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The U.S. Produce Industry and Labor

Facing the Future in a Global Economy

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The U.S. Produce Industry and Labor

Facing the Future in a Global Economy

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Abstract

Fruit and vegetable production is a labor-intensive process, and over half of the hired workers employed by growers are believed to be unauthorized immigrants. Reforms to immigration laws, if they reduce the labor supply, may increase the cost of farm labor. The authors of this report assess how particular fruit and vegetable commodities might adjust if labor rates increased. Analysis of case studies suggests a range of possible adjustment scenarios, including increased mechanization for some crops, reduced U.S. output for a few crops, and increased use of labor aids to improve labor productivity for others.

Keywords

Produce, agricultural labor, mechanization, immigration reform, apples, oranges, raisins, strawberries, asparagus, lettuce

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Contents

Summary

The U.S. fruit and vegetable industry is labor intensive, faces higher labor rates than many other countries, and operates in a global economy with relatively free trade. Currently, labor makes up almost half of the variable production expenses for U.S. fruit and vegetable farms, although labor's share varies significantly by commodity. As a result, efforts to reduce labor costs are an ongoing challenge for U.S. producers. Over half of the hired workers employed in U.S. crop agriculture are believed to be unauthorized immigrants, and most hired workers stay in the seasonal farm workforce a decade or less. As a result, agricultural employers are constantly seeking new workers.

What Is the Issue?

Growers are concerned that immigration reform (or stricter enforcement of current immigration or labor laws) could reduce the flow of unauthorized workers into the United States. Fewer workers could affect the cost and availability of farm labor for U.S. producers and reduce their ability to compete as suppliers in a global marketplace in which many competing countries have much lower wages. If wages increase, growers could respond in several ways. Grower response would vary across different fruit and vegetable commodities and across growers of particular commodities. In this report, the authors examine labor use for production of selected fruit and vegetables and assess likely adjustments if labor costs increase significantly.

What Did the Study Find?

Commodities differ in their vulnerability to increases in labor costs. The authors of this report look at the likely adjustment scenarios for Washington State's fresh-market apples; Florida's processing oranges; California's fresh-market oranges and strawberries; raisins; fresh-market asparagus; and lettuce. Analysis of the case studies reveals three major adjustments to rising labor costs:

- Three commodities have partially adopted mechanical harvesters. As labor costs rise, more growers will likely turn to mechanization, which may result in fewer and larger producers of these commodities. The raisin industry is mechanizing; between 2000 and 2007 the estimated share of the raisin crop harvested mechanically increased from 1 percent to 45 percent. Mechanization of the processing orange harvest is currently stalled, awaiting the U.S. Environmental Protection Agency's approval of a chemical compound that would loosen the ripe fruit and make it easier for machines to remove them. Approximately 70-80 percent of the baby leaf lettuce crop is harvested mechanically; the rest would likely follow if wages increased.

- Producers of unmechanized commodities that face substantial import competition, such as asparagus producers, are likely to lose market share to imports as labor costs rise unless there is a breakthrough in labor-saving mechanization. Similarly, growers of commodities that face substantial competition in export markets, such as apple and

orange producers, may lose export share if labor costs rise and growers are unable to keep their total costs per unit of output from rising.

- Producers of fresh-market strawberries and lettuce (other than baby leaf lettuce), with little import competition, are likely to cope with rising labor costs by providing labor aids to their workers to raise labor productivity or by mechanizing, if a harvester can be developed. These producers may be able to pass some additional costs along to consumers.

Rising wages could prompt the development and adoption of labor aids and mechanical harvesters. Mechanization is a complicated process and usually requires an integrated approach that includes changes in crop varieties, cultural practices, and harvesting methods. The progress of mechanization research is difficult to predict; some mechanization efforts quickly produce a solution while others fail to make progress due to complex technical challenges. Individual growers, grower organizations, machinery manufacturers, and the Government have all invested in mechanization research at one time or another. Interest in mechanization depends on current and future wages; when wages are low, interest in investing in mechanization research declines.

Even when a mechanical harvester is available, not all growers will adopt the new technology. Hand-harvested produce is usually of better quality, since it is hard to replicate the skill and care of hand harvesters. Until the technology has proved itself, farmers may be unwilling to risk investing in it. Mechanical harvesters often represent large fixed costs, and mechanization is more economical for large farmers who can spread such costs over more acres. For some crops, mechanical harvesters may be available in a range of configurations appropriate for farms of different sizes.

Rising wages could also result in increased imports. Labor wages and costs in foreign countries are often low, but total production costs of fruit and vegetables delivered to the United States are often comparable with costs of U.S.-produced goods during the same season. Increased U.S. imports are sometimes due to lower costs abroad, but more often result from year-round demand for fruit and vegetables that cannot be grown profitably in most of the United States during the winter.

How Was the Study Conducted?

The case studies are based on literature reviews, commodity statistics, and indepth conversations with industry experts to understand the economic conditions and ability to adjust to potentially higher labor costs. A small number of commodities—either hand-harvested or only partially mechanically harvested—were selected for assessment and represent a broad spectrum of produce items, including fresh, fresh-cut (bagged salads), and processed items (storable raisins and orange juice).

Introduction

Labor makes up 42 percent of the variable production expenses for U.S. fruit and vegetable farms, although labor's share varies significantly depending on the characteristics of the commodity and whether the harvest is mechanized (Lucier et al., 2006). The U.S. fruit and vegetable industry competes in a global economy with producers from other countries who often have much lower wages. With increasing trade, competitive pressures are greater than ever. In summer 2009, the Federal minimum wage was $7.25 per *hour* and the minimum wage in California was $8.00 per hour, while the minimum wage in Mexico ranged from $3.49 to $4.16 per *day*, depending on the region.[1]

In this report, we focus on the current situation of the U.S. fruit and vegetable industry with respect to agricultural labor and how growers might respond to higher labor costs. If farm wages increase, producers could respond in several ways. Labor is just one component of a complex production process. Producers could try to keep production costs competitive by reducing labor use, by adopting labor aids to increase labor productivity, or by mechanizing to reduce labor needs. Even if labor costs cannot be reduced, other changes, such as yield increases, may compensate for increases in labor costs and keep U.S. production competitive. If total production costs increase, growers could adjust by decreasing production or passing higher labor costs on to consumers if possible. Decreased production could, in some cases, open the door for imports. Producer responses to higher wages would vary by commodity.

Our analysis presents case studies of individual fruit and vegetable commodities. While the focus is on adjusting to higher labor costs, any factor that reduces the profitability of an individual commodity puts pressure on labor, the single largest input cost in the production of many crops. Therefore, each case study begins with an assessment of the commodity's economic situation. The case studies focus on Washington State's fresh-market apples; Florida's processing oranges; California's fresh-market oranges and strawberries; raisins; fresh-market asparagus; and lettuce.

Over half the hired workers on U.S. fruit and vegetable farms are believed to be unauthorized immigrants and most will move on to nonagricultural employment within a decade of beginning to work in the fields. This situation makes the U.S. produce sector vulnerable to potential immigration reform or changes in enforcement of current immigration and labor laws. Growers are concerned that any such changes could increase wage rates. Efforts to enact immigration reform legislation are ongoing, and many growers' organizations have made promoting immigration reform that is responsive to their needs an important legislative priority.

According to the U.S. Department of Labor's (DOL) National Agricultural Workers Survey (NAWS), 52 percent of the hired workers in crop agriculture between 2005 and 2007 were unauthorized immigrants, 27 percent were U.S. citizens, and 21 percent were authorized immigrants (Carroll, Saltz, and Gabbard, 2009). Three-fourths of the workers interviewed for the NAWS worked in fruit, vegetable, and nursery crops. Once, unauthorized immigrants were concentrated in certain States, but now they can be found

[1]The U.S. minimum wage increased to $7.25 on July 24, 2009; Mexican minimum wages for 2009 were evaluated at the exchange rate for the same date.

in fruit and vegetable operations across the country (Passel and Cohn, 2009). Any enhanced border control or workplace enforcement of immigration and labor laws could reduce the supply of workers available to fruit and vegetable growers.

A Federal guest worker program (H-2A) provides growers with a legal means of employing foreign workers in seasonal jobs. H-2A requires, among other things, that growers receive certification from the DOL that U.S. workers are unavailable. DOL certification allows employers to recruit foreign workers. Growers, however, must pay transportation costs and provide free housing to H-2A workers. Most growers find that it is easier to hire unauthorized workers who appear at their farms seeking jobs. Federal guest worker programs, including the Bracero Program,[2] have a long history in the United States. If the flow of unauthorized workers into the United States declines, the H-2A program could become more important for the fruit and vegetable industry. Growers would like to see employer-friendly administrative changes that would make the program less cumbersome to use.

[2]The Bracero Program was a series of laws and agreements that allowed U.S. famers to hire Mexican workers between 1942 and 1964. The number of Bracero workers admitted peaked in the mid-1950s.

Based on evaluation of unemployment insurance and NAWS data, most hired workers stay in the seasonal farm workforce a decade or less. As a result, employers are constantly looking for new workers (Khan, Martin, Hardiman, 2004; NAWS). Relatively low wages, hard physical labor, frequent adverse weather conditions, and seasonal work patterns make working on crop farms unappealing to most U.S. citizens and authorized immigrants. Those who do choose seasonal work on crop farms are generally workers with few alternative job options due to a lack of English language skills, education, and immigration authorization.

According to the NAWS, hired agricultural workers earned an average of $8 per hour in 2006, a little more than half of what U.S. nonfarm production workers earn (Carroll and Saltz, 2008; U.S. Bureau of Labor Statistics). In addition, the NAWS also found that crop workers were employed on U.S. farms for about two-thirds of the year. Earning half as much over less time means that the annual earnings of crop workers averaged a third of the annual income of nonfarm production workers (almost $35,000 per year).

Most analysts conclude that farmers will mechanize or reduce production before wages get high enough to induce U.S. workers into the fields (Huffman, 2007; Martin, 2009). As a result, the supply of farmworkers for the produce industry depends on a constant influx of new, foreign-born labor attracted to the United States by wages above those in the workers' countries of origin, primarily Mexico. Immigration policy determines whether that labor force will be authorized or unauthorized.

Download the charts in this report.

The Produce Industry in a Global Economy

The average annual farm value for U.S. fruit, vegetable, and tree nut crops harvested during 2005-07 was $36.3 billion. The United States produces a broad range of fruit and vegetables for fresh and processed use. Between 1990-92 and 2005-07, average annual fresh-market fruit production increased 7 percent and fresh-market vegetable production increased 36 percent (table 1). Individual commodities fared very differently. Fresh-market asparagus production declined 28 percent, while fresh-market strawberry production increased 103 percent. The overall growth in production reflects increasing domestic consumption.

The U.S. fruit and vegetable industry operates in a global environment. Both imports and exports have increased; between 1990-92 and 2005-07, U.S. imports of fresh fruit increased 212 percent and imports of fresh vegetables increased 163 percent (table 1). In 2005-07, imports of fresh fruit accounted for 30 percent of consumption (excluding bananas[3]) and imports of fresh vegetables accounted for 19 percent of consumption. U.S. produce exports

[3]If bananas are included, the share rises to 48 percent because bananas are the most consumed fruit, and virtually all bananas are imported.

Table 1
U.S. fresh fruit and vegetable statistics, 1990/92 to 2005/07[1]

	Unit	Average 1990-92	Average 2005-07	Percent change
Acreage				
All fruit (fresh and processed)	1,000 bearing acres	2,840	2,972	5
All vegetables (fresh and processed)	1,000 acres	3,356	3,194	-5
Production				
Fresh fruit	Million pounds	19,541	20,930	7
Fresh vegetables	Million pounds	35,335	47,964	36
Per capita consumption				
Fresh fruit	Pounds	68	76	12
Fresh vegetables	Pounds	142	179	26
Imports				
Fresh fruit	Million pounds	2,133	6,651	212
Fresh vegetables	Million pounds	3,874	10,205	163
Exports				
Fresh fruit	Million pounds	4,429	5,240	18
Fresh vegetables	Million pounds	2,949	4,011	36
Import share of consumption				
Fresh fruit	Percent	12	30	140
Fresh vegetables	Percent	11	19	76
Export share of production				
Fresh fruit	Percent	23	25	10
Fresh vegetables	Percent	8	8	0

[1]Bananas are excluded from the fruit group. Vegetables exclude potatoes, sweet potatoes, dry peas, dry beans, and lentils; but include melons.

Source: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook, Vegetables and Melons Situation and Outlook Yearbook.*

expanded at a slower pace. In 2005-07, 25 percent of fresh fruit production and 8 percent of fresh vegetable production were exported. The U.S. produce industry is vulnerable to import and export competition due to lower wages abroad.

The United States imports fruit and vegetables during times of the year when there is little or no domestic production and imports are cheaper than U.S. commodities. For example, bananas could be grown in U.S. greenhouses, but at a cost far higher than readily available imports. Imports of tropical fruit are not controversial if there is no domestic industry (table 2). American consumers have come to expect year-round supplies of fresh produce, and the United States has imported warm-weather crops during the winter for decades. For example, only Florida produces tomatoes outdoors in the winter and spring, when Mexico typically ships large quantities of tomatoes to the United States. Florida and Mexico share the market; imports lower U.S. tomato prices, which benefits consumers but provides additional competition for Florida producers. The emergence of the U.S. greenhouse tomato industry provides additional opportunities for profitable winter production (Cook and Calvin, 2005). More recent imports of commodities during warm-weather

Table 2
Import share of fresh fruit and vegetable consumption, 2007

Commodity	Import share of consumption 2007	Commodity	Import share of consumption 2007
	Percent		*Percent*
Mangoes	100	Apricots	22
Limes	100	Watermelon	21
Bananas	100	Raspberries	14
Papayas	94	Onions	14
Green onions	91	Snap beans	11
Pineapples	90	Broccoli	11
Asparagus	78	Peaches and nectarines	10
Kiwifruit	78	Carrots	10
Avocados	64	Cherries	9
Grapes	57	Strawberries	8
Cucumbers	52	Oranges	8
Squash	51	Apples	7
Blueberries	43	Lemons	7
Tomatoes	41	Cauliflower	6
Cantaloupe	35	Grapefruit	5
Honeydew	33	Cabbage	5
Radishes	29	Spinach	4
Tangerines	27	Head lettuce	3
Pears	23	Sweet corn	2
Plums	22	Leaf/romaine lettuce	2

Sources: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook, Vegetables and Melons Situation and Outlook Yearbook*; for green onion data USDA, Agricultural Marketing Service, *Fresh Fruit and Vegetable Shipments.*

U.S. production seasons demonstrate that some commodities face competition not related to climate alone.

Options for U.S. Producers if Wages Rise

U.S. fruit and vegetable producers are concerned about the cost and availability of labor to harvest their crops. The availability of labor is particularly important for growers of seasonally harvested crops, such as raisin grapes, where growers need to hire a large number of workers for just a few weeks during the year. For most crops, a harvest delayed by labor issues means less profit for growers, since even a short delay can reduce quality and price. In the case of a longer delay, the entire crop may be lost if the quality deteriorates to the point that it cannot be marketed.

