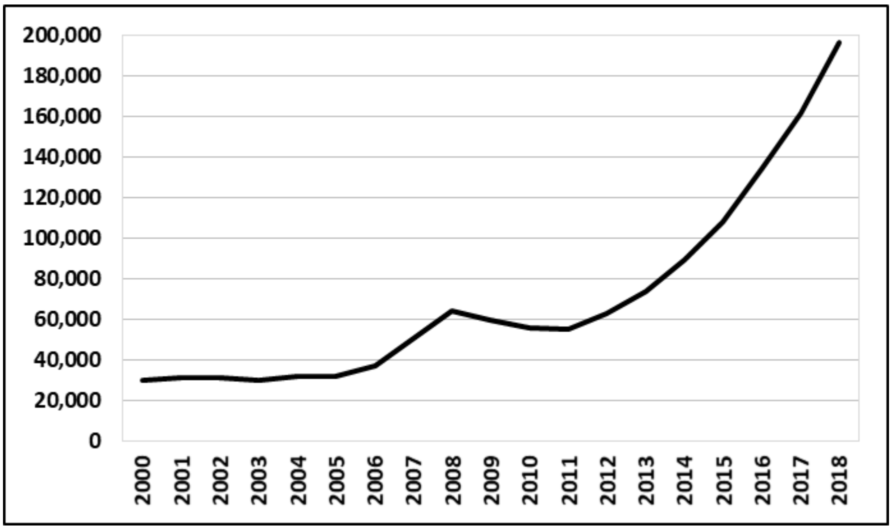


Note: Hired farm worker data were obtained from the National Agricultural Statistics Service (https://quickstats.nass.usda.gov/) and include farm workers directly hired by farmers and farm workers hired through agricultural service contractors. Farm worker wage data were obtained from the Community Population Survey (https://ipums.org/) and are in real (i.e., inflation-adjusted) $2017.

Figure 10.3: Hired U.S. Farm Worker Employment and Real Farm Worker Wages (1976-2010)

In addition to putting upward pressure on wages, farm worker scarcity has caused farmers to make adjustments to their labor management and production practices. Farmers growing labor-intensive crops are most vulnerable to changes in agricultural wages and labor availability. In some cases, farmers have switched from producing crops that must be harvested by hand to others that can be mechanically harvested in order to reduce the cost of labor and remove the risk of not being able to find enough workers during harvest time.

Others have turned to farm labor contractors and the H-2A agricultural guestworker visa program to ensure that they have access to the workers they need when they need them. Nationwide, the number of H-2A visa workers employed in the U.S. has more than tripled over the past decade, comprising nearly twenty percent of the overall hired farm workforce as of 2018 (see Figure 10.4). However, H-2A visa employment has lagged behind in California, in part because farmers who hire foreign workers through the H-2A program must provide housing, and housing costs in California have skyrocketed in recent years making the program less feasible from a cost-benefit standpoint.



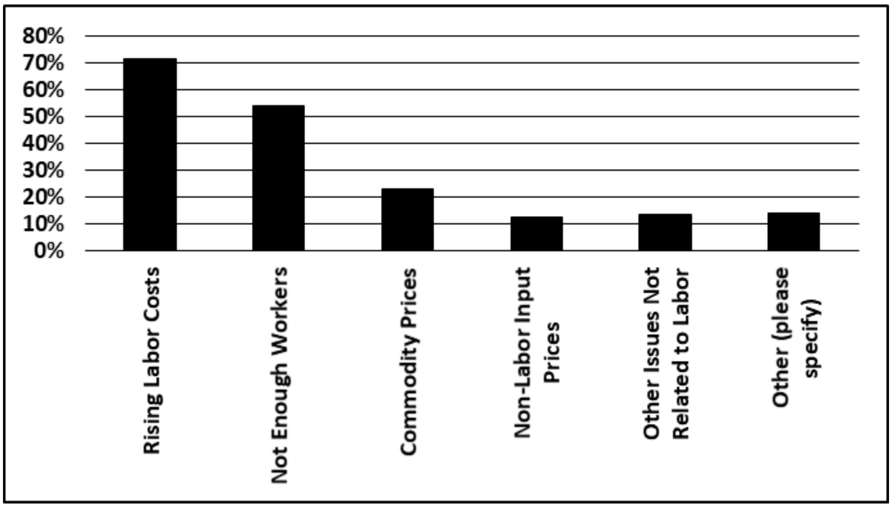
Note: Visa data were obtained from U.S. Department of State – Bureau of Consular Affairs and can be found at: https://travel.state.gov/content/travel/en/legal/visa-law0/visa-statistics.html.

