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Received 22 May 2015
Revised 28 August 2015
31 August 2015
Accepted 1 September 2015

Adoption of labor-enhancing technologies by specialty crop producers

The case of the Washington apple industry

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Abstract

Purpose – The purpose of this paper is twofold, first: to define the profile of adopters of labor-enhancing technologies (e.g. platforms) identifying factors – such as operations size, mix of fruits grown, apple operation location, principal operators socio-demographics – and second: to estimate the efficiency threshold for platform adoption during apple harvesting to be financially feasible considering future increases in farm labor wages.

Design/methodology/approach – The authors conducted a mixed-mode survey in January-February 2010. Data were analyzed using a bivariate probit model, considering that the decision to adopt platforms was related with the orchard planting system. The authors conducted simulation scenarios to estimate the efficiencies – harvest – platforms must achieve in order to be economically feasible.

Findings – In total, 11 percent of the 316 apple operations covered by the survey used platforms. Orchard operations most likely to invest in planar structures are relatively large, produce high-value varieties, use organic systems, and have relatively young and educated operators. Similarly, operations producing high-value fruit such as "Honeycrisp" and controlled or patented varieties and relatively large operations are more likely to invest in platforms. The results of the comparison of the cost of harvesting apples using platforms vs ladders under several production assumptions indicate that platforms must increase labor productivity by at least 13 percent in order to be adopted by the industry.

Research limitations/implications – This study caveat is the lack of inclusion of production and marketing uncertainties in the estimation of future apple harvest costs. Further research to deeper analyze these issues is needed.

Practical implications – The authors present information on the profile of mechanization adopters, so extension educators and engineers could concentrate efforts on them to increase adoption levels. In addition the authors provide a threshold of efficiencies for harvest platforms associated with cost savings compared to manual harvest.

Social implications – Enabling the adoption of mechanization technologies by specialty crop industries would decrease the dependence on labor, decreasing labor uncertainties and facilitating the production of high quality produce to satisfy the needs of consumers. Second, it will end an era of importing poverty, given that the specialty crop industry has long benefited from seasonal migrant workers. It will improve rural American communities to shorten pools of farm workers, giving them access to permanent jobs with higher salaries.

This project has been funded by the Washington Tree Fruit Research Commission – Technology Review and the Washington State University School of Economic Sciences IMPACT Center. Sincere gratitude to Dr Mykel Taylor who led the design and implementation of the survey and Dr Jared Woolstenhulme who conducted preliminary analysis of the survey data.

Agricultural Finance Review
Vol. 75 No. 4, 2015
pp. 514-532
© Emerald Group Publishing Limited
0002-1466
DOI 10.1108/AFR-05-2015-0022

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Originality/value – The contribution of this study is to improve understanding of the degree of mechanization, financial feasibility of current existing technologies, and barriers to greater mechanization by the Washington apple industry. Given the similar labor challenges faced, in general, by the US specialty crop agriculture, results could be applicable to the entire industry.

Keywords Technologies, Agriculture, Apples, Labour-enhancing, Labour-intensive, Specialty crops

Paper type Research paper

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Introduction

The persistent intensive use of labor in specialty crop production in the USA is in large part due to the continued abundant supply of labor from Mexico and other Latin American countries throughout the twentieth century. A technology optimist would thus seem to have relatively little concern over the "end of farm labor abundance" (Taylor *et al.*, 2012) by concluding that higher labor costs will induce innovation in mechanical aids to harvesting. However, the lack of adoption of labor saving technologies gives pause as to whether the technological challenges are large enough to consider the possibility that a more common adaptation strategy to high labor costs will be switching toward less labor-intensive crops where a greater share of domestic demand is met by importing food from countries with lower labor costs. Even if technologies adapt rapidly allowing for widespread mechanization there will likely be numerous effects on farm structure in these commodities such as increased farm size and geographic transitions to different terrain. What has been observed is that there are significant differences in the production systems across labor-intensive crops that will impact the ability to mechanize, as opposed to switching crops (United States Department of Agriculture Economic Research Service, 2010).

The US agricultural specialty crop industry has long depended on migrant labor (Martin, 2009). For example, the 1870s Chinese and the 1900s Japanese immigration to California, the 1920s Mexican immigration to Southwestern states, the World War I Bracero Program targeting Mexican farm workers, the 1930s Dust Bowl migration from Oklahoma and Arkansas to Western States and the World War II Mexican Bracero Program. Since these programs ended in 1963, farm labor supply has been supplemented by undocumented labor pools (Martin, 2009). In fact, Mexico accounts for 75 percent of hired farm workers in the USA (United States Department of Agriculture Economic Research Service, 2010).