If wages rise, growers have several options. Labor is one input in a complex production process. Individual growers of a commodity are not homogeneous, so there may be a range of responses to rising wages:

1. Growers may use less labor. For example, growers might make several harvesting passes over a field or orchard to pick produce as it ripens but, because of higher wages, decide to make fewer passes—reducing labor costs by accepting lower yields.

2. Growers may use labor more efficiently. Labor aids, such as conveyor belts in the fields, can increase worker productivity by reducing the time spent carrying the produce from where it is picked to the edge of the field. By making work less physically demanding, labor aids could increase the size of the labor force that can comply with work requirements.

3. Growers can mechanize to replace costly labor. While most of this report focuses on mechanical harvesters, the mechanization of any task that currently requires manual labor, including insect/disease scouting, spraying, pruning, cultivating, weeding, and thinning, reduces costs and frees up labor for other tasks that are not yet mechanized. Economically viable mechanized alternatives to hand harvesting, however, do not materialize instantaneously.

Research and development (R&D) takes time, and the success of mechanization efforts is difficult to predict. In some cases, growers are surprised by the rapid development and adoption of mechanical harvesters, while, in other cases, confident predictions of eminent mechanization have proved too optimistic. Mechanization often presents complex technical challenges. The judgment and dexterity of experienced farmworkers are often difficult for a machine to mimic, particularly when crops do not mature evenly, and workers must determine what can be harvested during multiple passes through fields and orchards. A nonselective mechanical harvester that harvests everything in the field, regardless of maturity, will reduce useable yield per acre.[4] In addition, the machines must be designed so that they do not create economically unacceptable levels of damage to the harvested produce or plants. Often growers switching to mechanical harvesters have lower harvesting costs but lower yields too.

[4] In some cases, growers could use cultural practices to encourage more even maturity, but this can raise production costs.

Even if growers cannot reduce labor costs, other ongoing changes may affect profitability and compensate for increasing wages. Precision agriculture, improved irrigation techniques, better pest control, and the availability of new plant varieties can lead to higher profits. For example, increases in wages can be offset by yield increases; between 1990-92 and 2005-07, average annual U.S. strawberry yields increased 63 percent. To concentrate on harvest mechanization as a strategy to deal with higher labor costs, we do not focus on these other strategies that growers could use to reduce total costs or raise yields.

Adjusting To Rising Costs

If total production costs rise with labor rates, growers will have to adjust. If agriculture is competitive, higher costs will be passed on to consumers. The exact response depends on consumer demand for the particular commodity and trade patterns. If there is no trade and consumer demand is perfectly inelastic—consumers buy the same quantity regardless of price—producers can pass all additional labor costs on to consumers without a decline in demand. This is unlikely for most fresh produce items, however, since there are many substitutes for any particular commodity. On the other hand, if demand is perfectly elastic because consumers have many choices, rising costs and prices will reduce quantity demanded sharply. In between these extremes, rising costs lead to lower demand as prices increase and production declines.

In today's relatively open international marketplace, it is hard for growers to pass on higher production costs if the same commodity can be imported for less during the same season. Some growers may then shift production to crops that are already mechanized. In some areas, selling farmland for housing is an attractive alternative. Some production of labor-intensive crops may shift to countries with lower labor costs; a number of U.S. growers already produce fruit and vegetables abroad (Calvin and Barrios, 1998). Production abroad for the U.S. market is not easy, however, and the resulting labor savings must be substantial to justify relocation. While labor rates may be lower in other countries, other input costs may be higher. For example, Mexican growers who export produce to the United States import many of their inputs from the United States, which may raise their production costs for those inputs relative to U.S. growers. There are other costs in growing abroad, including tariffs, transportation, and additional costs necessary to meet any U.S. phytosanitary standards. Newer concerns, such as consumer interest in the distance their food travels, may affect grower decisions about whether to move production abroad.

There are relatively few examples of U.S. growers moving most of their production of fresh-market commodities abroad if these commodities could be produced in the United States at the same time. Green onions are an example; this commodity requires as many as nine manual labor steps from harvesting to packing (Calvin, Avendaño, Schwentesius, 2004). The United States began importing green onions from Mexico in 1980; in 2007, Mexico supplied 91 percent of U.S. green onion consumption.

Competition from imports may be more intense for processed commodities. In the late 1970s, U.S. firms were producing frozen broccoli, particularly hand-cut broccoli spears, in Mexico to lower their labor costs. U.S. production of broccoli for freezing declined 63 percent between 1990 and 2007. In 2007, only 10 percent of U.S. *fresh* broccoli consumption came from imports, but 87 percent of *frozen* broccoli consumption came from imports. Almost all fresh broccoli imports came from Mexico and Canada, production regions where a perishable product can be transported quickly to the U.S. market by truck at relatively low cost. For frozen broccoli, 68 percent of imports came from Mexico and the remainder came from Guatemala, Ecuador, and China. Frozen broccoli can be transported by ship, which is slow but inexpensive and allows more distant suppliers to be competitive. Frozen broccoli, unlike fresh broccoli, does not face potential phytosanitary barriers.

Harvest Mechanization

Harvest mechanization is more advanced for vegetables than for fruit; it is also more common in processed produce than in fresh-market produce (table 3). Most vegetables are annual crops rather than perennials, so damage done to plants during harvesting is of less concern than when machines harvest fruit from trees and vines. It is also easier to use mechanical harvesters with annual crops that are planted in rows, than with trees and vines where the location of the fruit is not as predictable. About 75 percent of U.S. vegetable and melon production (in terms of acreage) is harvested by machine, compared with about 55 percent of U.S. fruit production (Sarig et al., 2000).

Most root vegetables are machine harvested. For potatoes, growers use a nonselective harvester that removes the potatoes from the soil, sifts out excess soil, and conveys the potatoes to a truck. This technology became common in the 1950s. Mechanical harvesting of nuts (and some citrus fruit for processing, where appearance is not important) is done with a shaker system; the whole tree or canopy is shaken to dislodge the fruit or nuts. Tree-shakers for nuts were developed in the 1960s and are now widely used. For relatively fragile tree fruit, such as apples and oranges, researchers are experimenting with a two-stage approach. A machine using vision technology locates and maps the fruit, and a second machine takes this information and uses robotics to selectively harvest the fruit as it matures. Mechatronics is a new term describing this marriage of mechanical devices with electronic and computational systems (USDA/CSREES, 2007). With the declining price of computing power and robotics, a new wave of selective mechanical harvesters may be on the horizon.

Processed products are more likely to be handled mechanically than fresh-market products. Processed fruit and vegetables can often withstand more wear and tear from machinery since they are immediately stabilized by processing to prevent further damage. For example, fresh table grapes are hand harvested, many raisins are mechanically harvested, and wine and juice grapes, which are immediately crushed, are largely mechanically harvested (except for some premium wine grapes).

Many crops are sold to both the fresh and processed market. For example, almost all Washington State sweet cherries are grown for the fresh market and harvested by hand, even though some that cannot be sold fresh are processed.[5] Washington State growers do not know in advance where their cherries will end up; that uncertainty encourages hand harvesting to preserve

[5]The only exception is a small quantity of sweet cherries that are grown specifically for the processed maraschino cherry industry, and these are mechanically harvested.

Table 3
Mechanization of fruit and vegetable crops

Commodity	Typical type of harvest: Fresh	Typical type of harvest: Processed
Noncitrus tree fruit:		
Apples	Hand	Hand[1]
Apricots	Hand	Hand [1]
Avocadoes	Hand	NA[2]
Cherries, sweet	Hand	Hand[1]
Cherries, tart	NA	Machine
Dates	Hand	Hand[1]
Figs	Hand	Other [3]
Nectarines	Hand	Hand[1]
Olives	NA	Hand/machine
Peaches, freestone	Hand	Hand[1]
Peaches, clingstone for canning	NA	Hand/machine
Pears	Hand	Hand[1]
Plums	Hand	Hand[1]
Prunes	Hand	Machine
Grapes:		
Wine/juice	NA	Machine[4]
Raisins	NA	Hand/machine
Table grapes	Hand	NA
Berries:		
Blueberries, cultivated	Hand/machine	Machine
Blueberries, wild	Hand	Machine
Cranberries	Machine	Machine
Kiwi	Hand	NA
Raspberries/blackberries	Hand	Hand/machine[5]
Strawberries	Hand	Hand
Citrus fruit:		
Grapefruit	Hand	Hand[1]
Lemons/limes	Hand	Hand[1]
Oranges	Hand	Hand/machine
Tangerines	Hand	Hand[1]
Melons:		
Cantaloupe, honeydew	Hand	Hand[1]
Watermelon	Hand	Hand[1]
Tree nuts:		
Almonds	Machine	Machine
Hazelnuts	Other[6]	Other[6]
Macadamias	Other[6]	Other[6]
Pecans	Machine	Machine
Pistachios	Machine	Machine
Walnuts	Machine	Machine
Root vegetables:		
Beets	Hand	Machine
Carrots	Machine[7]	Machine
Garlic	Hand	Machine
Green onions	Hand	Hand
Leeks	Hand	Machine
Onions	Hand/machine[8]	Machine
Parsnips	Hand/machine	Machine
Potatoes	Machine	Machine
Sweet potatoes	Machine	Machine
Radishes	Hand/machine[9]	NA
Turnips/rutabagas	Hand	Machine

-- Continued

Table 3
Mechanization of fruit and vegetable crops (continued)

Commodity	Typical type of harvest	
	Fresh	Processed
Other vegetables:		
Artichokes	Hand	NA[2]
Asparagus	Hand	Hand
Broccoli	Hand	Hand/machine
Brussels sprouts	Hand	Hand
Cabbage	Hand	Machine
Cauliflower	Hand	Hand
Celery	Hand	Machine
Corn, sweet	Hand/machine	Machine
Cucumbers	Hand	Hand/machine
Eggplant	Hand	Hand
Herbs	Hand	Machine
Lettuce	Hand/machine[10]	NA
Lima beans	Hand/machine	Machine
Mushrooms	Hand	Hand[1]
Okra	Hand	Hand
Peas	Hand	Machine
Peppers, chile	Hand	Hand/machine[11]
Peppers, sweet	Hand	Hand
Potatoes	Machine	Machine
Snap beans	Hand/machine[12]	Machine
Spinach	Hand/machine[13]	Machine
Squash, winter and pumpkins	Hand	Machine
Squash, summer	Hand	Hand
Tomatoes	Hand	Machine

NA=Not applicable; product not generally grown for this market.

[1]In most areas, these commodities are all hand harvested with the hope that the commodity will be sold in the fresh market. After harvesting, some product may be diverted into the generally less profitable processing market.

[2]In California, all avocadoes and artichokes are harvested just for the fresh market. Processed product is imported.

[3]Dried figs are dried on the tree and then they fall off naturally. Once the dried figs are on the ground, they are picked up by machine.

[4]Some wine grapes are hand harvested, primarily for premium wines.

[5]In California, which is mostly a fresh raspberry producer, raspberries are hand harvested for the fresh market, although some may end up in the processing market. Harvest method is often different in other States. For example, in Washington State, where most raspberries go to the processing market, raspberries are machine harvested; only raspberries for the fresh market are hand picked.

[6]Most nuts are harvested with shaker machines, but hazelnuts and macadamia nuts do not ripen at the same time and shaking damages the unripe nuts. These nuts dry, fall to the ground, and then are scooped up off the ground with machines.

[7]Most carrots are machine harvested. Bunched carrots with the tops on, now just a small portion of the industry, are hand harvested.

[8]Nonpungent onions are typically hand harvested because they have a high water content and bruise easily. Pungent onions are most often machine harvested since they have a lower water content. There are exceptions in both cases.

[9]The harvest method varies by the way radishes are sold. For example, radishes sold in bags without their tops are machine harvested, but radishes sold in bunches with their tops are hand harvested.

[10]Baby lettuces are often machine harvested.

[11]Green chile peppers for canning are hand harvested. Red chile peppers for ground paprika are machine harvested.

[12]Snap beans are both hand and machine harvested in Florida. Growers get a higher price for hand-harvested beans.

[13]Spinach to be marketed as bunch spinach is hand harvested, while spinach to be processed as bagged spinach and bagged salad is machine harvested.

Source: USDA, Economic Research Service.

their marketing options. Tart cherry growers in Michigan know their crop will be processed and it is all machine harvested.

Investment in Mechanization Research

Interest in mechanization rises and falls with the price and availability of labor. When labor is relatively scarce and wages rise, producers seek labor-saving innovations (Hayami and Ruttan, 1985). Growers, grower organizations, machinery manufacturers, and the public sector have invested in research to develop labor aids and mechanical harvesters.

Individual growers may do their own R&D if they think they can cut labor costs and make a profit. A grower may pay a machinery manufacturer to develop a machine. Growers could use any machinery they develop on their own operations and even sell the machinery to their competitors. Some commodity groups include large growers who can support private mechanization R&D, but many growers are too small to do so.

Grower organizations have funded mechanization research with member fees on each box of produce sold. In some cases, the investment in R&D may have some near-term payoff, particularly when a private firm has a promising prototype. In other cases, the R&D may be more basic with no immediate payoff.

Private machinery manufacturers pursue mechanization if expected benefits exceed expected costs. Economists are concerned that research costs can be high for fruit and vegetables, making some crops potential "technological orphans" because they pose special challenges to successful mechanization, but attract few private resources (Alston and Pardey, 2008). For example, the market for many fruit and vegetable mechanical harvesters is relatively small. The United States had over 93 million acres of field corn in 2007 but only 298,800 acres of lettuce. Conducting research to mechanize harvesting involves fixed costs that must be spread over a smaller market in the case of lettuce. Despite this challenge, there are many examples of successful innovations by private firms. Innovations in mechanization for one commodity can often be applied to other commodities. There is also a worldwide market for farm machinery, which provides potential for additional sales. Some of the machines used by U.S. producers are imported, and U.S. innovations are also exported to producers in other countries. Today, private machinery manufacturers, augmented by funds from individual growers, grower organizations, and Federal and State governments, conduct most agricultural mechanization research. Private-sector expenditures on general agricultural research have exceeded public sector expenditures since the early 1980s, and the gap is widening (Schimmelpfennig and Heisey, 2009).

Government investment in R&D is economically justified when private investors are unable to provide a socially optimal level of research. Most growers benefit from public mechanization research, although smaller growers may be at a disadvantage if a harvester is more economical for larger growers. There are, however, broader potential social benefits to public R&D that the Government might consider when deciding whether to invest, including any positive impact on fruit and vegetable consumption, the value of a strong domestic fruit and vegetable industry for national security, and employment goals—particularly when an industry may be the major employer in a region. Another potential public benefit to consider is that successful mechanization could reduce the reliance of the fruit and vegetable industry on unauthorized workers and reduce the lure of easy-entry agricultural jobs.