Figure 10.4: Number of H-2A Visas Issued (2000-2018)

After the passage of IRCA in 1986, researchers uncovered an upward trend in the share of the farm labor force employed through farm labor contractors (FLCs).[3] This trend emerged, in part, because of new laws that made it illegal for farmers to knowingly hire undocumented workers (Thilmany and Martin, 1995; Thilmany, 1996). When a farmer hires an FLC to bring workers to her farm, the FLC becomes the official employer of record, which from the farmer's

[3] Farm labor contractors are employers who enter into contracts with farmers to provide certain services, such as pruning, weeding, and harvesting.

standpoint reduces the risk of legal repercussions from the presence of undocumented workers on the farm. However, recent research reveals that farmers are becoming increasingly reliant upon FLCs to ensure they have enough workers, demonstrating that the motive for employing FLCs has shifted towards finding workers in recent years (Rutledge and Taylor, 2019a).



Note: Results are from authors' calculation of the U.C. Davis-California Farm Bureau Federation "Adapting to Farm Labor Scarcity Survey" data. Percentages add up to more than 100% because farmers were allowed to select more than one reason.

Figure 10.5: Reasons for Labor-Saving Technology Adoption

In response to rising wages and labor availability problems, farmers also report having to make changes to their usual cultivation practices. According to a 2019 survey of over 1000 California farmers conducted by the University of California, Davis and the California Farm Bureau Federation, an increasing share of farmers have had to reduce or delay pruning and weeding, and a nontrivial proportion reported an inability to harvest all of the fruit that was available in their orchards and vineyards (Rutledge et al., 2019; Rutledge and

Taylor, 2019a).[4] These changes have been accompanied by increased adoption of labor-saving technologies, such as mechanical harvesters, specialized tractor attachments, automated weeding and irrigation technologies, and hand-held power tools. When asked the reason for using a labor-saving technology, the vast majority of survey respondents reported using it, in part, because of rising labor costs. Most of them also cited labor availability as a factor (see Figure 10.5).

The decision to adopt a labor-saving technology in response to a shrinking labor force can be modeled as a cost-minimization problem. It is common to model technology adoption in a two-dimensional framework such as the one portrayed in Figure 10.6. For simplicity, we only consider two inputs in the production process: capital and labor. Capital inputs include land, buildings, and machinery, and for the sake of parsimony we assume that the farmer owns a fixed amount of land and buildings so that the only production decision she makes is with regards to how much machinery and labor she will use to produce a certain amount of an agricultural commodity per acre while minimizing her production costs. Figure 10.6-A depicts the optimal input mix for a farmer who uses a labor-intensive production process in a labor-abundant environment. The curve denoted $\mathbf{Q^0}$ is called an isoquant and represents all the combinations of capital machinery (denoted by **K**) and labor (denoted by **L**) that can be used to produce a given amount of the commodity per acre (say 10 tons of Cabernet Sauvignon wine grapes). The downward-sloping straight lines in the graph are called isocost lines, and they represent all the combinations of capital and labor that generate the same amount of cost at a market clearing wage (**w**) and cost of using capital (**r**). The equation of this isocost line is:

$$\mathbf{C = rK + wL}, \qquad (10.1)$$

where **C** denotes the total cost per acre to use **K** units of capital and **L** units of labor. Rearranging this isocost equation into its point-

