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Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries

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Abstract

This report examines how U.S. producers of major labor-intensive fresh fruit and vegetables are addressing the rising costs of labor. Farm labor costs are increasing for several reasons, including fewer newly arrived unauthorized workers, rising State minimum wages, and new requirements to pay overtime wages to some farm workers. Short-term options to meet the labor needs on farms include management changes, such as picking fields and orchards less often and introducing mechanical aids that increase worker productivity. Long-term options include the use of more labor-saving mechanization, additional H-2A guest workers, and a reduction of overall domestic production. This report provides an analysis of the ways in which producers are using different tools to address higher labor costs. A related report *Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fruit and Vegetable Industries: Case Studies,* analyzes adjustment options for four major fruit and three major vegetable and melon commodities.

Keywords: automation, farm labor, fruit, guest workers, H-2A program, harvest, imports, mechanization, produce, vegetables, melons

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Contents

Errata

On August 11, 2022, this report was reposted to correct minimum wage values in figure 2. The corresponding footnote was also updated to reference sources. No text or other figures were impacted.

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A report summary from the Economic Research Service

Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries

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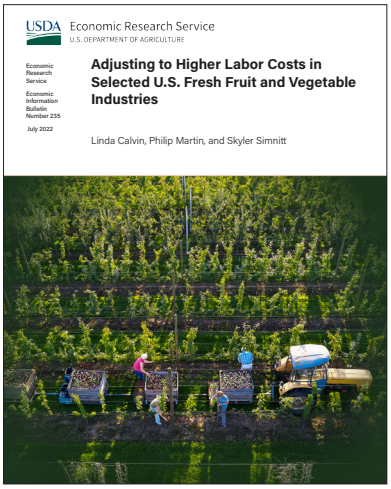


What Is the Issue?

Producers of labor-intensive agricultural commodities, including many fruit and vegetables, are especially concerned about labor costs, which typically account for a high share of these producers' variable production costs. Furthermore, farm labor costs rose faster than nonfarm labor costs over the last decade and are poised to continue increasing. Rising labor costs often cause producers to adjust their production and management practices to compensate for the changing cost structure. These adjustments vary by region and commodity, often depending on three factors: (1) the degree to which labor-saving mechanization technology can replace workers; (2) the availability of mechanical aids that do not replace workers but increase their productivity; and (3) the ability to recruit H-2A guest workers—a program to bring in foreign workers to fill seasonal farm jobs. Also, some farms adjust to higher costs by reducing production. This may ease the problem for farmers as declining total production leads to higher product prices. These higher prices, however, may attract imports, putting downward pressure on prices.

What Did the Study Find?

Farm labor is often a major cost of production for growers of fresh fruit and vegetables. Techniques to adjust to rising farm labor costs in fruit and vegetable production include:

- Labor-saving mechanization, such as mechanical harvesters that replace labor. Mechanical aids—for example, autonomous carts that move harvested product to the sides of fields—do not replace workers but make workers more efficient by allowing them to concentrate on harvesting. Durable and low-cost mechanical aids can raise labor productivity and may slow full-harvest mechanization. The harvest of certain fruit and vegetable commodities destined for the processing market (e.g., tomatoes) is already highly mechanized due to engineering advancements in the 1960s.

- Using H-2A guest workers to fill jobs when domestic workers in the United States cannot be found. Workers admitted under the expanding H-2A program fill 10 percent of the year-round equivalent jobs in U.S. crop agriculture.
- Reducing domestic production of crops that are not competitive with imports from lower wage countries.

How Was the Study Conducted?

The study reviews the literature on agricultural mechanization and labor trends within the fruit and vegetable industries and analyzes production and trade data to examine the relative importance of U.S. production and imports of selected fresh fruit and vegetables. In the related publication, *Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries: Case Studies*, specific commodity cases are discussed in detail. These case studies explain how labor is currently used in commodity specific contexts, including the roles of U.S. workers and H-2A guest workers, before examining alternatives to hand labor. The case studies relied on a review of biological and engineering research as well as insights from growers, marketers, other production participants, and other researchers to understand how producers are adjusting to rising labor costs now and are likely to adjust to these costs over the next decade.

Introduction

The availability and cost of farm labor is a major concern for the U.S. produce industry. In 2017, labor's share of total operating expenses was 38.5 percent in fruit and tree nut production and 28.8 percent in vegetable and melon production (Castillo et al., 2021). Due to tight labor markets in recent years, producers of traditionally labor-intensive produce commodities employ a variety of management strategies to adjust to increasing wage rates (Martin, 2017). These strategies include tactics such as importing foreign farm workers for seasonal contracts under the H-2A guest-worker program, substituting labor with capital where possible, and reducing the production of labor-intensive crops. The pressures facing growers and the alternatives these growers face change over time, necessitating periodic reviews of how they have responded to labor availability and costs.

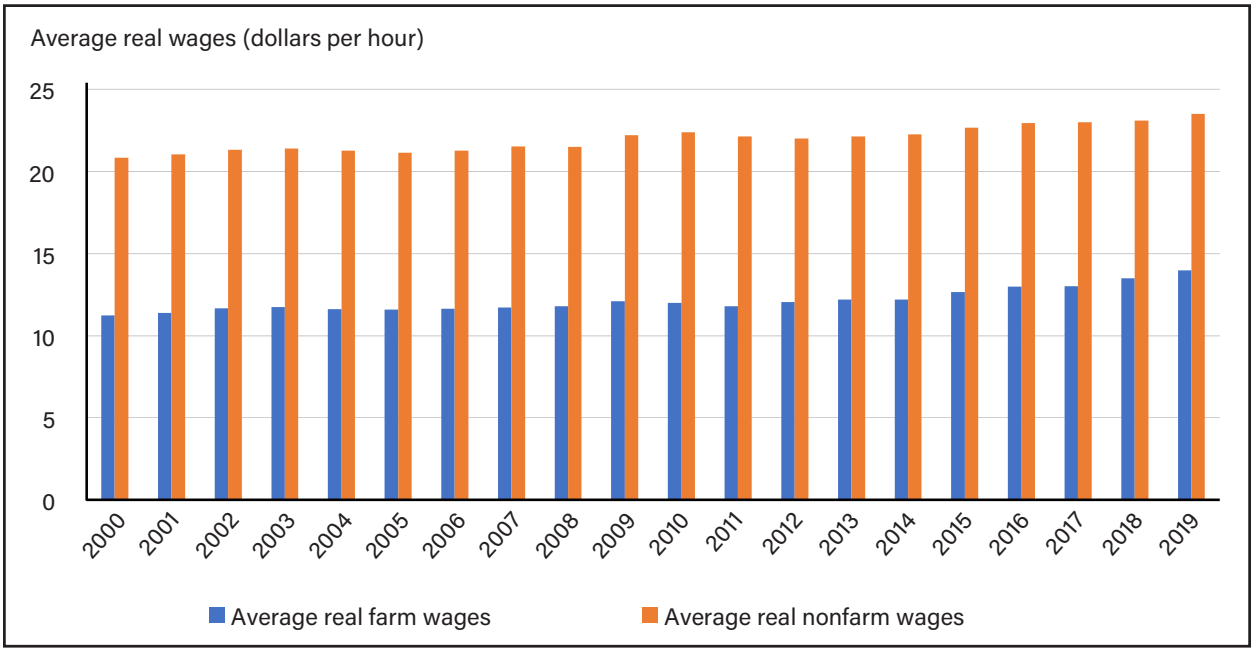
Farm labor wage rates—measured by real farm earnings—increased faster than nonfarm rates (16 percent compared with 5 percent) from 2000 to 2019 (figure 1), and they are expected to increase in the future.[1] Figure 2 shows 21 States had a minimum wage equal to the Federal minimum wage of $7.25 in 2021 and 29 States had a minimum wage above the Federal level. Earnings and earnings growth vary between States due to differences in local labor markets, housing costs, and State minimum wages. Farm earnings are often higher than the State's minimum wage and could continue to increase as more States raise their minimum wages beyond the Federal minimum. States such as California, New York, and Washington have removed exemptions from overtime pay requirements for farm workers, and more employers are hiring H-2A guest workers who must be paid a minimum wage—the Adverse Effect Wage Rate (AEWR)—which is higher than Federal or State minimum wages.[2] The coronavirus (COVID-19) pandemic in 2020 encouraged some employers to raise wages to attract workers. However, grower prices reflecting commodity supply and demand may make it hard to absorb higher labor costs for sustained production with hand workers, especially if imports constrain grower prices.[3] Mexico, a major supplier of U.S. fresh produce imports, had a minimum daily wage in 2020 of 123 pesos—or $5.80 per day. This corresponds to only 10 percent of the U.S. Federal minimum wage of $58 dollars for an 8-hour day ($7.25 per hour).