When the Government invests in R&D, it also has to consider potential social costs. The elimination of jobs is an important social cost, particularly at times of high unemployment. Jobless workers can have ripple effects on communities and local businesses that house, feed, and provide services to farmworkers. On the other hand, the machine operators and mechanics who replace hand harvesters usually earn higher wages; a small number of workers displaced by mechanization may find higher paying jobs working in the mechanized harvest. The skills, however, required for workers in the mechanical harvest system are not necessarily the same as those required in the hand-harvest system.[6]

[6] Many new jobs in fruit and vegetable production require more sophisticated skills than in the past. This may require changes in the way employers recruit, train, and retain workers.

Public support of fruit and vegetable mechanization reached its peak in the 1960s and 1970s, a period when farm labor costs were rising rapidly. Agricultural engineers in university and Government research institutions worked with growers and private machinery manufacturers to develop labor aids to increase worker productivity and mechanical harvesters to reduce labor requirements (Martin and Olmstead, 1985). Efforts to mechanize fruit and vegetable production stalled after 1980 because there was a large supply of labor available, which held down wages. In addition, the substantial, Federal- and State-supported mechanical research system for fresh fruit and vegetables was mostly dismantled during the 1980s, leaving such research primarily to the private sector (Martin and Olmstead, 1985).

Now there is renewed interest in agricultural mechanization associated with the loss, or potential loss, of unauthorized foreign workers. The Food, Conservation, and Energy Act of 2008 created the U.S. Department of Agriculture's (USDA) Specialty Crop Research Initiative (SCRI), providing $230 million for fiscal years 2009-12 to support research on five issues critical to the future of the U.S. fruit and vegetable industry, including "improved mechanization." This is the first major Federal investment in mechanization research for fruit and vegetables since the early 1980s. Research funded under this initiative requires 100 percent non-Federal matching funds.

Adoption of Mechanical Harvesters

Even if a mechanical harvester is available, there are economic obstacles to its adoption. Many growers prefer manual harvesting because quality is generally better and yields are higher. Moreover, switching to mechanical harvesting is often expensive and risky, requiring a major transformation of the farm's operations, such as replanting crops to accommodate the harvester, using new plant varieties, and developing new packing processes.

There are continuous and discontinuous adjustments to the cost of agricultural labor. An industry may adjust gradually, with a few new growers every year using labor aids or mechanical harvesters that slowly reduce the industry's demand for labor. In some cases, machine and hand harvesting systems may exist side by side. Dramatic changes may also occur. At some stage, the price of labor may reach a critical point where mechanization is the only realistic option to harvest a commodity, or a new machine may suddenly make mechanization more appealing and growers convert to the new technology quickly, causing the demand for labor to fall sharply.

Large-scale adoption of a new technology can change an industry's structure. The fresh produce industry is generally concentrated—the largest growers supply the vast majority of production. Depending on the type of machinery available, mechanization may accelerate the trend toward fewer and larger producers. If only a large mechanical harvester is available, larger growers are the most likely to invest in these expensive machines, since a large, fixed investment can be spread over more acreage. An alternative to buying specialized machinery is custom harvesting, such as when a third party buys machinery and harvests crops for multiple growers. Some growers worry that if they do not purchase their own machines, harvesting may not occur at the optimal time. In other cases, harvesters may be available in a range of configurations appropriate for farms of different sizes. Once growers invest in specialized machinery for a particular crop, they may reduce the number of commodities produced on their farms.

A major obstacle to labor-saving mechanization is the fact that many farmers send their produce to packers and processors (as opposed to packing in the field), who are usually equipped to deal with manually harvested produce or machine-picked produce but not both, making it hard for one farmer to mechanize in isolation. Packers and processors can encourage or discourage mechanization, however, by adjusting their standards.

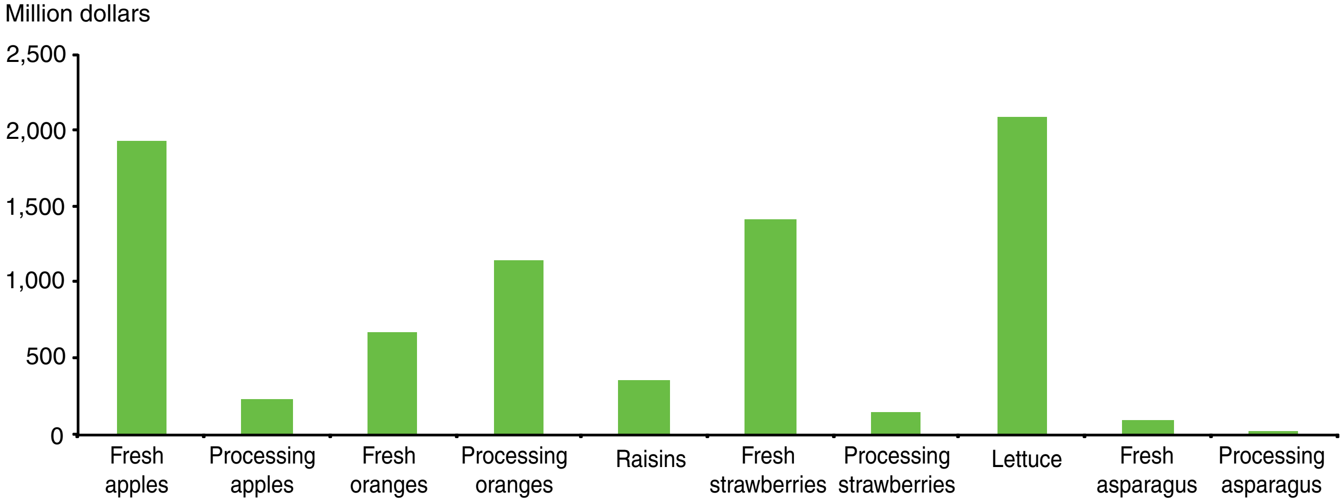
Mechanical harvesting does not eliminate the need for hand labor to harvest small fields, to pick what the machines miss, or to meet special customer requests. If a machine is less selective and gentle than hand labor, additional labor may be required to sort out undesirable product or debris.

Industry Case Studies: Pressure To Reduce Labor Costs and Industry Response

Our analysis reviews the economic situation, labor usage, and mechanization prospects for seven commodities: Washington State's fresh-market apples; Florida's processing oranges; California's fresh-market oranges and strawberries; raisins; fresh-market asparagus; and lettuce. These commodities represent a wide spectrum of fruit and vegetables, including fresh, fresh-cut (bagged salads), and processed items (storable raisins and orange juice). Some commodities represent a small portion of the produce market, such as fresh asparagus, with an average annual farm value of $91 million in 2005-07. Other commodities are a large portion of the market, such as lettuce, with an average annual value of $2.1 billion (fig. 1). All of the commodities discussed here are either hand harvested or only partially mechanized. Recognizing how growers of these commodities may respond to higher labor costs demonstrates how immigration reform and similar policy-induced labor market changes impact the industry.

Figure 1

Farm value of U.S. production, 2005-07 average[1]



[1]For citrus, year refers to the year the harvest was completed. Also for citrus, value is based on equivalent packinghouse-door returns.

Source: USDA, Economic Research Service, *Vegetables and Melons Situation and Outlook Yearbook*; USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook*; USDA, National Agricultural Statistics Service, *Citrus Fruits 2007*.

Washington State's Fresh-Market Apples

Washington State produced 57 percent of the U.S. apple crop in 2007. After a peak in 1998, production declined 7 percent from 1998-2000 to 2005-07. Growers in Washington State generally produce for the fresh market and processing serves as a secondary market; any apples that do not meet the demands of the fresh market can be diverted to processing. While overall apple production is declining, the share going to the fresh market is increasing, reaching an all-time high of 84 percent in the 2007/08 marketing year.[7]

Washington State's fresh apple industry faces several challenges, both domestic and foreign. U.S. per capita consumption of fresh apples declined 11 percent between 1990/91-1992/93 and 2005/06-2007/08 (table 4), perhaps due to the increasing variety of fruit competing for consumer attention. As a result, Washington State growers are increasingly reliant on the export market. In 2005/06-2007/08, U.S. fresh apple exports averaged 24 percent of production sent to the fresh market. Growers are concerned about increased competition from China, which is currently prevented from exporting fresh apples to the United States because of phytosanitary issues. Chinese apples, however, are displacing U.S. apples in some traditional Asian markets. In the 2007/08 marketing year, China was the world's largest producer and exporter of apples, accounting for 24 percent of the world's fresh apple exports, compared with 18 percent for Chile and 16 percent for the United States. U.S. imports of fresh apples are relatively small. The growth in imports is largely due to seasonal production differences across countries. In the spring, the

[7] The marketing year for U.S. apples begins in August of the first year shown and runs through July of the second year (i.e., the 2007/08 marketing year began in August 2007 and ended in July 2008).

Table 4
Washington State and U.S. apple industry statistics, 1990/91-1992/93 to 2005/06-2007/08[1]

		Average		
	Units	1990/91-1992/93	2005/06-2007/08	Percent change
Washington's total apple production	Million pounds	4,583	5,483	20
Washington's apple-bearing acreage	Acres	139,000	153,667	11
Washington's apple yield	Pounds/acre	32,967	35,667	8
Washington's fresh-market share	Percent	71	80	13
Washington's fresh-market price	$/pound	*	*	39
U.S. fresh apple per capita consumption	Pounds	19	17	-11
U.S. fresh apple imports	Million pounds	264	386	46
U.S. fresh apple imports as a percent of fresh-market consumption	Percent	5	8	38
Washington's processed-market price	$/ton	150	103	-31
U.S. processed apple (juice) per capita consumption	Gallons	2	2	32
U.S. fresh exports	Million pounds	1,011	1,460	44
U.S. fresh exports as a percent of production	Percent	18	24	31

[1]Marketing year is August through July.

*Price is less than $1. The average for 1990/91 - 1992/93 was $0.22 and for 2005/06 - 2007/08 it was $0.31.

Sources: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook 2008;* USDA, National Agricultural Statistics Service, *Noncitrus Fruit and Nut Report.*

United States imports just-harvested apples from the Southern Hemisphere, which provide an alternative to storage apples and varieties of apples that may be in short supply.

The processed apple market is also a concern for the Washington State apple industry. U.S. per capita consumption of processed apple products has increased, but U.S. growers are supplying fewer apples for processing because of rising imports of apple juice, mainly from China—the world's largest producer of concentrated apple juice. Unlike the case of fresh apples, the United States does not have any phytosanitary restrictions on Chinese concentrated apple juice, and imports have grown substantially. In 2007, Chinese imports accounted for 65 percent of U.S. domestic consumption of apple juice. In some years, the price received by U.S. growers for juice apples no longer covers harvesting costs, putting additional pressure on overall apple profitability.

Major Changes Affecting Labor Use

The Washington State apple industry faces challenges regarding both the availability of labor and a more competitive international market. Other changes in the industry affect the demand for and supply of labor, including increased use of smaller trees, development of new production areas, and changes in apple varieties.

Semi-dwarf and dwarf trees. Most newly planted apple trees in Washington State are semi-dwarf or dwarf; these trees are smaller and more compact than the standard apple tree. The decision to use dwarf varieties was not driven exclusively by labor issues, but reduced labor costs are an important benefit. Dwarf trees require structural support, such as a trellis, to support the weight of the fruit, which makes it expensive to develop a new orchard. Short trees make it easier for human harvesters to find apples, improving the efficiency of hand harvesting and paving the way for mechanical harvesting. Shorter trees reduce the amount of field work done from ladders, which increases labor productivity and worker safety.[8] As a result, labor costs are an important consideration in designing new orchards.

[8]Worker compensation premiums are an important cost of hiring labor. Efforts to improve safety for workers can reduce days lost due to injury and worker compensation premiums.

Changes in industry location and size. The Columbia Basin is a relatively new production area in Washington State. The average size of orchards in the Columbia Basin is more than twice that of older production areas, and the density of apple plantings is also much higher. Larger farms with dwarf trees in the Columbia Basin should be best positioned for future mechanical harvesting. In the meantime, however, the area has very few large towns, limited housing for seasonal workers, and an inadequate infrastructure to handle temporary population increases for the harvest. A few firms have built housing in this area to qualify for H-2A guest workers.

Changes in apple varieties. Substantial changes have occurred over the past two decades in the varietal composition of the apples grown in the Western United States, with Gala and Fuji becoming important varieties at the expense of Red and Golden Delicious. In 1990, Red and Golden Delicious apples accounted for 81 percent of the apples grown in the Western United States, compared with 11 percent for Granny Smith and 8 percent for other varieties which included Gala and Fuji. By 2007, the Red and

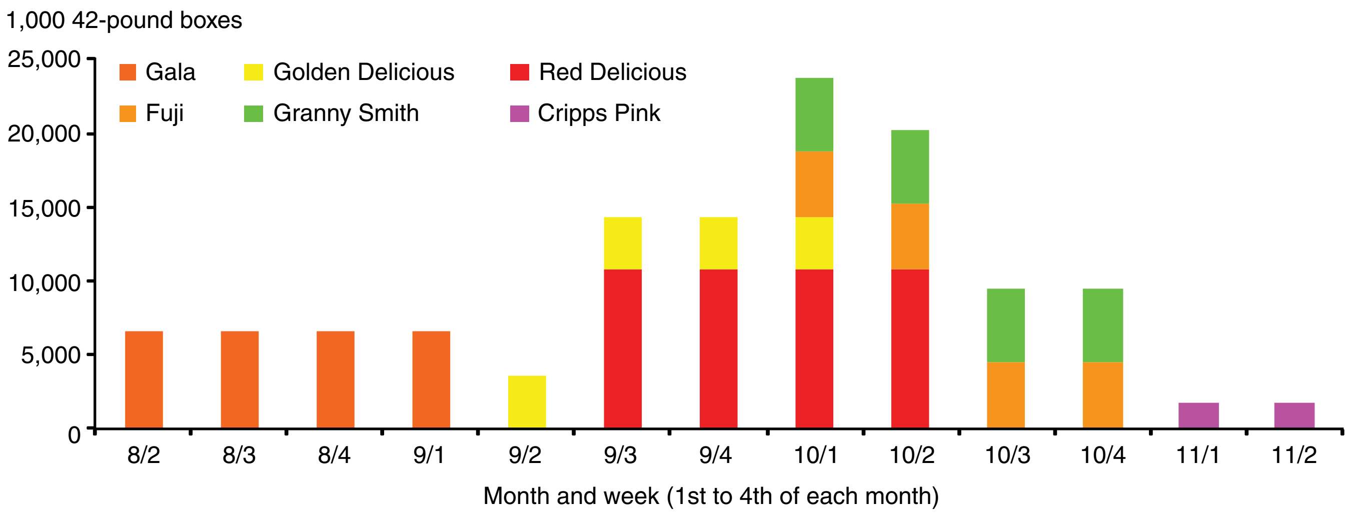
Golden Delicious share had declined to 41 percent; Gala and Fuji shares had expanded to 19 percent and 13 percent, respectively, and the Granny Smith share had increased to 15 percent (U.S. Apple Association, 1991 and 2008).