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[4] The survey collected information on farmers spanning a period of five years between January 1st, 2014 and December 31st, 2018.

slope form reveals the following equation:

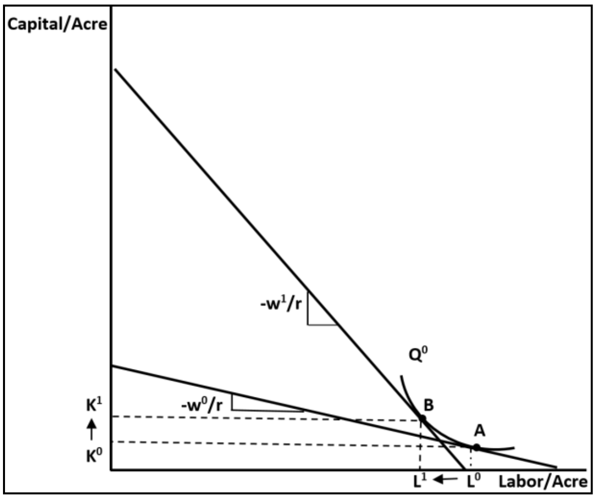
$$\mathbf{K = C/r - (w/r) \times L}. \quad (10.2)$$

Therefore, the slope of the isocost line when labor is abundant (i.e., when the wage is $\mathbf{w^0}$) in Figure 10.6-A is $\mathbf{-w^0/r}$. If the farmer wants to produce 10 tons of Cabernet Sauvignon wine grapes per acre in the labor-abundant environment, she will minimize her production costs by using the combination of capital and labor that corresponds to point **A** on the graph. At point **A**, the isocost line is just tangent to the isoquant curve $\mathbf{Q^0}$. Thus her cost-minimizing input mix includes the use of $\mathbf{K^0}$ units of capital and $\mathbf{L^0}$ units of labor per acre of land.

In a labor-scarce environment, the market clearing wage ($\mathbf{w^1}$) is likely to be higher than it is when labor is abundant (i.e., $\mathbf{w^1} > \mathbf{w^0}$), and the resulting isocost line will be steeper with a slope of $\mathbf{-w^1/r}$ such as the one depicted in Figure 10.6-A. In this labor-scarce environment, if the farmer continues to use a labor-intensive production technology, the cost-minimizing input mix will occur at point **B**. Because labor is relatively more expensive in a labor-scarce environment, the cost-minimizing solution requires more capital ($\mathbf{K^1}$) and less labor ($\mathbf{L^1}$) than it did in a labor-abundant environment.

The farmer may want to consider automating all or part of the production process (e.g., by purchasing and using a pre-pruner or mechanical harvester), which would substantially reduce the amount of labor required. If the farmer chooses to automate part of her production process, her production technology will change, so it can be represented by an entirely new isoquant such as the one denoted by $\mathbf{Q^1}$ in Figure 10.6-B. The cost minimizing input mix used to produce 10 tons of Cabernet Sauvignon wine grapes per acre in a labor-scarce environment using a labor-saving technology occurs at point **C**, where the farmer uses $\mathbf{K^2}$ units of capital and $\mathbf{L^2}$ units of labor. Note that the new isocost line associated with $\mathbf{w^1}$ in Figure 10.6-B has the same slope as the one shown in Figure 10.6-A, but it is closer to the origin of the graph, indicating that the total cost of employing capital and labor is smaller than it was when using the labor-

A: Change in Optimal Input Use Due to a Change from Labor-Abundance to Labor Scarcity While Using a Labor-Intensive Technology



B: Change in Optimal Input Use Due to a Switch from Labor-Intensive Technology to Labor-Saving Technology in a Labor Scarce Environment