[1] Hourly earnings are earnings divided by hours worked and are equal to workers' wages who are paid a single wage. However, workers who are paid piece-rate wages, overtime wages, or receive bonuses can have hourly earnings exceeding their hourly wage rates. USDA's National Agricultural Statistics Service (NASS) reports average hourly earnings to accommodate the several wage systems used to pay farm workers. According to USDA, NASS's Farm Labor Survey, farm earnings are for field and livestock workers—which includes data on workers hired directly by employers and not hired through farm labor contractors—whereas nonfarm wages are for private sector production and nonsupervisory employee earnings from the U.S. Department of Labor, Bureau of Labor Statistics' Current Employment Statistics.

[2] The Adverse Effect Wage Rate (AEWR) is the average hourly earnings (not hourly wages) of nonsupervisory crop and livestock workers in the previous year as reported by employers to the USDA, NASS's Farm Labor Survey. Because of the lagged manner in which the AEWR is calculated, it may influence regional wages. Although this ratcheting effect of the AEWR has yet to be shown empirically, it might operate similarly to the positive wage shocks observed in some regional labor markets (Kaur, 2019).

[3] Richards (2020) showed some workers are target earners, so raising wages may not alleviate labor shortages if workers can reach their earnings target with fewer hours of work.

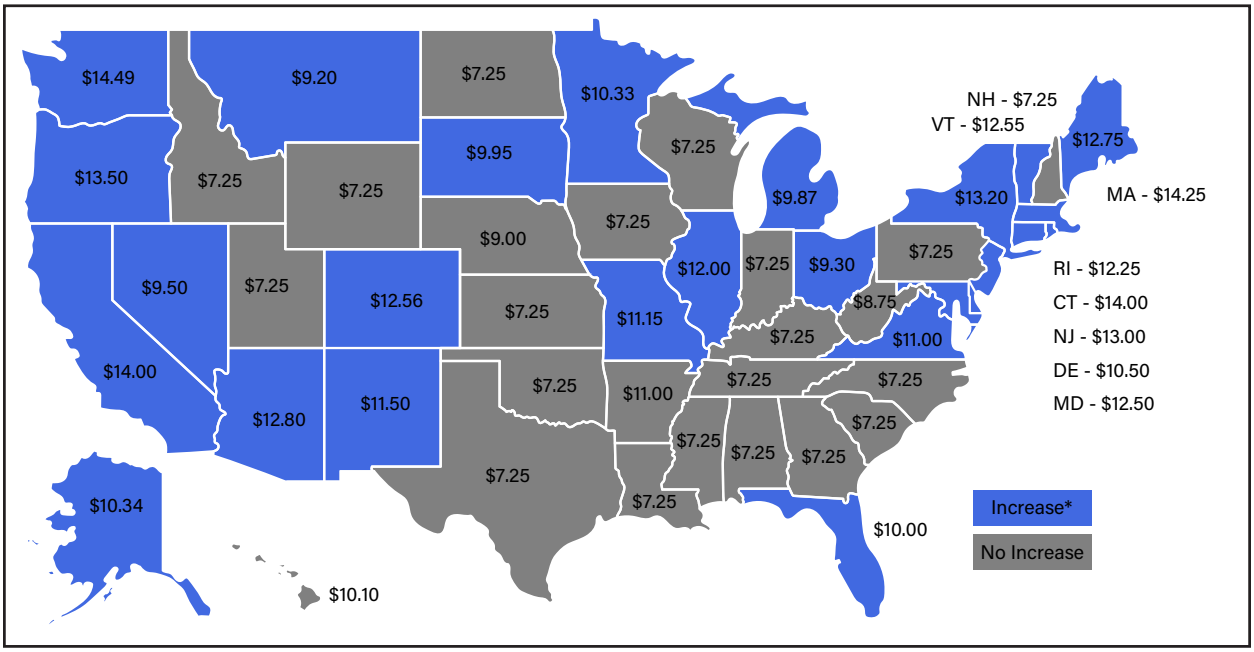
Figure 1
U.S. real farm and nonfarm earnings, calendar years 2000–19



Note: Farm wages are for U.S. field and livestock workers from the USDA, National Agricultural Statistics Service's Farm Labor Survey, and nonfarm wages are for private sector production and nonsupervisory employee earnings from the U.S. Department of Labor, Bureau of Labor Statistics' Current Employment Statistics.

Source: USDA, Economic Research Service using Rural Migration News Blog, "Farm Earnings Over Three Decades," 2021.

Figure 2
State minimum wages, 2022



Note: California's minimum wage of $14 is for employers with fewer than 25 employees and many cities and counties within that State have different minimum wages.

*Increased over wage in 2021.

Source: USDA, Economic Research Service using Morris, "2021 Minimum Wage Increases: Each State's Minimum Wage" and wikicommons, "State Minimum Wage, July 1, 2022."

Most workers employed on U.S. crop farms were born in Mexico (Martin, 2021; Zahniser et al., 2018). The U.S. Department of Labor's National Agricultural Worker Survey (NAWS) indicates that U.S. crop farms employ aging workers, a large share of whom are unauthorized immigrants (Rural Migration News Blog, 2020a).[4] The population of unauthorized immigrants within the United States declined by 28 percent (1.7 million people) between 2012 and 2019, which will likely negatively affect the supply of farm workers in the United States given the prevalence of unauthorized immigrants employed within the agricultural sector. Furthermore, the supply of potential farm workers in Mexico may shrink with declining birth rates, better education, and more people leaving agriculture (Charlton et al., 2019; Zahniser et al., 2018).[5] Growers in Mexico also reported difficulty finding workers (Escobar et al., 2019).

This report explores the fresh produce industry's response to the increasing cost of agricultural labor. Short-term options to get farm work done with fewer domestic workers—everyone except H-2A workers—include making fewer passes through a field to pick produce, growing varieties that need less labor, and using mechanical aids that make farm workers more productive. Long-term options include more labor-saving mechanization, more guest workers admitted via the H-2A program, and reduced production of labor-intensive crops. Some firms, including grower-shippers, can shift production abroad if the cost—including transportation to the United States—is cheaper than domestic production.[6] In some commodities, H-2A guest workers may serve as a bridge to more mechanization.

The uncertainties surrounding the three long-term options in response to rising farm labor costs of machines, migrants, and imports encourage some growers to invest in all three options until the optimal strategy for a particular commodity becomes apparent. Our work in the related publication, *Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries: Case Studies*, examines adjustment options for four major fruit—apples, grapes, blueberries, and strawberries—and three major vegetable and melon commodities—lettuce, melons, and tomatoes.[7] The case studies in the supplement volume discuss the three main alternatives to hand labor, as well as the key variables affecting which alternative is most likely to be adopted.