These varietal changes have had an important impact on labor demand. Figure 2 shows estimated harvest volumes by week for various types of apples. Total production divided by weeks of harvest is used as a proxy for actual weekly harvest volume. The Red Delicious harvest runs from mid-September to mid-October, and the Golden Delicious harvest starts and ends a week earlier. The Granny Smith harvest falls in October. This means that in 1990, over 92 percent of the apple harvest occurred between the second week of September and the end of October.

Today the apple harvesting season is much longer. Gala apples are the first major variety harvested each year, beginning in the second week of August and ending after the first week in September, just as the Golden Delicious harvest begins. Fuji apples are harvested in October, raising labor demand during the Granny Smith harvest. Cripps Pink apples (also known as Pink Lady) are harvested during the first half of November. With the addition of new varieties, the apple harvest now runs from the second week of August through the second week of November—13 weeks—compared with the 7-week harvest of 1990. The peak demand for harvest labor still occurs during the Red Delicious season. As the availability of labor becomes less certain, some growers with several varieties of apples may hire more workers than they really need for the early season to ensure that they have enough labor for the Red Delicious harvest. Smaller shippers and growers who produce only Red Delicious apples may find it more difficult to compete for labor.

Figure 2

Apple harvest, by major varieties and harvest period, 2007[1]



[1]Estimated weekly variety harvest is total production divided evenly over the typical weeks of harvest.

Source: USDA, Economic Research Service calculations based on the U.S. Apple Association's *Production and Utilization Analysis, 2008 Edition.*

Harvesting practices vary by apple variety. Even though apples ripen unevenly, a Red Delicious orchard might be harvested in just one pass because the price of Red Delicious apples is low relative to other varieties. A grower might have harvesters make several passes in an orchard of a high-value apple to select fruit at peak maturity. Some varieties require special handling; for example, when workers harvest Fuji apples they must clip off the stiff stems to avoid damage to other fruit.

Labor

The Washington Tree Fruit Research Commission (WTFRC) was established in 1969 to promote and carry out research for the industry. The formation of the WTFRC was motivated, in part, by concerns about labor cost and availability. Research on mechanization, however, was not a large part of the WTFRC's mission until recently. Today, active research and experimentation is taking place on the mechanization of the apple industry. The WTFRC spends about $600,000 a year on mechanization research. Since shaker machines used for most nuts are not appropriate for fragile (but heavy) apples, the WTFRC is focusing on a two-stage mechanical harvesting system. The first stage includes a self-propelled scout that would monitor tree growth, chlorophyll levels, disease, insects, yield, and optimum harvest time using cameras to map individual apples. The second stage relies on a robotic harvester that would use the information from the scout to develop a picking strategy, including multiple harvest passes to pick apples at the peak of their maturity. Using machines efficiently requires that orchards be designed to facilitate mechanical harvesting—specifically, short trees that are trellised to fit the machine's need for more homogeneous trees. Most prototypes of robotic harvesters for apples are slow, unreliable, damage the fruit, or in some cases, simply lack the power to be of immediate use. Labor aids, such as mobile platforms, however, offer ways to increase labor productivity until commercial harvesters are developed.

In 2008, USDA's SCRI awarded Carnegie Mellon University's Robotics Institute $6 million for its Comprehensive Automation for Specialty Crops project. Researchers at Pennsylvania State University, Purdue University, Oregon State University, Washington State University, the Federal Government, private machinery manufacturers, and growers are also part of the consortium to increase mechanization in apple production.

Apple growers require laborers for both field and packinghouse/warehouse operations. The most important field activities include pruning and training, thinning, and harvesting. Currently, all field operations are hand-labor activities, although there is research underway to mechanize these activities as well. In 2006, a budget study for a typical Washington State apple orchard found that 21 percent of variable labor costs were for pruning and training, another 21 percent was for thinning, and 48 percent for was harvesting (Seavert et al., 2007).

Pruning and training. Most pruning and training (shaping young trees), done by relatively skilled workers, occurs during the winter season when the trees are dormant. Labor availability has generally not been a problem at this time of year because there is less demand for farm labor and workers have a longer period to perform the task. Some firms employ year-round workers for these tasks. In orchards with shorter trees, some growers utilize mobile platforms for workers to stand on while they prune. These platforms were developed with funding from the WTFRC and are now manufactured by a private firm. The platforms move down the rows, eliminating the need for ladders and increasing both worker productivity and safety. Because pruning can be spread over many months, a grower does not need many motorized platforms.

Thinning. Growers use chemical thinners during and shortly after the bloom period to improve fruit quality by reducing the number of future apples. Later in the growing cycle, apples must be thinned by hand, removing poor quality apples and those that are too close together to ensure the remaining apples will be of good quality and size. Most of the hand thinning occurs in June and July. Thinning requires less skill than pruning; thus, temporary workers are often hired for this task. Motorized platforms may be used by workers for this task.

Harvesting. Apples are hand harvested, and harvesting is the most expensive labor component of apple production. Again, shorter trees aid workers, but motorized platforms have not been used in harvesting because putting heavy harvested fruit on platforms can make them unstable. In 2009, a private firm introduced a new harvest platform prototype which may prove useful since it suctions the apples away from the platform and potentially resolves the stability issue (Wilhelm, 2009). The WTFRC is providing some support to this firm to further its research. Several firms are currently developing promising prototypes. Studies show that when apple pickers are in the orchard, only 30 percent of their time is spent picking with the rest of their time spent positioning ladders, climbing ladders, and unloading bags of fruit. A motorized platform would enable workers to devote a greater proportion of their time to picking apples.

The harvest labor market must be put in the context of the larger Washington State tree fruit industry. Expanded cherry production in Washington State has increased the demand for labor in the tree fruit industry, increasing the competition for labor between apple and cherry growers. Between 1990-92 and 2005-07, Washington State cherry production increased 117 percent, and new varieties extended the cherry-harvesting season. As the late cherry harvest season encroaches on the traditional apple-thinning season, apple growers may have to raise wages to obtain workers. Both cherry production and prices were rising for most of the past decade, enabling cherry growers to offer higher harvesting wages.

Packing. Because apples are a storable commodity, packinghouse/warehouse operations and jobs are year-round for large operations. In some packinghouses, the apples are only touched once by human hands, when the apple is placed in a tray with the label side up. There is little problem recruiting workers to fill packinghouse/warehouse jobs, which are indoors, largely mechanized, and year-round.

Apple Outlook

How would the Washington State apple industry respond to sustained higher wages? If labor costs rose by 20-30 percent due to a decline in the labor supply, older orchards with traditional varieties located near towns would likely be replaced with new housing developments. Growers might look to other crops with higher potential returns, such as sweet cherries in some areas and wine grapes in others. Sharp and sustained increases in wages would probably be necessary to mechanize the fresh apple harvest, and such labor cost increases could also lead to structural changes in the industry.

Currently, offsetting trends in the apple industry keep the demand for labor fairly stable. Total apple production has declined, reducing the demand for labor. The use of smaller trees and mobile platforms has made labor more productive. On the other hand, changes in varieties have increased labor demand as these trees are often harvested more than once.

Florida's Processing and California's Fresh-Market Oranges

Florida and California produce most of the U.S. orange crop. The vast majority of Florida's oranges are sold to the processing (mainly juice) market (96 percent during the 2005/06-2007/08 marketing seasons), while more than two-thirds of California's oranges (69 percent during 2005/06-2007/08) are sold in the fresh market.[9]

Florida's Processing Oranges

Florida's orange acreage has declined because of urbanization, hurricanes, and two serious citrus diseases—citrus canker and citrus greening. Citrus canker causes blemishes on the skin of the fruit and makes oranges unsuitable for the fresh market. An infected tree also loses productivity. With proper management, however, oranges from infected trees can be used for juice. Citrus greening, which kills trees and cannot be eradicated, was first confirmed in Florida in 2005. Infected trees can have a mix of symptomatic (bitter, blemished, and unusable) and asymptomatic fruit. The asymptomatic fruit can be used for juice and the fresh market. Researchers are investigating methods to control citrus greening, including the development of varieties resistant to the disease.

U.S. orange juice production peaked in the 1997/98 season and has declined 35 percent since then. During the 2005/06-2007/08 seasons, orange juice imports accounted for 30 percent of U.S. orange juice consumption (table 5). Most U.S. orange juice imports come from Brazil, the world's largest orange juice producer and exporter. Due to lower labor costs, Brazil can produce orange juice at a lower cost than Florida (Muraro et al., 2003). The United States applies a tariff on frozen concentrated orange juice from Brazil and also levies antidumping duties against several Brazilian exporters.

Almost all of Florida's processing oranges are harvested by hand. Research on mechanical harvesting and labor aids for Florida citrus began in the mid 1950s, when consistent labor availability was the primary concern (Futch et al., 2005). Over time, the Florida Department of Citrus (FDOC)—a State organization supported by grower assessments—USDA, and the University of Florida have all invested in mechanization research. Three major freezes during the 1980s substantially reduced the size of the crop, reducing interest in mechanization. In the 1990s, however, interest increased due to the rising cost of labor.

The Florida industry has used three different mechanical harvest machines, all of which shake either the canopy of the tree or its trunk. Currently, only canopy shaker technology is used. Seven businesses use a self-propelled, continuous canopy shaker to collect fruit as it is harvested, and two businesses use tractor-drawn canopy shakers that drop harvested fruit on the ground, where it is picked up by workers. Growers have been reluctant to adopt trunk-shaking harvesters for fear of damage to the trees. As a result, this technology has not been used over the past several years. Some growers also have expressed fears about the potential damage to trees from canopy shaking.

[9] The Florida marketing season begins in October, while the California season begins in November.

Table 5
U.S. processing and fresh-market orange industry statistics, 1990/91-1992/93 to 2005/06-2007/08[1]

	Unit	Average 1990/91-1992/93	Average 2005/06-2007/08	Percent change
Orange juice				
Production	Million SSE gallons	999	1,006	1
Imports	Million SSE gallons	310	370	19
Import share of consumption	Percent	26	30	16
Exports	Million SSE gallons	105	137	31
Export share of production	Percent	11	14	29
Per capita consumption	Gallons SSE	5	4	-12
Price[2]	$/90-pound box	5	7	46
Fresh oranges				
Production	Million pounds	3,917	3,743	-4
Imports	Million pounds	65	188	190
Exports	Million pounds	944	1,103	17
Per capita consumption	Pounds	12	9	-21
Import share of consumption	Percent	3	7	162
Export share of production	Percent	24	29	24
Price[2]	$/75-pound box	12	12	1

SSE= Single-strength equivalent.
[1]For juice using the Florida season and for fresh-market oranges using the California season.
[2]Price is equivalent-on-tree returns. Florida price for fresh oranges for processing and California price for fresh-market oranges.
Source: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook*.

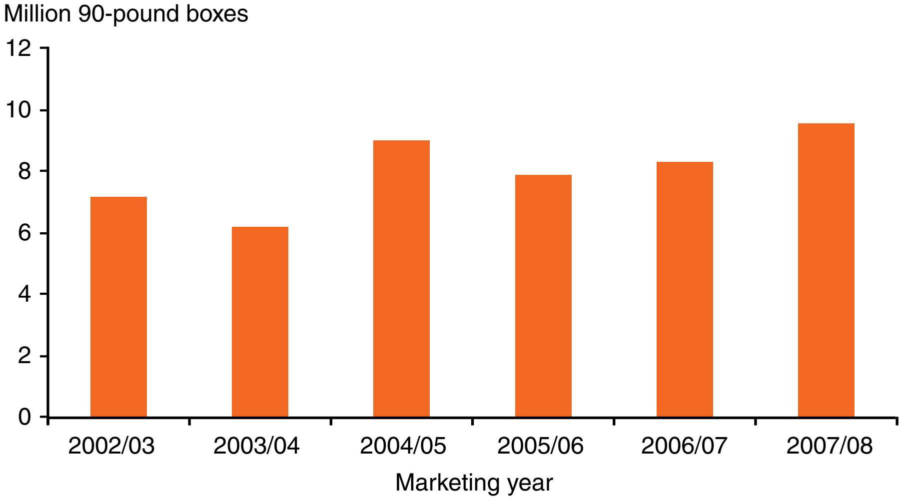
Continuous canopy shakers are expensive. In 2009, a set of left and right continuous canopy shakers cost a total of $1.15 million, prompting the development of a custom harvest system. Custom harvesters use their machinery to harvest groves for other growers. Of the nine Florida businesses that currently use canopy shakers, only two are private growing organizations. The others are primarily custom harvesters, although some of these firms may also own groves (Roka, 2009a).

Mechanical harvesting could reduce harvest costs by as much as 50 percent and production costs for a box of oranges by 20-30 cents (Roka et al., 2009). As a result of lingering technical issues, only a small share of Florida's processing orange crop is currently mechanically harvested—9.6 million boxes, or 5.8 percent of the total, in the 2007/08 season (fig. 3).

The most serious challenge to mechanization is that the mechanical harvester cannot be used on late-season Valencia oranges, which account for 25-30 percent of Florida's total orange harvest. At harvest time, late-season Valencia orange trees contain both mature fruit and immature fruit for the following season; mechanical harvesting removes too much of the following year's production. To address this problem, researchers developed an abscission compound, which is sprayed on trees to loosen the bond between the stem and the fruit on mature oranges. This allows mechanical harvesters to shake the canopy with less force and dislodge the mature fruit without

Figure 3

Machine-harvested Florida processing oranges[1]



[1]Total Florida processing orange production varied by year, so the share of the total harvested by machine ranged from a low of 2.7 percent in 2003/04 to 6.8 percent in 2006/07.

Source: University of Florida, Institute of Food and Agricultural Sciences, *Citrus Mechanical Harvesting Program.*

harming the immature fruit. Since 1996, the University of Florida has spent $500,000-700,000 per year to develop the abscission compound. In 2009, the FDOC presented its proposal to register the abscission compound with the U.S. Environmental Protection Agency (EPA), a process that will cost $7-11 million (Blanco and Roka, 2009). The industry expects a decision from EPA by July 2011.

Mechanical harvesting does not eliminate the need for manual labor, however. During the early part of the season, some growers who use mechanical harvesters also employ hand harvesters to ensure that they will have workers for the late-season Valencia harvest, when machines are not used. When the price of oranges is sufficiently high relative to labor costs, mechanically harvested trees are often harvested again by hand to glean the remaining oranges.

Mechanical harvesting requires specially designed groves, and growers now design most new plantings for machine harvesting. Due to the many challenges facing the industry, there have been relatively few new plantings in recent years. In the 2005/06 season, Florida's orange-bearing acreage declined 9 percent.

In light of these challenges, the Florida market for mechanical orange harvesters has declined. The sole U.S. manufacturer of these machines made its most recent sale in Florida in 2006.[10] While this firm continues to export mechanical harvesters to countries where demand is stronger, it is waiting to see if the abscission compound is approved, which would improve the profitability of mechanical harvesting and stimulate domestic demand.