However, the supply of migrant labor is unpredictable. Given the US economic recession in 2008, fewer migrant workers have been available to harvest fruit and vegetable crops, and increased spending on border enforcement has raised the cost of migration for potential workers (Taylor *et al.*, 2012). Indeed, the number of unauthorized Mexican immigrants estimated to be living in the USA has decreased 12.9 percent since its peak of 12.2 million in 2007 (Passel *et al.*, 2012). In addition, Latin America's economic growth and productivity in both farm and nonfarm sectors have generally been accelerating relative to such growth in the USA. In Mexico, fertility rates began to drop around 1980 in response to numerous cultural and economic factors and that demographic shift is now showing up in the working-age population. Finally, as the agricultural labor force ages and older workers exit, the US farm labor supply is likely to tighten further (Zahniser *et al.*, 2012). Even as the supply of farm labor appears to be shrinking, demand for it has remained relatively constant at an annual average of one million workers since 2007. So far, there has not been a widespread shortage (Zahniser *et al.*, 2012; Hertz and Zahniser, 2013).

This paper presents the case of the Washington apple industry and seeks to improve understanding of the degree of mechanization, financial feasibility of current

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existing technologies, and barriers to greater mechanization. Washington State produces the largest volume of apples in the USA with 2.98 million tons (57 percent of total US total production) valued at $2.1 billion (US Department of Agriculture, National Agricultural Statistics Service, 2014). During 2010/2011, Washington's apple industry contributed an estimated $7.02 billion dollars in direct, indirect, and induced economic activity to the state's economy, including 59,650 jobs and total annual employee compensation of $1.95 billion (Globalwise Inc., 2012).

Labor-related challenges faced by the Washington apple industry refer to the orchard tasks, especially harvest, that are time-sensitive and require a sufficient number of workers with orchard-handling skills. Hired labor is the most significant variable cost in apple production. For 2006 through 2010, hired labor represented 17 percent of the total average variable cost of production for agricultural crops and a much larger proportion for fruit (48 percent) and vegetable (35 percent) production (Zahniser *et al.*, 2012). A cost-of-production study (Gallardo *et al.*, 2010) of "Gala" apples revealed that labor represented 46 percent of the variable production cost for a full production year.

Given these conditions, the specialty crop agricultural industry could benefit from technologies to enhance the efficiency of agriculture labor (hereafter labor-enhancing technologies), especially those targeting activities such as harvest where a critical mass of workers is needed. We hypothesize that the return on the investment on labor-enhancing technologies is likely to increase as farmworker wages increase over the near term. In this context, higher wages and uncertain farm labor pools augment the motivation to reduce production costs and dependency on labor. Moreover, these technologies could bring additional benefits such as improved working conditions and higher wages for the remaining workers.

There are a wide variety of labor-enhancing technologies on the market and under development. We focus on the use of platforms in apple operations because they are one of the better-developed technologies, leading one to believe that there is a higher likelihood that producers would have adopted them. In addition, platforms have the potential to replace ladders, which are under scrutiny as it is believed ladders cause ergonomic injuries among orchard workers and deter productivity (Elkins *et al.*, 2011; Fathallah, 2010). This is not to say that new labor-enhancing technologies will be out of reach of the Occupational Safety and Health Administration guidelines. Numerous ergonomics and safety assessment studies are being conducted and prove that workers harvesting apples in platforms had less impact on their shoulders and back and lower exertion compared to workers in ladders. Platforms eliminate ladder-related risks such as climbing up and down the ladder with heavy bags and falling down the ladder. In addition, new methods to avoid risks due to repetitive arm motion are being developed and validated (Pacific Northwest Agricultural Safety and Health Center, 2014).

Moreover, previous studies have demonstrated that labor savings from using platforms augment when working at high-density orchards where trees grow on dwarf rootstocks and have flat narrow canopies[1] (hereafter planar structures) (Elkins *et al.*, 2011). Orchards with planar structured trees are increasing in its share of acreage (Washington State Department of Agriculture, 2011).

The objective of this paper is twofold. First, we assess the use of platforms in the Washington apples industry using a survey conducted in January-February 2010 to identify factors (e.g. operations size, mix of fruits grown, apple operation location, socio-demographics of principal operators, among others) affecting the likelihood of adoption[2]. This will enable characterizing the profile of mechanization adopters, so extension educators and engineers could concentrate efforts on them to increase adoption levels. Second, we estimate the efficiency threshold for platform adoption during apple harvesting to be financially feasible considering future increases in wage levels. That we focus the analysis on apple harvesting does not imply that we neglect labor savings by using labor-enhancing technologies in other apple activities, such as pruning and training, or that we neglect increases in returns for improved fruit quality in the packing line. We chose to focus on harvest because it is the activity that requires critical amounts of labor. In 2013, apple harvesting involved a total of 82,436 jobs representing 36 percent of all seasonal apple jobs for that year. The amount of labor needed in apple harvesting surpassed the labor needs in pruning by 112 percent and in thinning by 50 percent (Washington State Employment Security Department, 2013).