[4] For the period covering fiscal years 2016–17 and 2017–18, the U.S. Department of Labor's National Agricultural Worker Survey found that non-H-2A workers employed on U.S. crop farms were 38 percent U.S. citizens, 24 percent immigrants, 2 percent other work-authorized employees, and 36 percent unauthorized workers (U.S. Department of Labor, Employment and Training Administration, 2021).

[5] This has already occurred in the United States for many of the same reasons. Tyrchniewicz and Schuh (1969) showed how U.S.-hired farm workers were pushed out of agriculture by seasonal work and low wages.

[6] Grower-shippers are agribusinesses that grow, market, and ship their own produce.

[7] We did not cover all production regions for each commodity and recognize that labor demand and supply may vary by region.

U.S. Produce Industry and Trade

The United States produces many fruit and vegetable commodities for fresh and processed use. USDA, Economic Research Service (ERS) data show the total annual farm value of a selected group of U.S. fresh fruit and vegetable crops was $29.6 billion in 2019—$16.4 billion worth of fruit and $13.2 billion worth of vegetables (table 1). Tree nuts (not included in table 1) accounted for an additional $9.9 billion. Between the 2000–2002 and 2017–19 periods, average fruit production for the fresh market increased by 1 percent in terms of weight, and fresh vegetable production decreased by 5 percent in terms of weight.

The U.S. fruit and vegetable industry operates in a global environment. The average annual weight of fruit imports increased by 129 percent between the 2000–2002 and 2017–19 periods, while the weight of vegetable imports rose by 155 percent. During the 2017–19 period, imports accounted for 40 percent of fresh fruit availability—production plus imports minus exports plus any change in stocks—in terms of weight, and 31 percent of fresh vegetable availability. Fresh exports also remain important to U.S. fruit and vegetable producers, but they are much smaller than imports in terms of weight.

Most fresh fruit and vegetable imports are from Mexico, Central America, and South America (figure 3). In 2017–19, Mexico supplied 75 percent of imported fresh vegetables, Central America supplied 71 percent of banana imports, and South America supplied 20 percent of fruit imports. Mexico was the major source of fresh fruit and vegetable imports between 2017 and 2019, accounting for 49 percent of produce imports in terms of weight—63 percent of nonbanana produce imports by weight. Mexico's major comparative advantages include climate (i.e., producing in winter when it is colder in the United States), lower labor costs relative to the United States, the ability to transport perishable commodities quickly, and tariff-free entry into the United States under the United States-Mexico-Canada Agreement (USMCA).[8]

[8] These same advantages allow U.S. firms to operate abroad if total delivered costs are lower than domestic production costs.

Table 1

U.S. fresh fruit and vegetable statistics for selected commodities, calendar years 2000–2002 to 2017–19[1] [2]

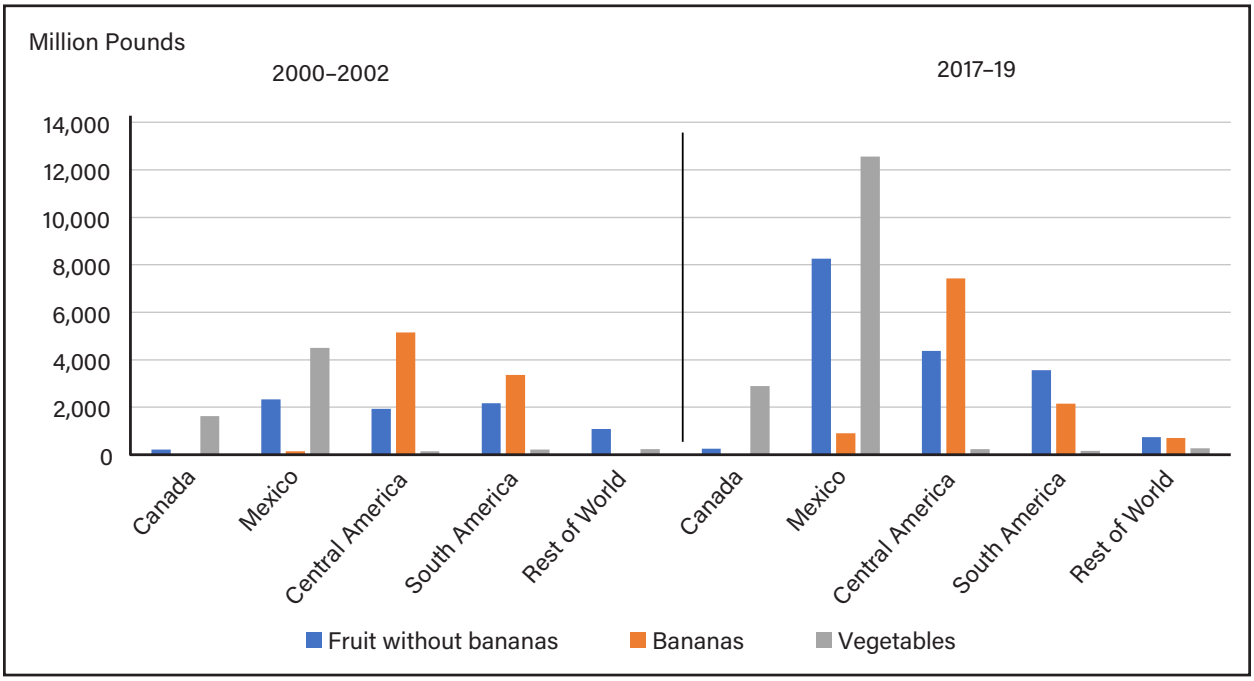
	Unit	Average		Percent change
		2000–2002	2017–19	
Farm value				
All fruit and vegetables	Billion dollars	NA	29.6	NA
All fruit (fresh and processed)	Billion dollars	NA	16.4	NA
All vegetables (fresh and processed)	Billion dollars	NA	13.2	NA
Acreage (planted)				
All fruit (fresh and processed)	1,000 bearing acres	3,232	2,635	–18
All vegetables (fresh and processed)	1,000 acres	1,716	2,664	55
Production				
Fresh fruit	Million pounds	28,299	28,451	1
Fresh vegetables	Million pounds	40,156	38,052	–5
U.S. per capita availability[2]				
Fresh fruit	Pounds	100	113	13
Fresh vegetables	Pounds	146	153	5
Imports				
Fresh fruit	Million pounds	6,472	14,812	129
Fresh vegetables	Million pounds	6,084	15,528	155
Exports				
Fresh fruit	Million pounds	6,141	6,332	3
Fresh vegetables	Million pounds	3,704	3,121	–16
Import share of availability (weight)				
Fresh fruit	Percent	23	40	77
Fresh vegetables	Percent	14	31	115
Export share of production (weight)				
Fresh fruit	Percent	22	22	3
Fresh vegetables	Percent	9	8	–11

[1] Fruit excludes tree nuts and bananas but includes melons. Vegetables exclude melons, sweet potatoes, mushrooms, and pulse crops. Fresh-cut vegetables are included in the "Fresh vegetables" category. These statistics are based on a subset of fruit and vegetable commodities that have adequate data to report production, imports, and exports.

[2] Availability (production plus imports plus net change in stocks minus exports) is a proxy for consumption.

Source: USDA, Economic Research Service, Fruit and Tree Nuts Yearbooks Tables, and Vegetable and Pulses Yearbook Tables.

Figure 3
U.S. fresh produce imports by region and commodity type, calendar years 2000–2002 and 2017–19



Note: The figure uses trade data from the U.S. Department of Commerce, Bureau of the Census, which includes all commodity trade data, unlike the previous figure which is based on a subset of commodities.

Source: USDA, Economic Research Service using U.S. Department of Commerce, Bureau of Census data.