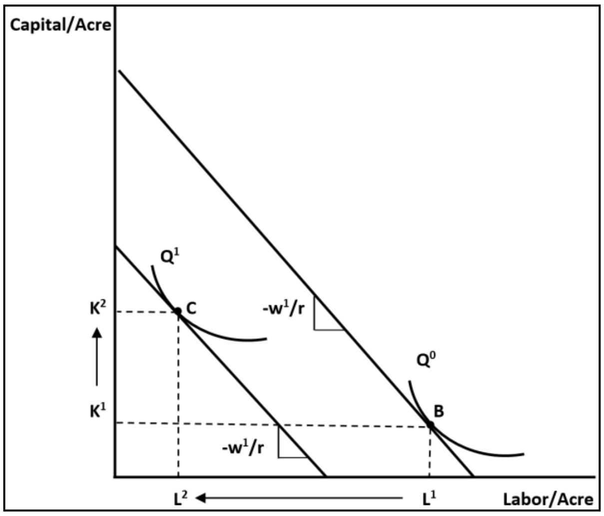


Figure 10.6: An Economic Model of Labor-Saving Technology Adoption

intensive production technology. The lower total costs here result from a large reduction in labor costs in a relatively high wage environment. However, the farmer must also factor in the per-period (annual) cost of the loan associated with purchasing the automated technology, so she will only adopt it if the annual cost of capital and labor plus the amount of the loan payment is less than the cost of producing under the labor-intensive technology. As a result, the decision to adopt the automated technology becomes a cost-benefit problem from the perspective of the farmer.

10.5 Agricultural Technology as a Service

One factor that plays a crucial role in the decision to adopt labor-saving technologies is farm size. As the farm size increases, so does the incentive to adopt new technologies because the loan payment required to purchase the new technology can be spread out over a larger number of acres. This means that the per-acre cost of purchasing the new technology is lower on larger farms, which increases the probability that new technologies will be cost effective. A corollary to this is that smaller farms may not be able to automate even if they would like to, so they may have to continue operating with labor-intensive production practices despite rising wages (or they may go out of business).

A popular model, particularly among agricultural technology startups, is to sell automation as a service (ATaaS). Besides keeping the technology under the control of the startup rather than selling it to the farmer, this business model helps address the challenge of adopting labor-saving techniques on farms too small to justify a large sunk cost of adoption. In theory, it could induce smaller farms (and perhaps larger ones, as well) to adopt automated production processes, enabling them to operate at a lower cost per acre. It could potentially help smaller farmers stay competitive and profitable in a world where larger farms tend to dominate the landscape. Nations around the world have realized the importance of agricultural technology adoption, and automation services could help fill an important void. In a declaration aimed at getting EU member states to support agricultural technology adoption, the European Agricultural Machinery Association (2019) stated that "Digital technologies [for agricultural production] should be available to farmers and farms of all sizes and may help attract younger generations, which remains one of the main social concerns affecting this sector today." According to a recent research report, the ATaaS market is expected to increase by more than 250% to $2.5 billion globally by the year 2024 (BIS Research, 2019).

According to this BIS Research report (2019), the most common ATaaS models are the pay-per-use and subscription models. Because the service providers own the equipment, this also alleviates any risk associated with having to repair or replace expensive electric or mechanical components when the machines break down. The key players in this market space include Trimble Inc., Deere & Company, AGCO Corporation, CNH Industrial N.V., Accenture plc, and several others. Within the ATaaS market, there are two main branches: i) Software-as-a-Service (SaaS), and ii) Equipment-as-a-Service (EaaS). The most common services currently offered include data analytics, navigation and positioning, yield monitoring, and soil and crop health management. Some companies, such as Blue River Technologies (which was recently acquired by Deere & Company for over $300 million), are in the process of developing automated weeding and fertilization technologies and hope to provide services to the public in the near future.