The adoption of mechanized harvesters can often affect packing or processing operations. Shaking the trees instead of hand harvesting introduces harvest debris into the containers delivered to processing plants, requiring not just additional sorting but also presenting a potential hazard to

[10]In the late 1990s, several companies were working to develop mechanical citrus harvesters, but today there is only one such company in business.

processing machinery (Roka, 2009b). Debris has become more of a challenge because recent hurricanes and disease problems have left larger amounts of dead wood in the trees. With an abscission compound, the fruit would come off the trees more easily, reducing harvest debris problems.

Successful mechanization may require adjustments on the part of the processor as well as the grower. Processors typically allocate a certain harvest volume to each grower on a daily basis, usually a percent of total production, to control the flow of product into the processing plant. This allocation system works well with flexible farmworkers; the grower is paying wages only while the workers are harvesting. For mechanical harvesting, however, a small allocation that takes a mechanical harvester only a few hours to finish would be an inefficient use of expensive machinery.

In 2008, USDA/SCRI awarded a grant of $4 million to Carnegie Mellon University for research on robotic harvest mechanization and autonomous vehicles for the orange industry. Autonomous vehicles would support precision agriculture, the scouting and detection of diseases, and the mapping of fruit. Robotic harvesting might also offer an alternative to the shaker technology used for processing oranges.

California's Fresh-Market Oranges

California orange growers produce oranges for the fresh market and use the processing market as a residual market. National statistics reveal some of the economic challenges facing the California industry:

- U.S. fresh-market orange production decreased 4 percent between 1990/91-1992/93 and 2005/06-2007/08;
- Per capita consumption of fresh oranges dropped by 21 percent over the same period; and
- U.S. per capita tangerine consumption (including the popular clementine) increased by 57 percent over the same period. The decline in U.S. fresh orange consumption is linked to greater availability of other fresh produce.

California growers are also concerned about the potential for citrus canker and citrus greening in their State. While citrus greening has not yet been found in California, the Asian citrus psyllid, an insect that is the vector of citrus greening, was detected in California trees in 2008. So far, the pests found have not tested positive for the disease (California Department of Food and Agriculture, 2009).

Imports of fresh oranges are small but increasing; most U.S. imports are navel oranges entering in the summer when there are no domestic navel oranges available. Exports are important to the U.S. fresh-market orange industry, accounting for 29 percent of U.S. production during 2005/06-2007/08. The top export markets for fresh U.S. oranges are Canada, followed by South Korea, Hong Kong/China, and Japan. Reducing labor costs may be particularly important to maintain U.S. competitiveness in the international market for fresh oranges, since China has identified fresh-market oranges as having export potential (USDA, Foreign Agricultural Service, 2008).

All of California's fresh-market oranges are hand harvested. The shaker technology used in Florida for processing oranges is inappropriate for fresh-market oranges, which must have a good appearance. The California Citrus Research Board (CRB)—a State marketing order program funded by grower assessments—has invested nearly $1 million in mechanical harvest research since 2004. CRB funding, however, varies from year to year depending on crop size, and mechanization research must compete with other industry priorities, such as controlling the Asian citrus psyllid.

The California fresh-market orange industry is exploring the development of a robotic harvester that would mimic hand harvesting. CRB has funded San Diego-based Vision Robotics to develop a harvest system that features a self-propelled scout machine and a robotic harvester that could have broad applicability to many citrus fruit. The first round of research focuses on oranges and lemons, the second round will focus on mandarins, which grow in clusters, and a third round will target grapefruit, which are larger and heavier. While commodities and harvesting processes vary, many industries are working together to reduce R&D costs. The apple industry has funded similar research with VisionRobotics, since the two-machine harvesting strategy would also work with apples. Other tree fruit and table grapes could benefit from this technology. In addition, the strawberry industry has invested in mechanization research with this firm, although strawberry harvesting and orange harvesting would have some different requirements.

Once a mechanical harvester is available for fresh-market oranges, the industry can adapt groves to the machine. This task may be easier for oranges than for other tree fruit, since new varieties are not needed. There are no dwarf commercial orange trees. Growers have pruned their trees to reduce height over time to improve worker efficiency and safety, facilitate pest control, and promote better fruit size and quality. Trees could be trimmed even shorter to accommodate a robotic harvester.

Processing and Fresh-Market Orange Outlook

With Florida's orange acreage shrinking, public policy plays a larger role in shaping the future of the processing orange industry. A decrease in the import tariff or a sustained increase in labor costs could speed the shift of Florida's orange groves toward the southwestern part of the State, where new plantings are most amenable to mechanical harvesting. Mechanical harvesters are available, but their use is currently limited. If the EPA approves an abscission compound that allows machine harvesting throughout the season, the use of mechanical harvesters may expand.

The California fresh-market orange industry does not have a mechanical alternative to hand harvesters, although research is ongoing. California's navel oranges do not currently face any serious import competition during their season, but when freezes occur imports increase, indicating that imports are possible at high prices. Lower harvesting costs and lower production costs, in general, are important to maintain export markets.

Raisins

The U.S. raisin industry, centered in Fresno County, California, faces several challenges. Average U.S. per capita raisin consumption declined by 15 percent between the 1990/91-1992/93 and 2005/06-2007/08 seasons (table 6).[11] Per capita consumption declined for several reasons: greater year-round availability of fresh fruit and competition from other dried fruit, including cranberries, blueberries, cherries, and various tropical fruit.

[11]The California marketing season runs from August to July.

With lower per capita consumption, exports are very important to the industry. In 2005/06-2007/08, 41 percent of raisin production was exported. Increased international competition also contributes to the economic challenges of the U.S. raisin industry. The United States and Turkey are the world's largest raisin producers, accounting for over half of global supply. Turkey is the world's largest exporter of raisins, and the cost of producing raisins is much lower in Turkey than in California (Martin and Mason, 2009). The U.S. industry depends on a complicated set of State and Federal marketing programs to remain competitive in export markets. There is a two-tier market for domestic and export sales, with a lower price for exports (Federal Register, 2009; Federal Register, 2007). Without these programs, U.S. raisin exports would decline substantially. U.S. raisin imports are relatively small but increasing.

Harvest Systems

The raisin industry has alternatives to hand harvesting, but only a few pioneering growers used them prior to 2000. In that year, production of fresh

Table 6
U.S. raisin industry statistics, 1990/91-1992/93 to 2005/06-2007/08[1]

		Average		
	Unit	1990/91-1992/93	2005/06-2007/08	Percent change
California raisin-type grape-bearing acreage	Acres	267,333	233,667	-13
Fresh grapes going to raisins (fresh-weight basis)	Million tons	1,635	1,563	-4
Percent of raisin-type grapes going to raisins[2]	Percent	69	75	9
Raisin shipments[3]	Million pounds	705	664	-6
Prices for grapes that are dried (fresh-weight basis)	$ per ton	215	227	6
Raisin imports	Million pounds	19	53	183
Raisin exports	Million pounds	284	275	-3
Per capita raisin consumption	Pounds	2	2	-15
Raisin import share of consumption	Percent	4	12	182
Raisin export share of production	Percent	40	41	2

[1]Statistics on a marketing-year basis, August to July.

[2]Grapes processed for raisins as a percent of raisin-type grape production.

[3]Raisins can be stored; shipments represent sales from annual production and stored raisins.

Source: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook 2008;* USDA, National Agricultural Statistics Service, *Noncitrus Fruits and Nuts*.

grapes used for raisins, mainly Thompson Seedless, peaked at a record 2.2 million tons and the price plummeted 56 percent from the previous season, remaining below 1999/2000 levels until 2004/05 (fig. 4). Between 2000 and 2004, the quantity of fresh grapes used for raisins declined 50 percent before production began to increase again. Growers began to adopt mechanical harvesting in response to this price shock, a few years of low labor supply, and the introduction in 2001 of a modified mechanical wine-grape harvester. Currently, there are three harvest systems—the traditional tray-drying system, the continuous-tray system, and the dried-on-the-vine (DOV) system.

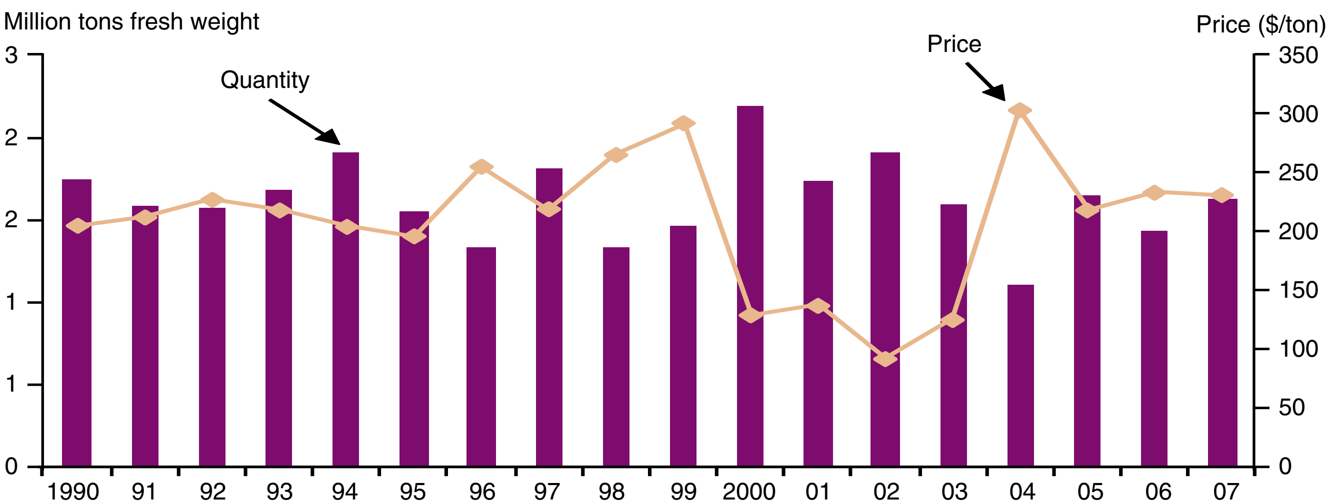
Tray drying. Tray drying is the traditional method of harvesting and drying grapes into raisins. Workers harvest the grape clusters by hand after the grapes reach the appropriate sugar content, usually by the first two weeks of September. Then, the workers place the clusters onto paper trays on terraces (smoothed soil surfaces) that have been prepared between the rows of grape trellises. The grapes dry into raisins in the 100-degree plus heat for 14 days. After the first week of drying, the trays of partially dried grapes are turned or rolled to expose the other side of the cluster to the sun and to ensure uniform drying. After the second week, the trays are rolled up and taken to a facility where the raisins are stored, packed, and sold.

Tray drying has several disadvantages. Tray drying requires a substantial amount of labor. Given a raisin yield of 2 tons per acre, three people working a 10-hour day can pick an acre of raisin grapes (University of California Cooperative Extension, 2006b). Based on an estimate for the mid-1990s, roughly two-thirds of raisin harvesters were unauthorized (Mason et al., 1997). With a labor force that is temporary and largely unauthorized, the raisin harvest may be more vulnerable to stricter immigration enforcement than other crops that employ workers for a longer season and may have a larger proportion of authorized workers (Mason, 1998).

Vulnerability to rain damage is another disadvantage of tray drying. Because of the threat posed by fall rains, growers must have their raisins drying on

Figure 4

U.S. fresh grapes used for raisins, 1990-2007



Source: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook 2008*.

the ground by the "rain date" (typically about September 20) to be eligible for payments under their crop insurance policies in the event of damaging rains. Because raisins must have a certain sugar content to be marketable and the grapes must be on the ground to dry by the rain date, growers have a short window for harvesting their raisins. The longer farmers wait to begin the harvest, the more workers they need. If the harvest begins 20 days before the rain date, twice as many workers are needed than if the harvest begins 40 days before the rain date.

Continuous-tray harvesting. Continuous-tray harvesting has evolved since its development and adoption by a single raisin grower in 1972. Numerous growers have adopted this system since 2000, in large part, because continuous-tray harvesting is virtually identical to the traditional tray-drying system until the harvest. With continuous-tray harvesting, workers sever the grape canes about 7 days prior to harvest, which allows the grapes to start drying on the vine.[12] The slightly withered grapes are then harvested using a modified wine-grape harvester, which strips individual grapes from the stems.[13] The grapes are laid down by machine on a long *continuous* paper tray (also laid down by machine) on the traditional terrace between rows. The individual grapes need only 7-10 days to dry on the ground, compared with 14 days using traditional tray drying where entire clusters are laid down to dry. Machines pick up the raisins from continuous trays when drying is complete and load them into bins. The paper is shredded during the pick-up process and incorporated into the soil.

Harvesting costs using the continuous-tray system are much lower than under the traditional tray-drying system, but yields under the two systems are the same. Using a mechanical harvester with the continuous-tray system can reduce hand-harvest labor costs by 83 percent and total harvest costs by 56 percent (University of California Cooperative Extension, 2006a and 2006b). In 2008, costs for the continuous-tray system included $185,000 for the harvester, $24,000 for the machine to lay down the tray, and $44,000 for a machine to pick up the raisins. High machinery costs could deter small farmers from purchasing machinery for this harvest system. If a custom harvest industry emerged, then small growers would not necessarily have to purchase the machinery themselves.

Dried-on-the-vine (DOV) systems. There are two ways of adopting a DOV system—retrofitting an existing vineyard or developing a new vineyard that will generate higher yields. For our purposes, we limit the discussion to DOV systems for new vineyards in which growers use new trellises, new grape varieties, and new cultural practices. Researchers at the University of California's Kearney Agricultural Center developed a DOV system in the 1960s, although Australian researchers were already tinkering with DOV systems in the 1950s. Around 1990, the first California raisin producers began using this system.

DOV systems eliminate the need for drying raisin grapes on the ground. When the grapes are ripe, the canes are severed and the grapes dry into raisins for 6-8 weeks on the vine. Since the temperature within the canopy, 5 to 6 feet above the soil, is substantially lower than on the drying terraces, grapes need to be mature by mid-August to complete drying before the fall rains begin. The DOV system reduces risk, since water from an early rain

[12] Severing the canes is the only manually performed harvest task that does not yet have a mechanized alternative, but researchers are working to develop such an alternative. Workers only sever the fruiting canes, not the renewal canes. Some growers using the continuous-tray system may have their workers perform additional work to separate the fruiting and renewal canes. This separation of canes is not necessary in the traditional tray-drying system, since only grape clusters are cut, not canes.

[13] The modified wine-grape harvesting machine, developed by a private firm, can be used on traditional raisin-grape trellises and reduces wear and tear on the trellises.

drains off the grapes drying on the vine, usually without causing damage. When canes are cut by August 15, the probability of successful DOV harvesting is 90 percent, but the probability falls to 70-80 percent a week later and to 50 percent by September 1 (Sun-Maid Growers of California, 2002).

The DOV system requires new grape varieties that mature earlier, since the traditional Thompson Seedless grape does not mature until late August or early September. USDA's Agricultural Research Service (ARS) developed several new varieties of raisin grapes that mature earlier and reduce grower risks of rain damage: Fiesta (released in 1973), DOVine (1995), and Selma Pete (2001) (Vasquez and Fidelibus, 2003). Each of these varieties can be harvested by August 15 or earlier. In addition, researchers are looking for new grape varieties that would dry on the vine without having to cut the canes (Bryant, 2010).