Rising Imports

The impact of increased imports on U.S. producers varies by commodity, season, and type of grower. Although the United States imports many fruit and vegetable commodities, this does not necessarily mean U.S. growers competing with imports are uncompetitive. Imports serve to ensure the availability of fresh produce year-round. Nonetheless, imports may compete with domestic production and put downward pressure on prices, which can result in reduced U.S. production (Hodges et al., 2019; U.S. International Trade Commission, 2008; Suh et al., 2017). Given the seasonal nature of most U.S. fruit and vegetable crops, the effects of imports depend on when the domestic grower produces. Growers only producing during a period of high and rising imports may reduce production and eventually stop producing crops that compete with imports. Growers who produce during periods of the year with little- or no-import pressure may be relatively unaffected.

Some products are imported because of climate constraints. For example, the United States has limited or no commercial production of tropical fruit. In 2017–19, 100 percent of mangoes and bananas were imported, whereas 99 percent of papayas were also imported (table 2). All limes and pineapples are now imported as well after domestic production shrank because of competition from Mexico and Central America. The United States also imports fruit and vegetables that are not produced on a year-round basis and cannot be stored for long periods, such as table grapes. In 2017–19, 49 percent of U.S. table grapes were imported. Although this benefits consumers, this can be problematic for U.S. producers who face increased competition at the beginning and end of their season, periods that once offered high prices to U.S. producers. Products that store well are less likely to be imported. Apples can be stored for a long period, partly explaining why imported apples only accounted for 6 percent of 2017–19 apple availability.

Table 2

Import shares as a percent of U.S. domestic availability, calendar years 2000–2002 and 2017–19

	Imports as a percent of domestic availability				Imports as a percent of domestic availability		
	Average				Average		
	2000–2002	2017–2019	Percent change		2000–2002	2017–2019	Percent change
Mangoes[1]	100	100	0	Snap beans	9	35	282
Limes[1] [2]	98	100	2	Watermelon	11	32	181
Pineapples[1]	79	100	27	Plums	19	26	38
Bananas[1]	100	100	0	Broccoli	7	22	203
Papayas	83	99	19	Cauliflower	4	21	437
Asparagus	61	98	60	Strawberries	6	18	204
Green onions[3]	89	93	4	Lemons	8	18	124
Avocados	36	89	149	Pears	20	18	–9
Cucumbers	44	81	81	Onions	11	18	67
Artichokes[4]	74	79	6	Oranges	4	16	333
Kiwi	73	72	–1	Carrots	7	14	96
Raspberries	41	68	66	Cabbage	4	12	189
Peppers, bell[4]	37	66	80	Peaches and nectarines	7	11	63
Tomatoes	32	61	92	Celery[4]	4	11	146
Squash	34	61	78	Lettuce, leaf/ romaine	1	10	629
Blueberries	47	59	26	Grapefruit	4	7	94
Eggplant[4]	40	58	47	Cherries	6	7	4
Grapes	48	51	7	Lettuce, head	1	6	500
Radishes	24	50	113	Sweet corn	2	6	185
Garlic[4]	32	49	52	Apples	8	5	–38
Honeydew	26	45	72	Apricots	16	4	–72
Cantaloupe	35	43	25	Spinach	3	4	17
Tangerines	23	36	57	Cranberries	0	0	0

[1] When the United States does not produce tropical fruit but does export it, the import share of availability is greater than 100 but is capped at 100 in this table.

[2] The 2000–2002 average is based on only 2000–2001 because data were discontinued.

[3] Green onion statistics come from USDA, Agricultural Marketing Service (AMS). Percent change is based only on domestic shipments and imports, not exports.

[4] Includes both fresh and processed imports.

Sources: USDA, Economic Research Service, Fruit and Tree Nuts Yearbook Tables and Vegetable and Pulses Yearbook Tables; and USDA, AMS, Market News.

Some commodities grown in the United States year-round are nonetheless also planted abroad and destined for the U.S. market. For instance, bagged salad processors sign contracts with buyers to guarantee specific weekly quantities of bagged salads on a year-round basis. These firms may plant in Mexico to meet their contract obligations in case their U.S. supply is reduced by weather or disease. Other factors, such as lower transportation costs, can increase imports. Some central Mexico production areas are closer to U.S. eastern markets than the production areas in the western United States.

Imports sometimes benefit U.S. producers, as in the case of avocados. Before 1994, the United States restricted avocado imports from Mexico—the world's largest producer—due to phytosanitary concerns. U.S. avocado producers worried fresh avocado imports from Mexico would lower prices to uncompetitive levels. However,

with year-round supplies, demand for avocados grew and per capita availability increased by 221 percent between the 2000–2002 and 2017–19 periods. While Mexican imports accounted for 88 percent of U.S. availability in 2017–19, increased demand for avocados helped the U.S. industry remain profitable.

Some imports compete with U.S. production. For example, California produces strawberries year-round, but with less volume in the winter. Some U.S. marketers import strawberries from Mexico during the winter to supply customers on a year-round basis. Florida's strawberry growers, however, compete directly with Mexico during their winter/spring season. Finally, some fruit and vegetables are nearly all imported because of the lower labor costs abroad. Growing asparagus is labor-intensive because spears must be frequently harvested over several months without harming the plant; in warm weather, asparagus fields might require daily harvesting. Efforts to develop a selective mechanical asparagus harvester have failed. U.S. asparagus production fell by 46 percent between 1990–92 and 2005–07 as imports from Mexico and Peru surged (Calvin and Martin, 2010). Imports accounted for 98 percent of U.S. availability in 2017–19 (table 2). Green onions are another labor-intensive commodity now mostly imported from Mexico (Calvin et al., 2004). In 2017–19, an average of 93 percent of domestic green onion availability was imported, right behind asparagus. Raspberries may be another industry shifting more production to Mexico. Between 2013 and 2020, U.S. production declined by 33 percent while imports increased by 237 percent.

The Future of Trade

Fresh fruit and vegetable trade presents both challenges and opportunities. The challenge for U.S. growers is to compete during their season with producers in countries with lower costs.[9] U.S. produce industries can use Federal trade remedy laws to redress their problems if they believe they were injured by imports or unfair trade practices (Johnson, 2020). In practice, growers' use of these laws may be limited due to the requirement that the identified trade grievance be supported by the majority of producers within an industry.[10]

Trade also provides opportunities for U.S. firms to take advantage of production in the United States and abroad. For decades, these firms have imported fruit and vegetables to meet their business' needs, demonstrating the ability of U.S. firms to organize relationships with foreign growers and to import produce (Calvin and Barrios, 1998). If economic incentives changed, these firms could shrink production in the United States by importing more.

[9] Although some U.S. producers may enjoy the benefits of certain improved production technologies, there is ample reason to believe these beneficial technologies are quickly disseminated to foreign nations, especially given the prominence of multinationals with farms for identical commodities in both the United States and foreign countries.

[10] Current dumping and countervailing duty laws require that growers seeking protection from imports must have the majority of support from the domestic industry. Some southeastern growers in the United States, who are often a small share of the domestic industry, want to allow regional groups—representing less than 50 percent of a seasonal and perishable crop industry—to pursue unfair trade practice cases even if the rest of the industry does not join or opposes the effort. Although unsuccessful, these growers tried including such changes when the North American Free Trade Agreement (NAFTA) was renegotiated—now called the United States-Mexico-Canada Agreement (USMCA). Some continue to advocate for ways to address perceived adverse impacts from imports (Rubio, 2021; Ruiz, 2021).