Literature review

Agriculture has commonly been the venue for testing various models of labor-enhancing technology adoption in the general economics literature. For example, Schmitz and Seckler (1970) in their review of the effects of mechanical harvesting for tomatoes on producers' labor requirements found that gross social returns to research and development were approximately 1,000 percent. Cuskaden (1973) concluded that selecting highly productive pickers and implementing management practices associated with faster picking would help alleviate the difficulties in recruiting harvest labor. Holt (1982) emphasized the need for anticipating the potential impacts of increased labor costs for labor-intensive crops and underscored the importance of continued research and development on mechanization and mechanical aids. Importantly, ways in which actual adoption deviate from the standard textbook model resulted to be common and significant. This motivates surveying of actual technology adoption rates as opposed to just assuming that adoption will occur when the return on investment exceeds a threshold.

Several studies have examined the effect of mechanical harvesting on net returns. Searcy *et al.* (2012) estimated that if Florida growers of oranges for the processing market increased the proportion of oranges harvested using a mechanical device from 5 to 95 percent, they would have increased their net returns by 17 percent. Iwai *et al.* (2009a) estimated that the difference in net present value (NPV) of Florida oranges that were mechanically and manually harvested was 0.36 percent. This small difference could explain why only 7.5 percent of all Florida's orange acres in 2006/2007 were mechanically harvested (Iwai *et al.*, 2009a). Iwai *et al.* (2009b) found that mechanical harvesters would be widely adopted by the Florida citrus industry when the free cash flow growth rate (when using mechanical harvesters) reached 4.05 percent. Blanco and Roka (2009) found that use of an abscission agent (CMNP 5-chloro-3-methyl-4-nitro-1H-pyrazole), which can enhance the efficiency of current mechanical harvesting equipment, resulted in the need for a minimum of 15,000 acres and a reduction in the harvesting cost of at least ten cents per box. Klonsky *et al.* (2012), in a study of California-grown olives, found that the net return per acre for mechanical harvesting at 80 percent efficiency was 19 percent higher than net returns per acre when manually harvesting. In an assessment of Washington sweet cherries, Seavert and Whiting (2011) estimated an increase of the NPV of 57 percent when using the mechanical harvester compared to manual harvesting, this led to a break-even price reduction of $0.17 per pound when using mechanical harvesting. In a study of platform use in apple orchards in Pennsylvania and Washington, Baugher *et al.* (2009) found that powered

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platforms could improve worker productivity by 20 to 65 percent compared to ladders, with the greatest gains in harvest and trellis string operations. Elkins *et al.* (2011) examined platform harvesting of mature Bartlett pear orchards in California and found that productivity for a 100 percent male crew paid at a per-piece rate over five days and two nights was 75 percent greater than productivity for the same crew using ladders (5.9 vs 3.4 bins per worker per day).

In terms of the effect of mechanical harvesting on yields, Moseley *et al.* (2012) found no statistically significant differences per acre and no cumulative effect on yield differences for mechanically and manually harvested Florida-grown oranges. On investigating the size of agricultural firms better positioned to adopt mechanical harvesters, Wright *et al.* (2006) estimated that to adopt an overhead mechanical harvester Polish tart cherry producers would have to have between 23 and 53 acres, while growers in Michigan would need yields of at least 9,654 pounds per acre.

Our review of the literature shows that mechanical harvesting systems have proven to be profitable in the long run relative to hand harvesting under realistic assumptions of efficiencies and economies of scale. However, the apparent low rates of adoption across the industries in the literature reviewed merit deeper investigation. A series of reasons could potentially explain this low rate of adoption. First, some producers are not financially capable of mechanizing. There are trade-offs between annual labor savings and the upfront investment required for new machines and new orchard plantings that can be harvested by machines. Second, the remaining uncertainty associated with the technology itself. This includes doubts on the potential labor savings, increased tree and fruit damage, and operating costs. Third, the costs associated with the managers and workers learning curve on how to adapt their management and working routines to the harvesters. Fourth, the uncertainty over possible wage increases which would affect the return on investment in a harvester. The present study attempts to prove if the reasons above explained apply to the Washington apple industry. More specifically, we seek to define the profile of the apple operation more likely to adopt platforms, a labor saving technology. In addition, we analyze the efficiencies mechanical harvesters must achieve in order to make economic sense for a "typical" apple orchard.