Automated service markets have also emerged in less developed countries where smallholder farming is the norm. For example, laser land leveling and mechanical transplanting services have proven to be valuable for small rice farmers in India (Lybbert et al., 2017; Gulati et al., 2019). In China, labor-intensive tasks, such as land preparation and harvesting, are increasingly being conducted by service providers (Yang et al., 2013). And service markets have started to develop in Africa; although, their development has lagged behind due to poorly integrated markets (Diao et al., 2019). ATaaS markets could be the key to helping less developed countries boost agricultural productivity growth, which has been sluggish compared to developed countries. A recent study of 11 African countries found that only 18% of agricultural households had access to tractor-powered machinery (Kirui, 2019), and it has been suggested that facilitating the development of rental markets for tractor services could help address this problem (Savastano, 2019).

10.6 Industry and University Responses to a Diminishing Farm Labor Supply

Driven by a perceived demand for labor-saving automation and exploiting major advances in mechanical, computer, and agronomic engineering, the public and private sector are investing heavily in developing labor-saving solutions for difficult-to-automate crops and tasks.

Take for example Blue River Technologies, which has recently developed machines that use cameras, computers, and artificial intelligence with deep learning algorithms similar to what is used in facial recognition systems to allow farmers to see every plant in the field. These systems can tell farmers what types of weeds are in their fields, as well as where and how many there are while permitting variable herbicide or fertilizer spraying regimes to be applied to each plant. These systems can dramatically reduce the need for workers and are designed to substitute machines and computers for manual labor. They also have the potential to help increase crop yields and cut down on non-labor input costs by minimizing the amount of chemicals used in the production process while applying them with a high degree of precision.

The University of California has also been developing technologies that capture data, which can be used to help inform farmers to produce crops more efficiently. One such project, the Virtual Orchard (or VO), is a technology that generates a three-dimensional model of an orchard using a series of aerial images that can measure the volume, height, size, and spacing of trees in an orchard. This system can be outfitted with near infrared cameras, and the data collected can be used to direct farmers to areas of their orchard that are water or nutrient deficient, which can help farmers reduce the amount of labor needed to properly inspect orchards during the growing season and can help minimize losses and increase yields (Pourreza, 2018).

In addition to the development of smart technologies, the U.C. system has also invested resources through its Cooperative Extension program to gain a better understanding of who is using automated systems and whether they are reliable and cost-effective. One such study has found that labor constraints are a "very important" factor in the decision to use currently-available automated technologies (Tourte and Siemens, 2018). However, this study also found that there has been a substantial amount of dissatisfaction with the technologies that are currently available and that farmers are generally not confident that they are reliable enough to adopt at this stage. Nevertheless, as resources such as labor continue to become scarce, the role of research and development to make agricultural production more efficient and sustainable will become increasingly important as farmers have to produce more food to feed a growing population.

The development of agricultural technologies has been evolving into a multi-national collaborative effort. For instance, the Israeli company Welaunch has started to set up shop in the U.S. by placing representatives in U.S. states to collaborate with farmers to address their problems. They take the information they gather in the U.S. back to Israel to develop and test new technologies on Israeli farms before bringing them to market in the U.S. (Bedford, 2019). In Europe, digital innovation hubs support the development and commercialization of "agri-food robotics" to achieve environmentally-friendly and labor-saving technologies (SPARC 2008). It is likely that developments in automation, and their subsequent adoption, will continue to diffuse globally. As software, mechatronics, and artificial intelligence algorithms become more advanced and capable of adapting to a myriad of new situations, these technologies will eventually be designed to target different regions and settings throughout the world.[5]

10.7 Economic Welfare and Automation

When agricultural labor is abundant, automation may be detrimental to agricultural workers and small farmers who cannot afford to invest in new technologies, even if the total benefits to society (e.g., through higher farm profits and lower food prices) are positive. In a labor-rich environment, where the majority of farm workers are not well-educated or technologically skilled, the adoption of automated technology has the potential to displace a large number of workers, many of whom may not have other employment options. Although automation leads to an increase in the demand for labor in the technologically-skilled farm labor market, it is not likely to offset the overall decrease in welfare experienced by the large number of farm workers who are displaced from employment in the low-skilled farm labor market. Adoption of the tomato processor created a large increase in the supply of processing tomatoes, which in turn stimulated the creation of new jobs in downstream food processing plants. The extent to which those non-farm jobs compensated for the loss of employment in the field is unclear.