Harvest Mechanization in Agriculture

Mechanization is another option for growers facing high-cost labor and unpredictable labor supplies. Crop commodities generally fall along a spectrum from harder to easier to mechanize. At the easier to mechanize end of the spectrum are commodities that can be mechanized with current available plant varieties and machines (e.g., blueberries, raisin grapes, wine grapes, and baby lettuce/leaf lettuce). Many of these commodities are either already mechanized or likely to embrace existing mechanical harvesters as a response to rising labor costs. At the harder to mechanize end of the spectrum are commodities for which few or no viable mechanical harvesters exist. This lack of viable mechanical harvesters for some commodities is usually due to a couple of issues: (1) the fruit or vegetable is too sensitive to harvest without damage with current technologies, and (2) even if a mechanical harvester could be developed, there are so few producers that it would be economically unattractive to mechanization companies to develop such machines.

Mechanizing tasks that are still completed by hand labor is a difficult process because the work is outdoors and done in unpredictable settings (Manyika et al., 2017). Most of the innovation discussed in this report is focused on mechanization—replacing human muscles with mechanical power. Automation—replacing human judgment with computers and machines—is a growing segment of innovation as computers become cheaper, the field of robotics advances, and sensor technologies improve (Karkee and Zhang, 2012). Both mechanization and automation reduce the number of workers involved in production systems and increase the skills required of the remaining workers. For simplicity, we use the term "mechanization" in this report to encompass both mechanization and automation innovations. This report also discusses mechanical aids—machines that make workers more productive. For example, one mechanical aid for apples is a platform that raises and lowers workers to levels appropriate for hand harvesting, which improves worker production by eliminating the time-consuming and dangerous work of using ladders for harvesting. An anticipated future mechanization innovation would locate an apple in a tree, determine if it is ripe, and harvest it.

Innovation is initiated to solve an economic problem. In agriculture, the high cost and limited availability of labor induces labor-saving innovations (Hayami and Ruttan, 1984).[11] There are constraints to innovation, particularly regarding the level of research and development (R&D) funding to move the science forward. Produce growers might want a mechanical harvester, but the prototypes available may not be physically or economically feasible. Innovation is an expensive and risky process and it often requires public support for basic research before breakthroughs that encourage private investment (Alston and Pardey, 2008). Government funding for agricultural mechanization research has fluctuated over time, and the case studies discussed in the related publication *Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries: Case Studies* show a variety of funding sources, including Federal and State Governments, grower organizations, individual growers (usually very large growers), and—more recently—venture capital, that support labor-saving research (PitchBook, 2021).

In general, growers adopt new technologies when the difference between expected benefits minus expected costs for the new technology is greater than for the older technology. Some growers may be too small to profitably adopt an expensive new machine, although there are sometimes custom harvest operations—as in the case of raisin grapes—that could enable growers to use labor-saving machines. There is usually some uncertainty about how a new mechanical harvester will work, which can act as a constraint on adoption. If farmers are unsure whether they will have an adequate harvest workforce, they may prefer to buy a harvest machine to reduce the risk that their crop will not be harvested. Producers with an adequate—albeit expensive—labor supply may prefer to wait until the mechanical harvester is more of a proven technology. In the produce industry, many innovations require retrofitting of fields and orchards, which can be expensive. Growers with

[11] Sunding and Zilberman (2001) provide a comprehensive review of the economics of innovation and adoption of new technologies.

long-living perennial crops may be reluctant to remove the plants until the end of their productive life. Not all mechanical harvesters or mechanical aids work well in all terrains. For instance, hills often cause problems.

Another characteristic of machines that can slow the rate of adoption is the fact that a purchased machine becomes a fixed cost to the grower. Hand workers are variable costs, meaning farmers do not pay wages if weather or disease ruins the crop or if prices are so low the crop is not harvested. However, once a machine is purchased, it is an expense that must be paid whether there is a crop to be harvested or not.

Types of Mechanization

There are two types of mechanical harvesters—nonselective and selective. Nonselective—or one-pass harvesting—is the easiest since the machine harvests everything (Vougioukas, 2019). This strategy requires discarding immature or bruised produce after it is harvested. Selective harvesting, by contrast, makes several passes through the fields to identify and harvest only marketable commodities while avoiding damage to immature product or plants that will be harvested in future passes.

Many vegetables are harvested in one pass through the field. Seeds are planted in rows so it is clear where the produce is. Conversely, tree fruit in a traditional orchard is spread through the trees in unpredictable locations and may be obscured by leaves. Most vegetables are annual plants, so the machine can harvest everything in one pass and destroy the plant at the same time. Once in a packing house, mechanical aids and robots can efficiently separate marketable from nonmarketable produce. Although harvest mechanization lowers labor costs, yields may be reduced since immature or bruised produce harvested with a once-over harvesting process must be discarded reducing grower revenues.

Harvesting fruit from perennial plants poses more challenges for machines. Shake-and-catch harvesters are nonselective in that they remove all of the fruit and nuts from trees in one pass through an orchard. This process does not work on all perennial plants. For trees, shake-and-catch systems use a rubber-coated arm that grasps the trunk or limb and delivers a jolt to dislodge the fruit or nuts. During the 1960s, the tart cherry processing industry mechanized the harvest process in Michigan with the shake-and-catch system and a destemming machine, which served as an essential part of the mechanized harvest system (Roberts, 1968; Ghassan, 1986). The shake-and-catch system does not work well for fresh-market apples since apples bruise easily.[12] A selective harvester for apples would make multiple passes through the orchard and pick only mature apples. Such a machine is in development. Grapes for wine and raisins, as well as blueberries can be harvested by nonselective machines that pass over or between rows of plants and use rotating fingers to dislodge the fruit so it falls onto conveyor belts for transport to bins or gondolas.

It is easier to mechanize commodities destined for processing than those sold fresh to consumers (Vougioukas, 2019). Processors are less concerned about blemishes and other damage, since the produce will be stabilized immediately with some kind of processing, such as freezing, drying, juicing, and canning. Some crops, like blueberries, are dual-use—meaning they may be sold in the higher-price fresh market or the lower-price processing market. If growers want to harvest by hand for the fresh market and by machine for the processed market, they may not know in advance which market their product will be sold to, which encourages hand harvesting.

[12] Similar attempts were made to mechanize Florida's citrus for processing industry, but no one in Florida currently uses the shake-and-catch system that was developed, demonstrating the risk of investment in innovation. The Florida Department of Citrus spent about $10 million of grower-box taxes on the mechanical harvesting program between 1997 and 2005. An abscission chemical is required to loosen fruit for harvest with the shake-and-catch system. An effective abscission chemical for use on late season Valencia oranges has yet to be approved by the U.S. Environmental Protection Agency, which relegates machine harvesting to only early and mid-season oranges. The arrival of citrus greening disease (Huanglongbing) made growers very reluctant to use a machine that might harm trees' health (Huffman, 2012).

The Mechanization Process: Systems, Cooperation, and Trial-and-Error Refinement

Mechanizing hand tasks in agriculture usually involves a systems perspective, cooperation, and diffusion through trial-and-error refinement. The first key to mechanization is to develop a systems perspective that may begin with changes in production practices and end with changes to the packing or processing operation to accommodate machine-harvested produce. The second key is coordination between engineers and scientists. Engineers prefer uniformly ripening plants that can be harvested in one pass through a field, whereas plant breeders traditionally focus on maximizing crop yields and other characteristics such as resistance to disease. Developing new plant varieties amenable to machine harvesting takes time and involves trade-offs. For example, breeding tomatoes for maximum flavor may make them more fragile and less amenable to machine harvesting, although modern breeding technologies speed up the development of new varieties suitable for machine harvesting. The third key to labor-saving mechanization is refining labor-saving machines so they are more likely to be adopted.