With the DOV system, grapes are harvested mechanically, placed directly into containers, and taken to storage, eliminating the use of paper trays and reducing foreign material in the raisins. Without the need for drying terraces, growers have new options for vineyard architecture and can experiment with trellises that maximize the sunlight available to the grapes and increase yields. New trellis systems are being developed by individual growers and University of California researchers, with some support from the California Raisin Marketing Board, a grower-supported organization. New trellises can be expensive; one estimate put the cost at $10,000 per acre in 2009 (Pollock, 2009). Yields, however, increase substantially with DOV. The traditional tray-drying system and the continuous-tray system yield about 2 tons of dry raisins per acre. With the DOV system, yields can range from 4.7 to 7 tons per acre.

New trellises require new cultural practices. Growers spend more time pruning to separate fruiting and renewal canes so that the harvester has easy access to grapes on the fruiting canes without damaging the renewal canes. This requires more skilled labor during the winter, encouraging many DOV growers to employ a small, permanent, year-round staff for pruning and then hire a relatively small number of temporary workers for the harvest.

The DOV system is a dramatic departure from the traditional tray-drying system and requires a major investment. There is no harvest until the third year after replanting a vineyard to one of the new early maturing varieties. Even if growers are interested in adopting new varieties, they may be reluctant to pull out an existing vineyard that has a productive lifetime of at least 30-35 years. In addition, there are concerns about whether cutting canes for the continuous-tray or DOV system reduces the long-term vigor of the vineyard (Christensen, 2000). Industry structure will likely affect the speed of adoption. California has an estimated 3,500 raisin growers, many of retirement age with small vineyards (Cline, 2008). Output is concentrated among the larger growers, with 30 percent of the growers producing about 70 percent of the raisins. Older farmers with small vineyards may be less likely to adopt the DOV system. As these growers retire, their vineyards may be consolidated into larger operations, which would make the adoption of new technology more profitable.

One industry source estimated that growers produced 45 percent of the raisin crop using some type of mechanical harvesting system in 2007, up from 1 percent in 2000 (fig. 5). There was little change in 2008, perhaps reflecting rising raisin prices and increasing labor availability due to the economic downturn, but more mechanization is expected in the future. In 2007, growers harvested about 33 percent of the raisin crop using continuous-tray and 12 percent using DOV harvest technology. The continuous-tray system, with less up-front costs and substantial labor savings, is clearly expanding. To remain competitive in an international market, growers may eventually be forced to adopt DOV, which provides higher yields.

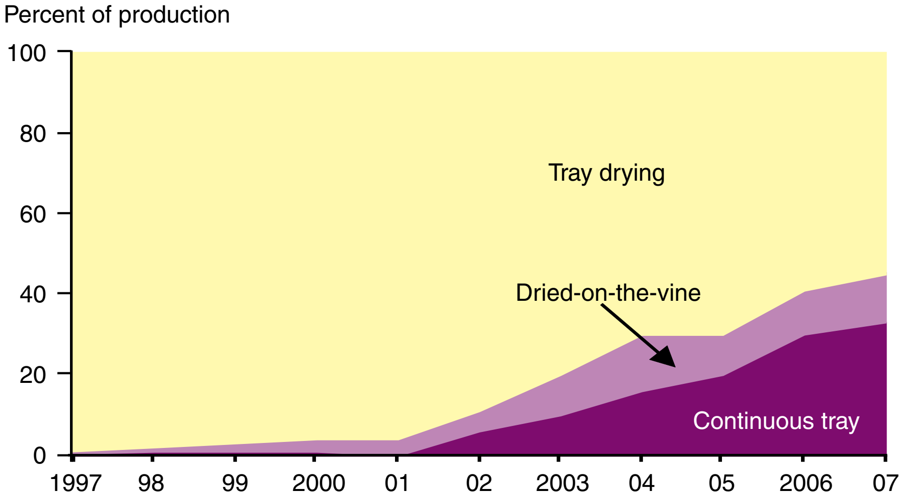
DOV raisins differ slightly from traditional tray-harvested grapes in appearance and taste (Angulo, Fidelibus, and Heymann, 2007), but the raisin industry has not had any trouble dealing with this variation. Raisin handlers do not mix raisins produced using different harvest methods since the raisins differ in appearance and other attributes. Currently, all raisins of the same type receive the same price, regardless of harvest method, and the harvest system is not advertised to the retail consumer.

Raisin Outlook

With increased mechanization, the demand for labor in the raisin industry has already peaked. The raisin harvest once required 50,000 workers; the industry now estimates it uses 20,000-30,000 workers (Cline, 2008). To remain competitive in a global market, California producers aim to reduce production costs, a process most easily achieved by reducing harvest labor costs and increasing yields in DOV systems. With current economic conditions, adoption of mechanical harvesters has slowed. If wages increased or prices declined, there would likely be an increase in adoption. Major obstacles to mechanization include the industry's structure, which features a large number of relatively small producers.

Figure 5

Estimated share of California's raisin production, by harvest technology, 1997-2007



Source: Ron Brase, California AgQuest Consulting, 2009.

California's Fresh-Market Strawberries

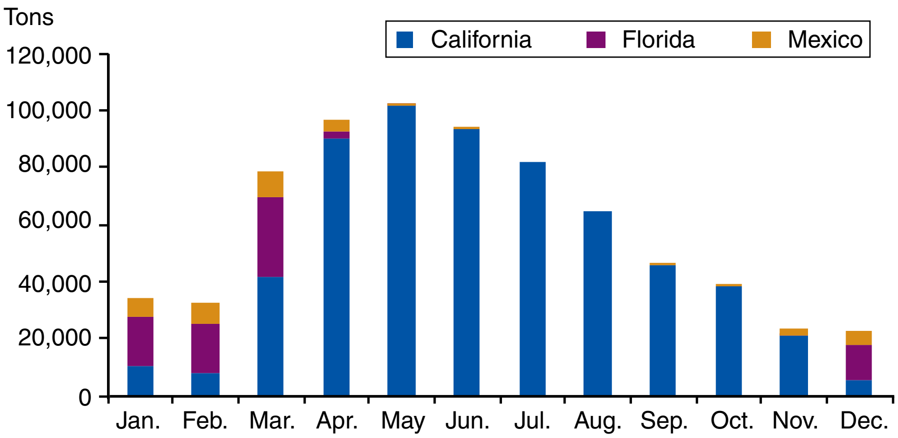
In 2007, California accounted for 88 percent of U.S. strawberry production. With growing areas extending from San Diego to Santa Cruz counties, the California industry produces year round, although winter supplies are relatively low (fig. 6). Florida produces in the winter when the United States imports small quantities of strawberries from Mexico. California produces for the fresh market and uses the processing market as a residual market.

The U.S. fresh strawberry industry has experienced tremendous growth over the past two decades (table 7). Between 1990-92 and 2005-07, harvested acreage increased 12 percent, yield increased 63 percent, and total utilized production increased 81 percent. Growth in supply was met with an increase in per capita consumption of 75 percent.

Fresh-market strawberries are one of the more labor-intensive horticultural crops, but the U.S. industry does not face significant import pressure, even from countries with lower labor costs. California's climate is ideal for growing strawberries, and there are not many potential foreign suppliers who can deliver this fragile and perishable product to U.S. consumers at a competitive price. Imports were 8 percent of domestic consumption of fresh strawberries in 2005-07. Mexico, mostly the State of Baja California, supplied 99 percent of U.S. imports of fresh-market strawberries during 2005-07. Several California strawberry growers operate in Mexico since California has limited land appropriate for winter strawberry production. Baja California has little land, water, and labor to devote to strawberry production, prompting some U.S. growers to develop a winter strawberry export industry in central Mexico. Unless U.S. wages increase dramatically, imports pose little threat to U.S. fresh strawberry producers. While imports from Mexico have increased, Mexico is also an important and growing market for fresh strawberry exports. In 2007, Mexico was the second largest U.S. export market with a 13-percent share, after Canada with an 80-percent share.

Figure 6

U.S. fresh strawberry shipments, 2007



Note: California, Florida, and Mexico represent virtually all fresh-market shipments reported by the Agricultural Marketing Service.

Source: USDA, Agricultural Marketing Service, Market News Service, *Fresh Fruit and Vegetable Shipments.*

Table 7
U.S. strawberry industry statistics, 1990-92 to 2005-07

	Unit	Average 1990-1992	Average 2005-2007	Percent change
Acres harvested	Acres	47,230	52,700	12
Utilized production	Tons	659,017	1,195,300	81
Yield	Tons/acre	14	23	63
Fresh utilization	Tons	471,917	949,200	101
Processed utilization	Tons	187,100	246,100	32
Fresh share of utilization	Percent	72	79	11
Grower price (fresh)	$/ton	1,139	1,488	31
Grower price (processed)	$/ton	539	567	5
Fresh imports	Tons	14,573	72,301	396
Fresh import share of consumption	Percent	3	8	137
Fresh exports	Tons	47,201	112,835	139
Fresh export share of production	Percent	10	12	19
Fresh per capita consumption	Pounds	3	6	75
Frozen strawberry production	Tons	150,774	203,332	35
Frozen imports	Tons	33,470	87,550	162
Frozen import share of consumption	Percent	20	32	61
Frozen exports	Tons	14,815	13,723	-7
Frozen export share of production	Percent	10	7	-32
Processed per capita consumption	Pounds	1	2	41

Source: USDA, Economic Research Service, *Fruit and Tree Nuts Situation and Outlook Yearbook 2008*.

The share of strawberries going to the fresh market has increased, but strawberries going to the processing market are still an important component of grower revenue (an average of 21 percent of production went to processing in 2005-07). If the fresh price or the quality is low, growers often sell to the processing market to help defray production costs. The processing strawberry industry, mainly frozen, is more vulnerable to imports. Between 1997-99 and 2005-07, the import share of frozen strawberry consumption rose from 20 percent to 32 percent. Over the same period, average frozen exports fell 7 percent, but from 1997-99 (the peak) to 2005-07, frozen exports fell 49 percent. California growers are concerned about lower returns in processing.

Strawberry Labor

All California strawberries for the fresh or processing market are harvested by hand. In 2004, one acre of strawberries in Monterey and Santa Cruz counties required nearly 1,000 hours of harvest labor (Bolda et al., 2004).[14] In this same area, labor costs represented 53 percent of the cost of strawberry harvesting in 2004 and 36 percent of total operating costs. The growth of organic strawberry production has an impact on demand for labor. Organic growers, who cannot use herbicides and fumigants for weed suppression, tend to use more labor than conventional growers.

[14] This cost of production study does not consider the use of a labor aid, which is discussed later.

Growers would like to reduce their labor costs, but strawberries present a difficult challenge for a mechanical harvester. The fruit is very fragile and does not mature at one time. It is difficult to develop a machine that duplicates the skill and speed with which a worker can sort through foliage, identify a ripe strawberry, and pick the fruit without damaging it. Since the plants are harvested continuously for many months, a mechanical harvester must avoid damaging the strawberry plants as well as the immature fruit. In 2007, the California Strawberry Commission began funding research on a robotic harvester, spending $75,000-$100,000 per year. The strawberry industry is looking at a two-machine harvest system like that being developed for apples and California citrus. As of early 2009, research had progressed to the stage where an experimental prototype could identify and pick a ripe strawberry and then deposit it safely into a container. An *economical* robotic harvest system will take more time to develop. Many believe that strawberries will be the last or one of the last fruit and vegetable crops to be mechanically harvested.

Adoption of a labor aid, rather than a mechanical harvester, has increased labor productivity in the strawberry industry in Southern California. In 2002, a slow-moving conveyor belt that serves as a receiving station for pickers was introduced in Ventura County. The conveyor belt moves down the field in front of the harvest crew, straddling many rows of strawberries. The work crew still picks the strawberries by hand and places them into trays, but full trays are now deposited onto the conveyor belt a few steps away rather than being carried to trucks at the end of the row. This increases worker productivity, particularly in large fields, and reduces the hours of labor required per acre. Early in the adoption process, a firm in Ventura County reported that the new technology reduced harvest hours per acre by about 40 percent (Rosenberg, 2004).

This conveyor-belt technology was developed and patented by a private custom fabrication firm that specializes in machinery for the strawberry industry. Approximately 250 such conveyor belts were in operation in 2008, mostly in Ventura County. Industry experts estimate that 50-75 percent of the Ventura County strawberry acreage was harvested with the assistance of conveyor belts in 2008. A single conveyor belt cost approximately $115,000 in 2008; the cost may be a deterrent to its adoption for some small growers, but a custom harvest industry could evolve to allow smaller growers to use the new technology. Alternatively, a smaller and cheaper conveyor belt could be developed to handle the volume of smaller farms.

Most growers who adopted conveyor-belt technology reduced their piece-rate wages because of the increased labor productivity. This raised fears among workers that their total income could drop. An early adopter of the conveyor belt reduced the piece rate, but because workers could harvest substantially more trays per hour with the assistance of the conveyor belt, their average hourly earnings actually rose (Rosenberg, 2004). Nonetheless, reactions of harvest crews to the conveyor belts have been mixed. Some crews have refused to use the machines; others have experimented with the machines, only to reject them; and still others have made a successful transition to the machines. Some growers use a combination of conventional labor crews and conveyor-belt crews with separate piece rates for each.

Growers outside Ventura County have been less likely to adopt the conveyor belt. Ventura County has very flat terrain, and the technology may be less suitable for California's northern production area, which has more hilly terrain. The northern area accounted for 44 percent of California's strawberry production in 2007, compared with 27 percent for Ventura County. One grower in the north has been experimenting with two conveyor belts for several years, but has not yet deployed them for commercial use.[15] Another grower is developing a machine that may be more appropriate for smaller operations. Some reports suggest that growers in the northern area have not adopted the conveyor belt because they are anxious to avoid the labor issues inherent in adopting any new technology (*The Packer*, 2008).

[15]One grower in Florida experimented with the Ventura conveyor belt technology without success.

Strawberry Outlook

Between 1990 and 2007, strawberry production increased at an average annual rate of 5 percent. Labor aids can make harvest workers more efficient, reducing labor hours per acre. Commercial mechanical harvesting technology is not currently available nor is it expected in the near future. The fresh strawberry market is not very vulnerable to import competition but the processed strawberry market is. An increase in processing imports is likely to encourage adoption of labor-saving technologies, such as the conveyor belt, and to increase the urgency of finding an economical mechanical harvesting technology.

Fresh-Market Asparagus

The U.S. asparagus industry is in decline due to import competition. Production decreased by 46 percent between 1990-92 and 2005-07, even though U.S. per capita consumption of fresh asparagus increased by 91 percent over this period from 0.6 pounds to 1.1 pounds per capita. Imports, mainly from Mexico and Peru, supplied 76 percent of U.S. fresh-asparagus consumption during 2005-07 (table 8). Since the bulk of the U.S. fresh asparagus harvest is marketed from March through June, not all fresh imports compete directly with domestic production (imports of nonperishable processed products, such as canned and frozen asparagus, which do not have a season, compete directly). For many years, the U.S. asparagus industry was protected from imports by high tariffs compared with those of other fruit and vegetables.