On the other hand, in the current era of labor scarcity, labor-saving automation is more likely to create benefits for workers and consumers, as well as for agricultural producers and society as a whole. As the labor force transitions into a technologically-skilled one, wage gains in a labor scarce environment have the potential to be much larger for those who can acquire the skills necessary to remain in the workforce. Take for example Figure 10.7, which portrays the labor market for technologically-skilled farm workers with fixed labor demand under labor-abundant (Panel A) and labor-scarce (Panel B) environments. This scenario depicts a situation where the automated technology only requires a fixed number of personnel to

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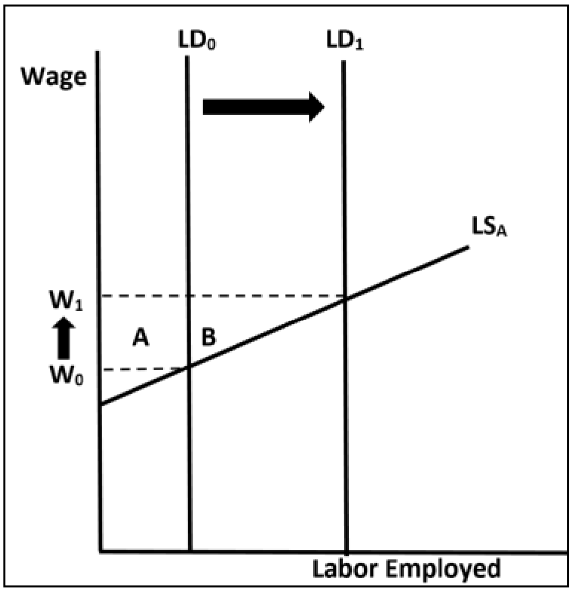
[5] A number of media reports and technologies are featured on the farmlabor.ucdavis.edu website.

A: Labor Abundant Environment



B: Labor Scarce Environment

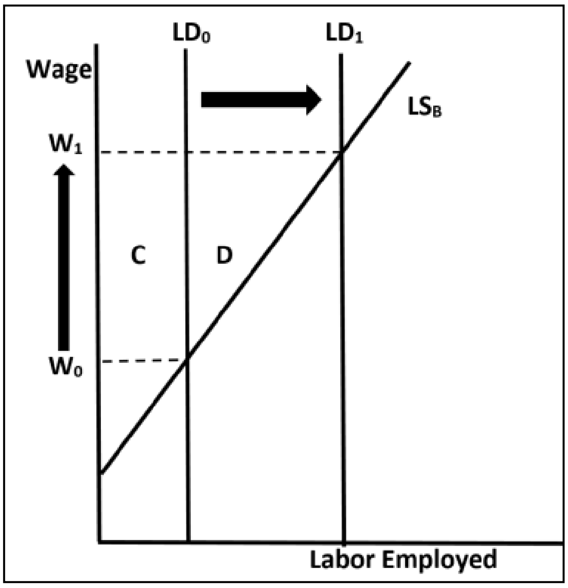


Figure 10.7: Technologically-Skilled Farm Labor Market Under Labor Abundant and Labor Scarce Environments

operate it. Both of the scenarios depict the same initial wage ($\mathbf{w^0}$) and amount of labor supplied at the initial equilibrium. The crucial difference between the two panels is represented by the slope in the labor supply curves (labeled $\mathbf{LS_A}$ and $\mathbf{LS_B}$). The increase in labor demand for technologically-skilled farm workers is represented by the same shift from $\mathbf{LD_0}$ to $\mathbf{LD_1}$ in both panels. However, the increase in demand for labor in this market leads to dramatically different outcomes under the two scenarios. The market-clearing wage in the labor scarce environment after the increase in labor demand is much higher than it is in the labor-abundant one, and the gain in farm worker welfare (represented by the area **C** + **D**) in Panel B is much larger than the gain in welfare in Panel A (represented by the area **A** + **B**).