A Mechanization Success Story: California Processing Tomatoes

The mechanization of the California processing tomato industry in the 1960s is an example of successful mechanization. When the Bracero Program—a guest worker program—expired in 1964, braceros comprised almost 75 percent of harvest workers in the processing tomato sector.[13] A systems approach re-examined the entire field-to-factory chain of growing, harvesting, and processing tomatoes into paste and other products and made changes to facilitate mechanization. Initially, plant scientists needed to develop uniformly ripening tomatoes with a shape to withstand machine harvesting, and engineers had to develop machines to separate tomatoes from dirt, stems, and leaves.[14] Private manufacturers improved university-developed plants and machines, which promoted the rapid diffusion of mechanical tomato harvesting.[15]

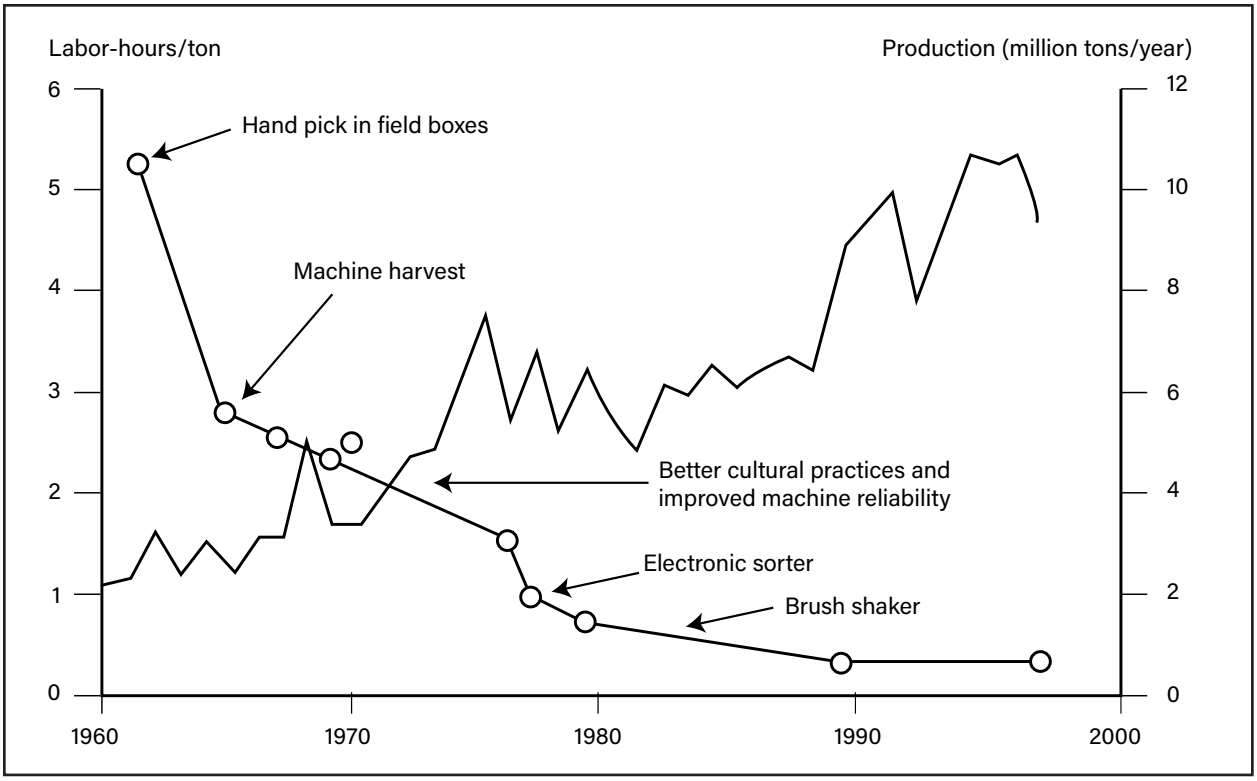
Adoption of the mechanical harvester was rapid. In 1962, less than 1 percent of California's processing tomatoes were harvested by machine; by 1969, almost 100 percent were machine-harvested (figure 4). Processing tomato production increased from 3 million tons per year in the early 1960s to 12 million tons per year in 2019. Mechanization changed the processing tomato industry. Before mechanization, many growers had a few acres of processing tomatoes alongside other commodities so hand-harvesting processing tomatoes into 50-pound lugs was one of several jobs for hired workers. Farmers began to specialize in growing processing tomatoes, planting longer rows in larger fields with room at the ends of the rows for the machinery to turn around. Other changes involved improved weed control, changes to field preparation, and new irrigation techniques (Thompson and Blank, 2000).

[13] The U.S. Government allowed farm employers to hire workers from Mexico under various Bracero guest-worker programs. 1965—the first year without the Bracero Program—was a year of adjustment for the U.S. produce industry marked by some labor-saving mechanization, including the mechanical processing tomato harvester, increased wages, and increased union activities (McElroy and Gavett, 1965).

[14] The groundwork for tomato harvest mechanization was laid by University of California-Davis researchers. A plant scientist bred tomato varieties in the 1950s that ripened uniformly. These tomatoes also had a pear-shape so tomatoes at the bottom of large gondolas could better withstand pressure from the tomatoes on top. An agricultural engineer—in conjunction with a local equipment manufacturer—designed a machine to cut the plant, shake tomatoes from the vines, and transport them to gondolas for delivery to processing plants.

[15] Tomato mechanization also involved a testing system to determine the quality of 12.5-ton gondolas of harvested tomatoes. Growers are paid by weight, and processors can reject or reduce the price of substandard tomatoes. Rejecting a 50-pound lug of tomatoes costs a farmer $2—at a price of $80 per ton for processing tomatoes—but rejecting a 12.5-ton gondola costs $1,000. With more risk for the grower in the case of a dispute over quality, the State of California opened testing stations (later privatized) that took random samples from each gondola to determine quality. This resolved what could have been a contentious issue between growers and processors that could have slowed mechanization.

Figure 4
Processing tomato production rose as the use of the harvester spread



Source: Thompson and Blank, 2000, "Harvest mechanization helps agriculture remain competitive."

Tomato-processing mechanization is an example of a public-private partnership that promoted innovation in response to the end of the Bracero Program, but mechanization also generated controversy. The United Farm Workers of America union sued the University of California (UC) in 1977 for using taxpayer funds, which were to benefit all rural Americans, to benefit only those farmers capable of adopting the tomato harvester (Martin and Olmstead, 1985). The suit was settled with UC winning the right to continue doing labor-saving mechanization research but farm worker advocates were added to UC advisory boards that reviewed mechanization research proposals. In 1979, USDA Secretary Bob Bergland said USDA would stop spending Federal funds on research that could lead to the "replacement of an adequate and willing workforce with machines" (U.S. Congress, Office of Technology Assessment, 1983).

Current Research Funding

There was little Federal investment in fruit and vegetable mechanization and automation research until the Food, Conservation, and Energy Act of 2008 created the USDA's Specialty Crop Research Initiative (SCRI).[16] SCRI supports research on five issues critical to the future of the U.S. fruit and vegetable industries: (1) breeding, genetics, genomics, and other methods to improve crop characteristics; (2) efforts to identify and address threats from pests and diseases; (3) improving production efficiency handling and processing, productivity, and profitability, (4) new innovations and technology including improved mechanization and technologies that delay or inhibit ripening; and (5) methods to prevent, detect, monitor, control, and respond to potential food safety hazards. This program requires 100-percent, non-Federal matching funds.

Between 2008 and 2018, four USDA agencies—Agricultural Marketing Service, Agricultural Research Service (ARS), National Institute of Food and Agriculture, and Rural Development—provided $288 million in fund-

[16] Specialty crops include fruit, vegetables, tree nuts, horticulture and nursery crops, including floriculture.

ing to accelerate the development and use of mechanization or automation in specialty crops (Astill et al., 2020). The shares of agency funding for specialty crop research going to mechanization or automation were small, 1–3 percent, but the percent of specialty crop research dedicated to this topic was more substantial (60 percent at ARS).