Before the North American Free Trade Agreement (NAFTA) took effect in 1994, the United States applied a most-favored-nation tariff of 25 percent on imported fresh asparagus during the critical February 1-June 30 period, when most of the U.S. production is harvested. Under NAFTA, this seasonal tariff was gradually phased out for Mexican asparagus over a 14-year period that ended in 2008. U.S. asparagus imports from Mexico increased as the tariff gradually declined to zero. Peruvian asparagus has entered the United States tariff-free since 1991 under the Andean Trade Preference Act.

Table 8
Asparagus industry statistics, 1990-92 to 2005-07

	Unit	Average 1990-92	Average 2005-07	Percent change
Total production	Million pounds fresh weight	235	127	-46
Fresh production	Million pounds fresh weight	139	99	-28
Fresh imports	Million pounds fresh weight	51	258	402
Fresh import share of consumption	Percent	34	76	124
Fresh exports	Million pounds fresh weight	40	18	-53
Fresh export share of production	Percent	29	19	-35
Fresh price	$/cwt (constant 2000 $)	95	79	-20
Fresh per capita consumption	Pounds/person	*	*	91
Canned production	Million pounds fresh weight	75	20	-73
Canned imports	Million pounds fresh weight	2	29	1,237
Canned import share of consumption	Percent	3	61	1,973
Canned exports	Million pounds fresh weight	4	1	-78
Canned per capita consumption	Pounds/person	*	*	-41
Frozen production	Million pounds fresh weight	20	8	-63
Frozen imports	Million pounds fresh weight	3	17	562
Frozen import share of consumption	Percent	10	68	599
Frozen exports	Million pounds fresh weight	N.A.	2	N.A.
Frozen per capita consumption	Pounds/person	*	*	-20

cwt=Hundredweight.
N.A.=Not available.
*Less than 1 pound per capita.
Source: USDA, Economic Research Service, *Vegetables and Melons Situation and Outlook Yearbook*.

Traditionally, California's growers dominated the fresh asparagus market, while growers in Washington State and Michigan focused on the processing market.[16] In recent years, however, Washington State growers shifted to production for the fresh market. The minimum wage exceeds the Federal level in all three States—a serious problem for a labor-intensive crop, such as asparagus. In California, increased imports from Mexico resulted in lower prices and reduced early-season profitability. In March 1990, Mexican asparagus accounted for 30 percent of total shipments (fig. 7). Over time, Mexican asparagus volumes and the length of the season increased. By March 2007, Mexican asparagus dominated shipments with a 63-percent market share. Some California producers, who once harvested asparagus for up to 3 months, now harvest only during a 6-week period when prices are highest. Many growers in California have stopped producing asparagus altogether. Between 1990-92 and 2005-07, California's asparagus production declined 37 percent. As the season shrinks, growers cannot justify allocating so much valuable land to a perennial crop. California producers now face competition for labor at the end of their season because they have to compete for workers against the expanding California cherry harvest, which begins in May.[17]

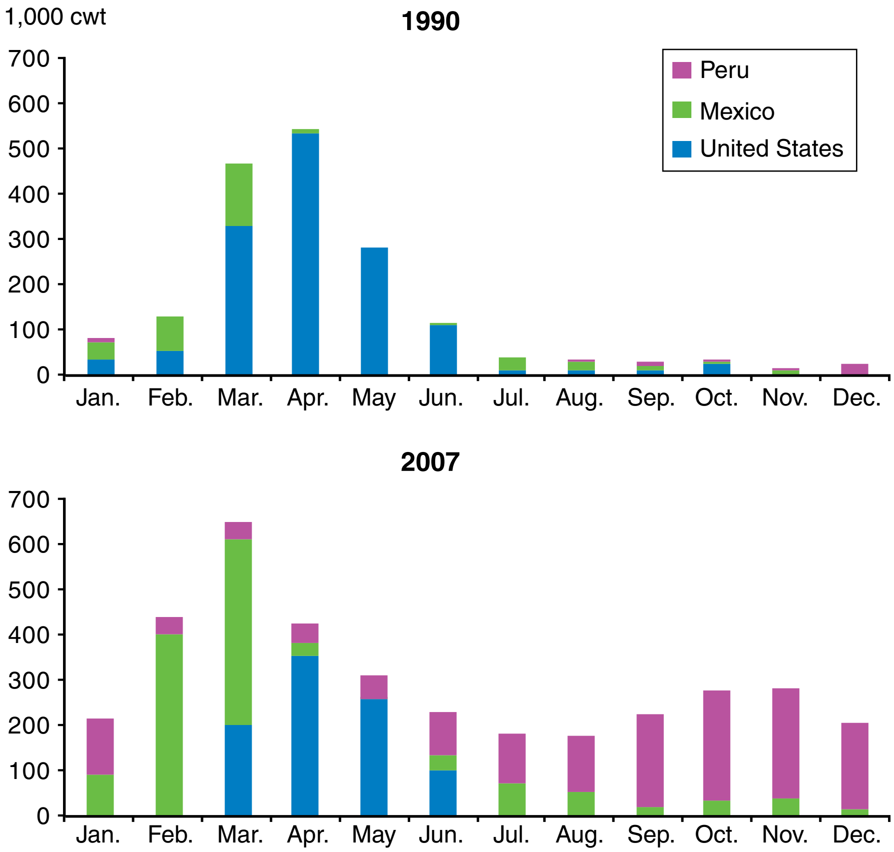
The Washington State asparagus season runs from early April through June, following the California season. The main Mexican asparagus season is over by the time the Washington State season begins, and imports from

16 New Jersey and other States produce smaller amounts of fresh asparagus.

17 Since asparagus is one of the earliest crops harvested each year in California's Central Valley, the industry generally has no trouble with labor supply at the beginning of the season.

Figure 7

U.S., Mexican, and Peruvian fresh asparagus shipments, 1990 and 2007



cwt = Hundredweight.

Source: USDA, Agricultural Marketing Service, *Fresh Fruit and Vegetable Shipments.*

Mexico are low. Shipments from Peru are low but could increase, since Peru is the only country that exports fresh asparagus year-round. Traditionally, Washington State growers could not rely on the early season price premiums received by the California industry; they instead depended on high yields and concentrated on canned spears. Canned asparagus consumption, however, has been declining as consumers switch to fresh asparagus which is now available year round. Washington State's asparagus harvest declined 59 percent between 1990-92 and 2005-07. Between 2003 and 2005, the three biggest canners (all multinational corporations) closed their Washington State operations and opened new plants in Peru, the main source of both canned and frozen asparagus. The now smaller Washington State industry has been forced into the fresh market. With lower production in the last few years, the price of fresh-market asparagus has risen during their season. Growers, as a result, must decide whether to increase acreage for a crop that has an uncertain future due to import competition and concerns about labor price and availability.[18] Washington State growers, like their California counterparts, face strong competition at the end of their season for labor from cherry growers. As a result, some fields are abandoned prematurely at the end of the season.

Michigan's asparagus industry traditionally has focused on canned and frozen asparagus, particularly the product known as cuts and tips, which requires less hand trimming than whole spears. Michigan asparagus production declined only 5 percent between 1990-92 and 2005-07. Many of Michigan's asparagus processing firms are small and locally owned, making them less likely to move to Peru than the large, multinational processors that used to operate in Washington State.

Harvesting

Asparagus is harvested by hand, and it is difficult to build a mechanical harvester that can compete with the speed and accuracy of harvest workers. Asparagus shoots mature over several months. When the weather is particularly warm, asparagus fields must be harvested on a daily basis, and workers must be careful not to damage the spears that will be harvested at a later date. Growers in Michigan use a labor aid—a self-propelled cart—to support workers as they hand harvest asparagus, reducing worker fatigue and labor needs. The machine was developed by a local farmer and is now manufactured by a local firm. Michigan asparagus is harvested as a short spear in flat fields. This labor aid has not caught on in California and Washington State, where asparagus is harvested as much taller spears and grown on ridges to accommodate furrow irrigation—characteristics that make the self-propelled cart difficult to use.

Asparagus is harvested in the field and then transported to the packinghouse. Asparagus packing is also a labor-intensive activity, but mechanical grading equipment is available. One California grower reported cutting his packinghouse labor force by about half after adopting a mechanical grader that grades and sorts asparagus spears by diameter, length, shape, and color (Chadwell, 2008). Growers uncertain about their economic future, however, may be reluctant to invest in mechanical sorters.

[18] Some Washington State fruit growers have expressed interest in producing early-season asparagus to offer workers an attractive extended work season as a means to ensure an adequate workforce later in the season for the fruit harvest (*Lewiston Morning Tribune*, 2008).

The University of California conducted research on developing a nonselective mechanical asparagus harvester in the 1950s. Later research efforts were mostly small-scale private endeavors, and many of them focused on developing a selective harvester.[19] In the 1960s and 1970s, there was still some interest in the development of a mechanical harvester for asparagus, but this interest declined in the 1980s (Clary et al., 2007). In the mid-1990s, the Washington Asparagus Commission used a grower check-off program to fund mechanization research, with no success. Since then, the commission has focused mostly on limited research on varieties and cultivation practices that would be necessary for the use of mechanical harvesters. Beginning in 2001, Washington State University (WSU) and Michigan State University received $1.74 million in Federal funding for mechanization research, as well as other types of research, for asparagus.

[19] See Lund (2009) for an account of a small-scale, private research effort to develop a mechanical asparagus harvester.

The Washington State Legislature also has invested in mechanizing the asparagus industry. Beginning in 2004, the legislature provided $1 million over a 3-year period to WSU to fund research on mechanical harvesters, but not on complementary research concerning new varieties or cultural practices. Since the university's researchers did not have a machine-design shop of their own, they used the money to fund private-sector work on prototype machines.[20] The researchers at WSU evaluated efforts around the world to develop a mechanical asparagus harvester and identified 10 promising machines, some of which had been in development for many years. After initial assessments of the efficiency of these machines, WSU provided some funding to four developers (all private firms—one from New Zealand and the others from the United States) and conducted field-performance tests. None of these machines worked as the evaluators desired.

[20] Due to the reduction of Federal funding for mechanization research during the 1980s, many university researchers lack machine-design shops.

In 2009, WSU researchers looked at a promising harvester that had not been in the evaluation program. This machine was produced by a small private firm in Washington State that has worked without any Federal or State support and only received some Washington Asparagus Commission funding in 2010 (Milkovich, 2010). The harvester represents the firm's 15th prototype since 1971. The machine has an electronic eye that identifies spears of the right size and selectively harvests just those spears. The estimated cost of this machine is about $250,000 and it would only be used during the short spring harvest season.

In 2004, the Washington State Legislature allocated $1.5 million to subsidize leases of packinghouse sorting machinery and another $500,000 for this purpose in 2006. After 5 years, the machinery would be declared surplus and packers could then buy it at a reduced price. Most packinghouses now use mechanized sorting machines, although all still use some hand labor. In 2007, the legislature authorized $840,000 for a similar program to subsidize the lease and eventual purchase of mechanical harvesters, but only a prototype was available at that time. Since an organization could not be found to oversee the program, it did not go into effect and the funds reverted to the State general fund.

U.S. producers will receive some economic relief from the import situation from the Asparagus Market Loss Program, part of the Food, Conservation, and Energy Act of 2008. A total sum of $15 million will be distributed to producers of fresh, processed, and frozen asparagus based on losses incurred from 2004 to 2007 due to increased imports. This financial support is welcome relief, but concerns remain as to whether the industry can be revived when the larger problem of depressed prices due to increased foreign competition remains. The Peruvian and Mexican asparagus industries have established themselves as forces in the world asparagus market. Similarly, at some stage, additional private and public investment in mechanization research may come too late to gain a positive return.

Asparagus Outlook

With less land now devoted to asparagus, the demand for labor in the U.S. asparagus industry has peaked. An increase in labor costs would put further pressure on a declining industry; more land would probably switch to other crops and imports would increase. The California asparagus industry, experiencing intense competition from Mexican imports, is in a more precarious situation than its Washington State counterpart, which faces less import competition due to its late season harvest. Can mechanization advance fast enough to provide economic relief to the remaining U.S. asparagus growers? At some point, it may be too late for growers to adopt mechanical harvesters, as they may be unwilling or unable to afford to take a chance on an expensive, new technology that *might* make their industry profitable again.

Lettuce

Most U.S. lettuce is grown in California during the spring to fall season and in both California and Arizona during the winter. USDA's National Agricultural Statistics Service reported that in 2007, 74 percent of lettuce was grown in California, 25 percent in Arizona, and less than 1 percent in Colorado and New Jersey. Small production in other States is not reported. Between 1990-92 and 2005-07, the lettuce crop increased 18 percent in volume (table 9). The types of lettuce produced in the United States have changed over time. Head lettuce (iceberg) production has been declining slowly (down 14 percent between 1990-92 and 2005-07), while production of leaf and romaine lettuces (including baby leaf lettuce) increased by 209 percent over the same period. Bagged salad technology enables many fragile leafy greens, such as baby leaf lettuce, to be shipped long distances, making them an important part of the U.S. lettuce industry. In 2007, head lettuce accounted for 60 percent of U.S. lettuce production, romaine 27 percent, and leaf 13 percent.

Since the United States produces lettuce year round, imports have never supplied a large share of U.S. lettuce consumption. In 2005-07, imports accounted for only 2 percent of U.S. lettuce consumption. In 2007, 75 percent of U.S. lettuce imports came from Mexico, and 24 percent (mostly hydroponic lettuce) came from Canada.[21] Changes in the U.S. lettuce market, however, are providing an additional incentive to import lettuce. Bagged salads are frequently sold under annual or multi-year contracts that specify weekly quantities to be delivered. Some large firms are growing lettuce in Mexico to enable them to fulfill bagged-salad contracts in the event that bad weather or some other issue restricts the availability of U.S. lettuce, particularly during the winter months when cold weather can adversely affect production in the

[21]U.S.-Mexican lettuce trade is small; the United States exported 63 million pounds of lettuce to Mexico in 2007 (only 8 percent of total exports but the second largest market after Canada) and Mexico exported 171 million pounds to the United States.

Table 9
U.S. lettuce industry statistics, 1990-92 to 2005-07

	Unit	Average 1990-92	Average 2005-07	Percent change
Total lettuce production	Million pounds	8,362	9,889	18
Head production	Million pounds	7,160	6,174	-14
Leaf/romaine production	Million pounds	1,203	3,715	209
Head per capita consumption	Pounds	27	20	-25
Leaf/romaine per capita consumption	Pounds	4	11	167
Head imports	Million pounds	20	128	547
Leaf/romaine imports	Million pounds	9	63	613
Head import percent of consumption	Percent	0	2	639
Leaf/romaine import percent of consumption	Percent	1	2	118
Head exports	Million pounds	457	389	-15
Leaf/romaine exports	Million pounds	159	467	193
Head export percent of production	Percent	6	6	-3
Leaf/romaine export percent of production	Percent	13	13	-5

Source: USDA, Economic Research Service, *Vegetables and Melons Situation and Outlook Yearbook*.