In both labor-abundant and labor-scarce environments, the appearance and adoption of new agricultural technologies can lead to a concentration of production on fewer farms. It may not be cost-effective for small farmers to adopt an expensive automated technology because the fixed cost of adoption per unit of output (or land) can be much higher for them than it is for large farmers. If automation leads to increased production or efficiency, prices will decrease, which leads to increased consumption. This increases the overall welfare of consumers and the society as a whole, but it can also create winners and losers. Lower commodity prices can drive small farmers out of business, particularly if small farmers lack the scale to benefit from the new technologies.

10.8 Conclusion

A 2018 *Investor's Business Daily* article warned that "Farming robots are about to take over our farms." Extrapolating from current trends in technological development and a diminishing farm labor supply, it is not difficult to imagine a future in which automation in tree fruit orchards and vineyards expands and deepens to encompass more tasks on more farms. Early automation favors tasks for which labor-saving solutions are easiest to develop, as well as commodities for which the delicacy of human hands matters least at harvest time (for example, fruits to be processed, like wine grapes, versus fruits sold fresh to consumers, like table grapes). However, over time, advances in mechanical engineering and information technology (IT) put automation solutions within the reach of more tasks and commodities. "Robots in the fields" refers to labor-saving solutions that integrate IT with mechanical engineering and other fields, exploiting advances in machine learning and artificial intelligence that enable machines to do things once limited to the domain of humans.

What does a future with robots in the fields portend for farmers, consumers, farm workers, and rural communities?

For farmers, the impact will depend on how new and accessible technological developments keep pace with a declining farm labor supply. If technological development lags, crop production will be more vulnerable to rising wages and declining farm worker availability. Confronted by rising wages and less access to workers, there may be incentives to shift to less labor-intensive crops. If large farms are better able to experiment and become early adopters of new labor-saving technologies, a lag in the development of affordable labor-saving technologies could create challenges for small farmers and accelerate a concentration of crop production on fewer farms.

For consumers, access to fresh fruits and vegetables at an affordable price depends critically on how farmers adapt to a declining farm labor supply. If farmers have access to new labor-saving technologies, they may be able to increase the supply of food to consumers despite rising wages, minimizing food price increases. On the other hand, if these technologies are not available, labor shortages will put upward pressure on food prices for consumers, unless consumers are willing to shift to lower-cost foods, including imports of fresh fruits from countries that find themselves at an earlier stage of the agricultural transformation.

As some farms and crops shift to more sophisticated automation solutions, their labor demands will shift from less-skilled workers to workers who have the skills to work with new technologies. That is, employment will decrease, but human capital demands will rise.

Workers who are able to acquire the skills to work with new technologies can benefit from higher wages. Those who are not will have to shift to new crops, tasks, or farms that have not yet adopted the new technologies. Societies that succeed in training a new generation of tekked-up agricultural workers will have an advantage over those that do not. Against a backdrop of declining farm labor supply, it is possible to have rising farm wages (for both skilled and less-skilled workers) and increasing automation. This depends on technological change keeping pace with, but not outstripping, the negative trend in farm labor supply over time.

In the era of farm labor abundance, the expansion of labor-intensive agriculture created serious economic and social challenges for rural communities in California and elsewhere, as new seasonal farm jobs increased poverty and welfare demands (Martin and Taylor, 2003). Rising farm wages and a shift toward more skilled farm jobs and non-farm employment do the opposite. The impacts of a declining farm labor supply on rural communities, like the impacts on farmers, consumers, and workers, will depend on whether technological solutions keep pace with rising farm wages over time.

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