The Future of Mechanization

Rising farm labor costs, uncertainty about labor availability, and the declining cost of new technologies collectively promote the development and diffusion of plants and machinery that reduce the need for farm labor. Many commodities that were once hand-harvested are now mostly machine-harvested—such as wine grapes—or are amenable to machine-harvesting, as with blueberries and raisin grapes. Federal and State Government investments can influence the speed of mechanization by subsidizing the development of new plant varieties and machines to tend and harvest them.

There are also private efforts to mechanize hand-harvested fruit and vegetables. The Western Growers Association organized the Global Harvest Automation Initiative "to accelerate harvest automation across the fresh produce industry, with a goal of automating 50 percent of harvests within 10 years by accelerating the commercialization of harvest automation innovations (Western Growers Association, 2021)." Associations for apple, strawberry, and other commodity producers are supporting mechanization efforts, often collaborating with startup firms with private venture capital to apply innovations in vision systems and robotics to harvest fruit and vegetable crops.

H-2A Guest Workers

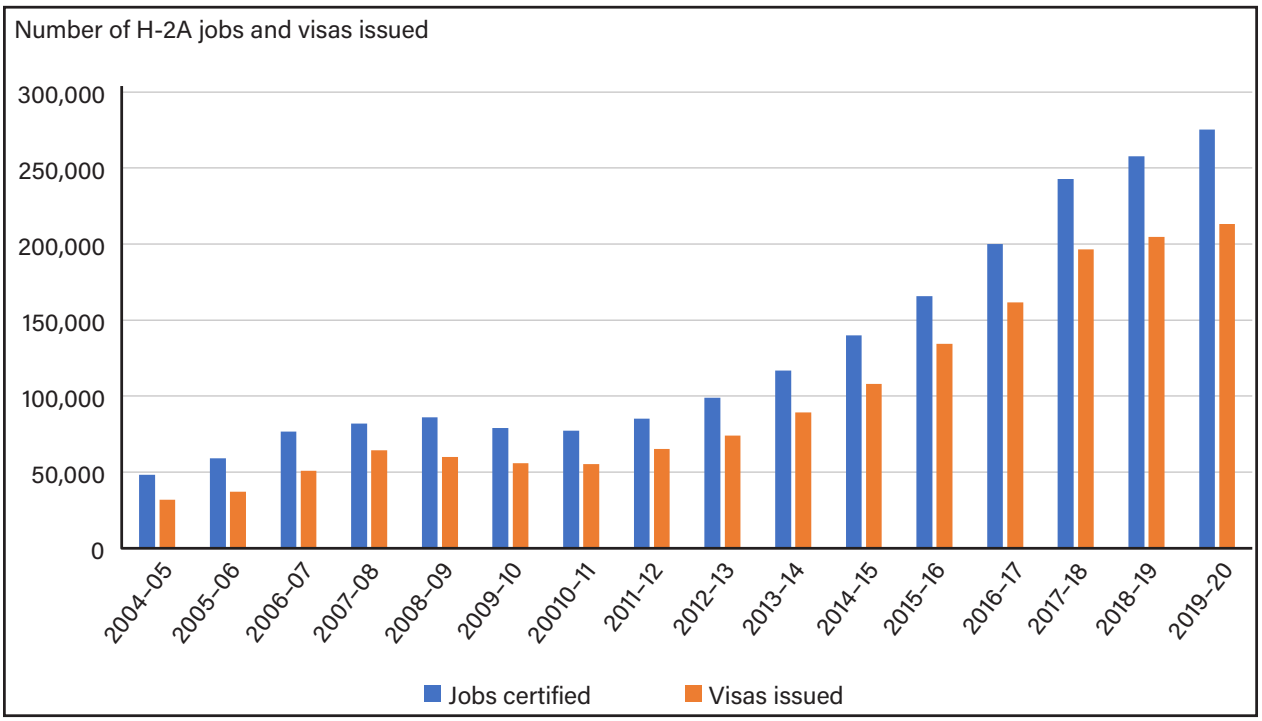
H-2A is the third option for growers facing uncertain labor availability. The H-2A program allows U.S. farmers who anticipate labor shortages to be certified by the U.S. Department of Labor (DOL) to recruit and employ foreign guest workers to fill seasonal farm jobs by satisfying three major criteria. First, farmers must create job offers that satisfy DOL wage and other criteria; if they find too few domestic workers (all workers except H-2A workers) to fill these jobs, they may be certified to employ H-2A guest workers. Second, employers must cover specific costs for their H-2A workers, including travel to the United States and housing costs for H-2A workers while they are employed in the United States. Third, farmers must pay at least the State's Adverse Effect Wage Rate (AEWR)—which ranged from almost $12 to over $16 an hour across States in 2021—to ensure domestic workers are not adversely affected by H-2A workers.

The H-2A program was part of the Immigration Reform and Control Act of 1986 (IRCA).[17] The law included the Special Agricultural Worker (SAW) program, which legalized over 1.1 million unauthorized workers—95 percent of whom were from Mexico—most of whom were not doing farm work by the mid-1990s. IRCA imposed Federal sanctions on employers who knowingly hired unauthorized workers to encourage employers to hire legal workers—including H-2A workers—to avoid fines. The H-2A program did not expand rapidly because employer sanctions failed to deter unauthorized migration (Rural Migration News Blog, 2020b). Unauthorized migration surged in the 1990s, and the DOL's National Agricultural Worker Survey found unauthorized workers who presented false documents when hired were half of U.S. crop workers by the mid-1990s (Martin, 1990; Martin and Taylor, 1990).

The 2008–09 recession decreased unauthorized Mexico-U.S. migration and the H-2A program began to expand (Zahniser et al., 2018). Figure 5 shows the number of jobs certified to be filled with H-2A workers increased by 223 percent between FY 2012 and FY 2020 to a total 275,430 jobs. The numbers rose to 317,000 jobs certified in FY 2021. About 80 percent of DOL certifications result in H-2A visas being issued to foreign workers and over 213,000 H-2A visas were issued in FY 2020. The number of visas issued is 75–80 percent of the number of jobs certified because some employers do not follow through to employ H-2A workers and some H-2A workers fill more than one U.S. job.

[17] H-2A has origins in the Immigration and Nationality Act of 1952, which created a visa category for temporary foreign workers. Under the Immigration Reform and Control Act, a distinct visa category, H-2A, was created for temporary agricultural workers.

Figure 5
H-2A temporary agricultural workers program certified jobs and visas issued, fiscal years (FYs) 2004–05 to 2019–20



Source: USDA, Economic Research Service using U.S. Department of Labor, H-2A Temporary Agricultural Program, and U.S. Department of State Travel, Bureau of Consular Affairs data.

The Cost of H-2A Labor

H-2A workers are generally more expensive than domestic workers because employers must pay the AEWR wage and provide H-2A workers with transportation and housing. For example, an H-2A worker who earns an average of $16 per hour picking apples in Washington may earn $16,000 for 1,000 hours of work over 5–6 months. Transporting the worker to the U.S. farm and home at the end of the season may cost $600. Housing and transport to and from the fields costs $13 per day for 150 days or $1,950, making nonwage costs $2,550 per season—or $2.55 per hour—and making the total labor costs of H-2A workers $18.55 per hour.[18] [19] Employers do not pay Social Security or Federal Unemployment Insurance taxes on the H-2A workers' wages—saving about 8 percent on payroll taxes or $1,280 per worker earning $16,000. In contrast, a domestic worker making the same $16 hourly wage costs employers $17.92 due to payroll taxes, which narrows the H-2A-domestic worker cost gap to less than 5 percent.