Yuma, Arizona, region. Most Mexican lettuce destined for the U.S. market is grown in central Mexico, where frost is less of a risk than in Yuma, but rain is more of a problem. Total production costs in Yuma and central Mexico are similar. While wages are lower in Mexico than in the United States, yields in Mexico are also lower. Central Mexico may enjoy a slight advantage over Yuma in freight costs when shipping to certain areas of the United States.

Harvesting

Harvest methods vary by how the lettuce will be used. Head, leaf, and romaine lettuce wrapped individually for final consumer sale are all hand harvested and field packed. Workers cut and trim the lettuce by hand. Typically the harvesters are working with a harvest platform—a large labor aid—that moves slowly through the field. The harvesters place the cut and trimmed lettuce on the harvest platform. Other workers, walking behind the platform, wrap and pack the lettuce in boxes that are stacked and palletized on another part of the platform. Using the harvest platform minimizes heavy lifting for the harvesters and cuts down on injuries and workman compensation costs.

One of the main challenges to harvesting lettuce mechanically for sale as individual heads is that the crop does not mature evenly, and growers want uniformity in head density and size. With a mechanical once-over harvest, about 25 percent of the lettuce would be immature and wasted. It is possible to produce lettuce that will mature more evenly, but cultural costs are higher. Growers and machinery manufacturing firms are experimenting with ways to mechanize the lettuce harvest. Hand harvesters can identify defective heads of lettuce and either not harvest them or remove the defects before packing them. If a machine harvester was not as discriminating, additional hand labor might be needed for sorting and quality control.

Lettuce, except for baby leaf lettuce, destined for bagged salads is also hand harvested but the process is different. Workers place the lettuce on a conveyor belt that empties into bins. The bins are transported to the processing plant, where the lettuce is washed, cut, and packed. These fields are often harvested only once since head size and shape are not as critical for this product as they are for lettuce sold to consumers as individual heads.

Baby leaf lettuce, which is almost always bagged, lends itself to mechanical harvest. Since all baby leaf lettuce plants are immature, they can be harvested in one pass through the field, and the variation in product size will be small. The first harvester was developed by a baby leaf lettuce grower. The mechanized harvest of baby leaf lettuce began in the late 1990s, and by 2008, an estimated 70-80 percent of the crop was harvested mechanically. Some smaller growers and short-season growers still rely on hand harvesting. Without mechanization, baby leaf lettuce production might not have expanded as quickly as it did. There is a range of machines appropriate for many different growing operations. One brand of harvester costs about $240,000, and the manufacturer estimates that the machine can cut 13,000-15,000 pounds an hour, equivalent to a harvest crew of 140. For a small operation, small push machines can be used that cost about $10,000 and cut 300 pounds an hour. Even with a mechanical harvester, some labor is still required to minimize debris uptake as the harvester moves across the field.

Large growers, shippers, and salad processors have been innovators in their industry, developing systems that cool lettuce in vacuum tubes, packaging fresh salads in bags, and transplanting seedlings to obtain 2-3 harvests per year from a single plot of land. Machinery manufacturing firms are developing harvesters for mature lettuce, but none have been widely adopted. The lettuce industry is concentrated in production; in 2007, 8 percent of the lettuce farms in the United States controlled 97 percent of total lettuce acreage (USDA, National Agricultural Statistics Service, 2009). This concentration means there are many large firms that can invest in new technologies. The bagged-salad processing industry is also highly concentrated because of the large capital requirements for processing plants. In 1997, five firms accounted for 88 percent of retail sales of bagged salads (Calvin et al., 2001), and concentration has increased since then.

Currently, there are no collective efforts by the industry to fund research on harvest mechanization. The California Leafy Greens Research Program—a California State marketing order that collects assessments from handlers—has funded research on machines to thin lettuce plants, plant breeding, pest management, and cultural practices.[22]

Labor Situation

California's central coast lettuce-growing season is 7 months long and relies on well-established, stable, and skilled work crews. In this area, the H-2A guest worker program is not used to obtain seasonal workers, both because farmworkers are available and because of the high cost of providing the free housing required by the program. The Yuma, Arizona, lettuce production region has a shorter growing season, just 4 months. Traditionally, most Yuma farmworkers were "green-card commuters"—Mexican citizens with U.S. immigrant visas who lived in Mexico and commuted daily to the Yuma fields. Green-card commuters are aging, however, and some of the younger workers joining the harvest crews are unauthorized, relying on false documents to get hired. With increased border security, unauthorized workers who successfully cross the border tend to seek employment further north where they may not be as vulnerable to detection. Some growers have turned to the H-2A program in Yuma to obtain authorized farmworkers. One large lettuce firm recruited 200 workers from Mexico for the 2008-09 harvest and housed them in two apartment complexes in Yuma that it had bought and refurbished (Neyoy, 2009).

Lettuce Outlook

The baby leaf lettuce harvest is largely mechanized. Private machinery manufacturing firms are working to develop prototypes for mechanical harvesters for the rest of the lettuce crop. The industry does not face substantial competition from imports, so it could pass on some costs to consumers if wages rose. A substantial increase in wages would likely spur increased mechanization, including a nonselective harvester for mature lettuce.

[22] Like the processed tomato industry, the lettuce industry was concerned about the labor situation when the Bracero Program ended. In the 1960s and 1970s, agricultural engineers from USDA's Agricultural Research Service and the University of California at Davis worked on a mechanical harvesting machine that would identify mature lettuce heads and selectively harvest them. This research ended, however, following a lawsuit over the mechanical processing tomato harvester. The California Lettuce Research Board (an earlier version of the California Leafy Greens Research Program) wanted to support this research, but the then governor of California would not allow it to do so. Most research efforts on harvest mechanization for lettuce now focus on a once-over harvest instead of a selective harvester. In contrast, the emphasis in asparagus harvest research has gone in the opposite direction.

Download the charts in this report.

Conclusions

The authors of this report reviewed labor use in the U.S. produce industry and assessed how producers of specific commodities would fare if labor rates increased. The case studies of selected fruit and vegetable commodities, none of which are completely mechanized, show that the U.S. produce industry's ability to respond to rising labor costs varies across commodities and across growers within each commodity.

Changes in labor rates have an immediate impact on growers since labor costs account for a high share of total production costs for most fruit and vegetables. Moreover, whenever profitability is reduced by other factors, such as decreased consumer demand, increased competition in trade, or new diseases, the incentives to reduce labor costs increase. Even if a grower cannot reduce labor costs, other changes can compensate and keep total costs of production steady. For example, increasing yields may reduce costs per unit of output. Of the case studies, yields increased for apples, strawberries, asparagus, and lettuce (table 10).

If wages increase, growers have various options they can employ to manage labor costs. Growers can use less labor, although this frequently involves settling for a lower yield. In the case of apples, growers may only make one harvesting pass through an orchard instead of making several passes to select apples at peak maturity. Asparagus growers may stop harvesting a field before the end of the season if the labor cost is too high relative to the price of asparagus. Growers can use labor more efficiently by adopting labor aids. Some apple and strawberry growers have recently adopted labor aids, such as platforms and conveyor belts.

Growers can mechanize the harvest if there is an economical alternative to hand labor. Some growers of raisin grapes, processing oranges, and baby lettuce have mechanized their harvests. Developing a viable mechanized harvest system usually depends on breakthroughs in three areas: machinery, varieties, and cultural practices. Results from all three lines of research may not emerge at the same time. For example, the DOV harvest system for raisin grapes was not successful until an earlier-maturing grape variety was developed. The adoption path, however, can be unpredictable. In the case of processing oranges, mechanization appears to have stalled while growers wait for the development of a complete mechanization *system* and not just the mechanical *harvester*. Specifically, the Florida processing-orange industry hopes to obtain regulatory approval of an abscission compound that would enable mechanical harvesters to be used on the entire processing-orange crop, not just the early season oranges. Raisin mechanization was at 45 percent of production in 2007, but adoption may have slowed because current economic conditions (higher raisin prices) have made mechanization less urgent. With a viable mechanical alternative available, individual growers will adopt as their economic conditions dictate. Most large or extended-season producers of baby lettuce already use mechanical harvesters, but other lettuces do not yet have economical mechanical harvesters. The apple, fresh-market orange, strawberry, and asparagus industries do not yet have mechanical harvesters either.

Table 10
Economic conditions for case study commodities

		Oranges					
	Apples	Fresh-market	Processing	Raisins	Strawberries	Asparagus	Lettuce
				Million dollars			
Average value 2005-07[1]							
Fresh	1,932	660	NA	NA	1,416	91	2,080
Processed	229	NA	1,539	355	140	16	NA
				Percent			
Import share of consumption							
Fresh produce	8	7	NA	NA	8	76	2
Processed produce	81	NA	30	12	32	60	NA
Export share of fresh production	24	29	14	41	12	19	9
Change in production from 1990-92 to 2005-07							
Fresh	20[2]	-4	NA	NA	81	-28	18
Processed	NA[3]	NA	1[4]	-4	NA[3]	-71	NA
Change in consumption from 1990-92 to 2005-07							
Fresh	-11	-21	NA	NA	75	91	1
Processed	32	NA	-12	-15	41	-36	NA
Change in yield from 1990-92 to 2005-07	19	-7	-7	-1	63	12	7
Mechanization	No	No	Partial	Partial	No	No	Partial[5]
Current industry support for mechanization R&D	Yes	Yes	No	No	Yes	Yes	No

NA=Not applicable.
[1]Farmgate value for all but citrus; equivalent packinghouse-door returns for citrus.
[2]Production declined 7 percent from the average of the 1998-2000 harvests.
[3]Production is used in both the fresh and processed market but all production is shown as fresh.
[4]Production declined 35 percent since the 1997-98 season.
[5]Only baby leaf lettuce is mechanized.
Source: USDA, Economic Research Service calculations based on *Fruit and Tree Nuts Yearbook and Vegetables and Melons Yearbook*.

Growers do not automatically adopt a complete mechanized harvest system as soon as it becomes available. Many factors influence the individual adoption decision. Growers may be reluctant to adopt mechanical harvesters if they have any economic alternative; the quality of mechanically harvested commodities is usually lower and mechanical harvesters may damage plants, particularly perennials, such as orange trees. In addition, the long-term economic viability of some new harvest systems is often a concern, and there is the risk that early adopters will invest in the wrong technology. Some mechanical harvesters, such as processing orange harvesters, are very expensive, and economic incentives tend to favor adoption by larger growers who can spread the cost over a larger volume of product, potentially impacting the structure of an industry. For smaller growers, hiring someone else to harvest a crop is an alternative to buying the machinery outright, but there are often concerns about the timeliness of harvest when someone else owns the machine. Mechanical harvesters for some crops, like baby leaf lettuce, come in a variety of sizes appropriate for all types of growers.

If total production costs increase with labor rates, farmers will generally produce less and prices will increase. Growers may switch to more profitable crops or sell their farmland. In some cases, U.S. consumption needs might be supplied by imports instead of domestic production. International competition for a commodity affects the ability of growers to respond to higher production costs. Even if wages do not increase in the United States, imports can often put economic pressure on U.S. growers to reduce labor costs. Among the case studies, the strawberry industry has the lowest short-run vulnerability to increased labor costs, as U.S. growers face little competition from imports and domestic per capita consumption is growing (see table 10). If strawberry labor costs rose, growers would likely be able to pass along some of the higher costs to consumers. Although there are no immediate prospects for the mechanization of strawberry harvesting, some in the industry have adopted a labor aid that has reduced the demand for labor in some regions. By contrast, the U.S. asparagus industry has perhaps the greatest short-run vulnerability to an increase in labor costs. U.S. growers face strong competition from imports from countries with substantially lower labor costs, and domestic acreage has declined. A prototype mechanical harvester is currently being tested that may reduce some pressure; at best, it will be a race for the U.S. asparagus industry to find an economical mechanical harvest system before the U.S. industry declines further. Several commodities sold as both fresh and processed products, like Washington State apples and California strawberries, have experienced import competition in just the processing market, but this also puts additional economic pressure on growers.

R&D is critical to the development of new labor aids and mechanical harvesters. Individual growers, grower organizations, researchers in private machinery manufacturing firms (ranging from one person to many), universities, and the Government have all invested in these new technologies. Private investment in R&D implies that private benefits exceed private costs. The Government may invest in R&D if private investment does not yield a socially optimal level of research.

For processing oranges and raisin grapes, developing a mechanical harvester involved a range of private and public investment. The mechanical harvester for baby lettuce was developed entirely by private initiatives. The lettuce industry is the largest, in terms of value, among the case studies and includes many large producers capable of funding private research. Several mechanization firms are currently experimenting with new protoypes. The asparagus harvester prototype, now in testing, was also developed by a private initiative. In terms of value, asparagus is the smallest industry of the case study commodities. The lettuce and asparagus examples demonstrate that the size of the industry (and potential market) alone does not determine investment in mechanization.

Private interest in mechanization research has varied over time. Industry interest in labor-saving research tends to rise and fall with the supply, or anticipated supply, of labor. Unfortunately, the pace of mechanization is unpredictable. The harvest of some commodities was mechanized much sooner than many observers had expected, while other industries still are not mechanized despite predictions that they would be. As the case of asparagus demonstrates, a mechanical harvester may not be available in time for the industry to compete successfully against imports from countries with much lower labor costs.

Grower organizations fund research with assessments on grower output, but their willingness to do so depends on the industry's economic condition. Growers who are doubtful about their long-term economic prospects, perhaps due to import competition, may be less willing to support mechanization research when benefits are likely to accrue only in the long term. Events, such as freezes or diseases, can reduce an industry's ability to invest in long-term research initiatives. Grower organizations for apples, fresh-market oranges, strawberries, and asparagus are currently funding mechanization R&D; grower organizations for raisins, lettuce, and Florida's processing oranges are not currently funding harvest mechanization research but have in the past. For raisin growers, a viable mechanical harvester is already on the market and the grower organization funds complementary research, such as developing optimal trellis design. For lettuce, private machinery manufacturing firms are actively working on harvester prototypes and the grower organization funds other types of research. For Florida oranges, a commercial harvester is available and grower organization funds now support work on the abscission compound.

Federal Government funding for mechanization R&D has also varied over time. For most of the past three decades, USDA has provided no direct funding for research to mechanize fruit and vegetable production. In 2008, USDA resumed such funding, which can sustain the basic research for the innovations that eventually lead to mechanization. This funding requires 100 percent non-Federal matching funds. The first round of awards funded projects involving apple and orange harvest mechanization research. Other related Federal funding has contributed to the success of mechanization. For example, USDA's Agricultural Research Service contributed to the success of raisin mechanization by developing new varieties of grapes.

Adapting to higher labor costs is a complex issue. Labor is only one component of firm profitability, and growers have various strategies for responding to higher labor costs. These case studies demonstrate that fruit and vegetable commodities would not all respond in the same way nor would all growers within a commodity.

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