H-2A workers provide several advantages for growers who specify the labor commitment's start and end dates, wages, and working conditions for each job, making labor supply and costs more predictable. H-2A workers provide labor assurance because they must stay with their employer rather than seek higher wages elsewhere. In addition, these workers must accept the tasks they are assigned or they face termination and—subsequently—are returned to their country of origin. H-2A workers are usually younger than domestic workers. Some

[18] These costs are estimates based on conversations with State of Washington labor experts. Roka et al., (2017) determined that average pre-employment costs for employing an H-2A worker in Florida's citrus industry were $2,000 per worker per season. Included in this sum were expenses related to the H-2A application process, worker recruitment, round-trip travel between Florida and the workers' respective hometowns, and the provision of housing facilities.

[19] Employers often rent, buy, or build housing for H-2A workers, which can be costly—particularly in areas with high housing costs such as coastal California.

growers find H-2A workers can be more productive in terms of produce picked per hour (Martin, 2020).[20] H-2A workers are often willing to work long hours, if needed, to maximize their U.S. earnings.

The Adverse Effect Wage Rate

The Adverse Effect Wage Rate (AEWR) was developed to ensure H-2A workers do not adversely affect domestic workers' wages in similar jobs. Economic theory suggests adding to the supply of labor could depress wages, so the AEWR is a special minimum wage that must be paid to H-2A workers to avoid domestic wage depression.[21] Any domestic workers who are employed on the farm in the same job type as H-2A workers must receive the same wages and have the same working conditions as their H-2A counterparts.

Since 1987, the AEWR for each State has usually been based on data from the USDA, NASS, Farm Labor Survey (FLS). The AEWR is the average hourly earnings (not hourly wages) of nonsupervisory crop and livestock workers the previous year as reported by employers in that State or region.[22] Employers complain the average hourly earnings they report to FLS increase AEWRs each year. The AEWRs annually increase since they include the earnings of higher skilled workers such as equipment operators and piece-rate workers who typically earn 15–25 percent more than minimum wage.

After more than three decades using the FLS-derived hourly earnings of farm workers to set AEWRs, there is still controversy over whether there should be AEWRs and how they should be determined.[23] The Farm Workforce Modernization Act (FWMA or HR 1603) was approved by the House of Representatives in March 2021. The FWMA's goal is to further streamline the H-2A program, which would—among other things—freeze the AEWR for 1 year and limit annual AEWR increases and decreases for a decade as DOL and USDA study the need for and effects of AEWRs. The FWMA would permit more than one AEWR per State since each job title would have its own AEWR, so equipment operators' AEWRs would be different from crop workers' AEWR.

Recruitment

U.S. employers must try and fail to find domestic workers before they can hire H-2A workers. State Workforce Agencies (SWAs) circulate employer job orders within the United States so domestic workers are aware of the jobs employers want to fill with H-2A workers. Generally, employers and SWAs find few domestic workers to fill these jobs.

There is disagreement about why the recruitment of U.S. workers largely fails. Employers say domestic workers do not want the seasonal jobs they offer or they want a job immediately rather than in the future when the crop will be ready to harvest. In addition, employers worry domestic workers who accept job offers will not

[20] Analysis of payroll records from 2 farm labor contractors who hire both domestic and H-2A workers, found H-2A workers were on average 15–25 percent more productive on the basis of tons or flats picked per hour or day. One reason is they were on average a decade younger than domestic crop workers (Martin, 2020).

[21] The assumption that more workers depress wages has been questioned by several natural experiments. Card (1990) showed a 1980 influx of Cuban migrants that increased Miami's labor force by 7 percent did not adversely affect the wages or the unemployment rates of low-skilled U.S. Black workers.

[22] The term "earnings" is used to refer to contexts where workers may be paid via a piece rate or other compensation scheme that is not strictly limited to receiving an hourly wage.

[23] In fall 2020, USDA cancelled the USDA, NASS' Farm Labor Survey (FLS) and the U.S. Department of Labor (DOL) issued a final rule that changed the basis for calculating Adverse Effect Wage Rates (AEWRs). The U.S. Department of Labor's November 5, 2020, rule froze AEWRs for most field and livestock occupations at 2020 rates until 2023 and proposed to adjust AEWRs according to changes in DOL's Employment Cost Index for private-wage and salary workers. Worker advocates sued to block these USDA and DOL actions and persuaded a Federal judge to order USDA, NASS to resume FLS and for DOL to issue AEWRs for 2021 based on 2020 FLS data.

show up when work is ready to begin and will not stay through the season. Worker advocates counter that employers already recruit the H-2A workers they want before trying to recruit domestic workers discouraging domestic workers from applying for jobs (Tofani, 1987).

Future of the H-2A Guest Worker Program

More growers are turning to the H-2A program despite AEWRs, housing, and other costs. For growers of commodities in the early stages of mechanization or anticipating the availability of a mechanical harvester in the near future, H-2A workers may be a bridge to full mechanization. So far, U.S. growers report few problems recruiting H-2A workers from Mexico because U.S. farm wages are at least 10 times higher than the Mexican minimum wage. Furthermore, many workers in El Salvador, Guatemala, and Honduras—where wages are lower than in Mexico—are eager for H-2A jobs (Zahniser et al., 2018).

Conclusions

The United States produces most of the fresh fruit and vegetables for U.S. consumers. Produce is harvested with the help of a hired farm workforce that is largely made up of laborers from Mexico and this workforce includes a significant share of unauthorized workers. Farm labor costs are rising due to declining unauthorized migration, increasing State minimum wages, and some States removing overtime-pay exemptions for farm workers.

Rising labor costs are encouraging farmers to re-examine their management and work practices to reduce their reliance on hand labor. In the short term, management changes include fewer repicks of fields and orchards, the introduction of mechanical aids such as robots that transport harvested produce from pickers to collection stations. In the long term, there is likely to be more labor-saving mechanization—with H-2A guest workers sometimes serving as a bridge to more mechanized production methods—and increased imports. The exact mix of mechanization and imports is likely to vary by commodity and be shaped by migration, trade policies, as well as research and development.

Government support for and coordination of plant science and mechanization research can speed the development and diffusion of labor-saving mechanization as exemplified by the rapid mechanization of California's processing tomato harvest in the 1960s. Changes to H-2A guest worker policies could affect the cost of foreign workers. These changes include proposals to end requirements that employers must try to recruit U.S. workers before being allowed to hire H-2A workers, employers must provide guest workers with free housing, as well as proposals to freeze and study the AEWR. Free-trade agreements and science-based inspection protocols can facilitate imports of labor-intensive commodities such as avocados, while tariffs can discourage trade. If U.S. growers cannot reduce production costs, domestic production may decrease while imports increase.

There is widespread agreement among stakeholders about needing to reduce farm labor costs in the fresh produce industries. However, there is also disagreement over the speed with which changes can or should occur to keep U.S. production competitive. Growers who produce when prices are high often want to hand harvest their commodities to maximize their revenues. However, as imports arrive for longer periods and reduce high prices for commodities, such as early season blueberries and table grapes, growers are divided over the appropriate response. Some growers want to curb imports whereas other growers aim to mechanize or use mechanical aids to reduce labor costs.

Farm labor costs rose faster than nonfarm labor costs over the last decade, accelerating the race in the fields between mechanization, H-2A guest workers, and imports. With an uncertain future, many growers and marketers are pursuing all three responses until a winning strategy comes into focus. It is safe to predict there will be more labor-saving machines and productivity-increasing mechanical aids in U.S. fields and orchards, more guest workers, and more imports by 2030. However, the exact combination of mechanization, guest workers, and imports is likely to vary by commodity reflecting the decisions of U.S. growers and consumers, as well as Federal and State research, migration, and trade policies. The linked report, *Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fruit and Vegetables Industries: Case Studies*, reviews how four fruit industries and three vegetable and melon industries have adapted to higher labor costs.

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