Methodology

Data collection

A mixed-mode survey was implemented using a tailored design method consisting of a pre-notification letter, a paper questionnaire, a reminder, and a replacement questionnaire (Salant and Dillman, 1994). The survey was implemented in January and February of 2010. We obtained a randomized list of mailing addresses for 750 apple growers from the Washington Apple Commission[3]. Of those 750 growers, 316 returned fully or partially completed surveys, yielding a response rate of 45.3 percent.

The questions in the survey fell into four categories. First, questions on apple orchard characteristics including its regional location and size in acres; the number and type of apple cultivars grown; the average age of bearing trees; whether they planted organic apples; the number of privately owned cultivars planted; types of orchard tree structures used; the amount of unobstructed space available for driving between rows; and the percentage of orchard acres that were leased. Second, questions related to platform adoption and performance, asked for the number of years platforms had been used; the number of platforms used; their type, make, and model; the frequency of mechanical breakdowns, the number of people assigned to work on a platform,

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activities in which platforms were used, forms of payment provided to workers using them (piece rate, hourly wage), benefits associated with the use of platforms and the importance of those benefits, and disadvantages associated with using platforms. The survey also explored growers' reasons for not using platforms and their plans for using them in the next 12 months. Third, questions on the importance of various sources of information (e.g. other growers, family members, Washington State University (WSU) extension and research) when making decisions about purchasing machinery. Fourth, questions asking about demographic information for the principal operator (including age, gender, race, amount of education, and years of experience in apple cropping). A copy of the survey used is available from the authors upon request.

To complement results from the survey, we included a partial budget analysis along with simulation scenarios to estimate the efficiencies platforms must achieve in order to be economically feasible. This case study benefits from data obtained from an apple operation in eastern Washington and a local platform manufacturer. Other apple growers who have invested in similar platforms validated the data.

Analysis of survey data

We examine a qualitative response using a discrete choice model: the probability that a grower uses a platform to perform orchard tasks. A grower's decision to use platforms is interrelated with the structure of the trees; there must be some type of planar fruiting wall system, with narrow canopies, that is conducive to platform use (Elkins *et al.*, 2011). These two variables – the likelihood of using a planar structure and of using platforms – are discrete so we use a bivariate probit model. We model the two probability density functions simultaneously, and error disturbances are correlated following Greene (2008):

$$y_1^* = \beta_1 x_1{}' + \varepsilon_1 \quad y_1 = 1 \text{ if } y_1^* > 0,\ 0 \text{ otherwise}$$

$$y_2^* = \beta_2 x_2{}' + \varepsilon_2 \quad y_2 = 1 \text{ if } y_2^* > 0,\ 0 \text{ otherwise}$$

$$E[\varepsilon_1 | x_1, x_2] = E[\varepsilon_2 | x_1, x_2] = 0 \tag{1}$$

$$\text{Var}[\varepsilon_1 | x_1, x_2] = \text{Var}[\varepsilon_2 | x_1, x_2] = 1$$

$$\text{Cov}[\varepsilon_1, \varepsilon_2 | x_1, x_2] = \rho$$

where y_1^* is the probability that a grower uses any type of fruiting wall system (hereafter referred to as a planar system), y_2^* is the probability that a grower uses platforms, $x_1{}'$ and $x_2{}'$ are vectors of independent variables to explain the probability under discussion, ε_1 and ε_2 are error terms that follow a standard normal distribution and have a covariance ρ. Parameter estimates are obtained via maximum likelihood using Proc Qlim in SAS®.

The set of independent variables includes a vector of binary variables that describe geographic orchard locations. There are three distinct tree fruit production areas in Washington. The Wenatchee area includes Okanogan, Chelan, and Douglas County; the Yakima area includes Kittitas, Yakima, and Benton County; and the Columbia Basin includes Grant, Adams, and Franklin County (Washington State Department of Agriculture, 2011). The Yakima area is the reference category. Also included is a vector of binary variables that indicate which apple cultivars are grown in the operation.

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Information on the planar structure combined with FOB prices motivated to identify four groups, each with different effects on the marginal product of platforms. The groups are: first, "Red Delicious" and "Golden Delicious," which typically come from a standard or semi-dwarf rootstock and have the lowest FOB origin prices ($17.84-$19.59 per 40-pound box); second, "Gala" and "Fuji," which are grown with dwarf and semi-dwarf rootstocks and have higher prices ($22.53–$22.74 per 40-pound box); third, "Honeycrisp," which comes from mostly dwarf and semi-dwarf rootstocks and earns the highest prices ($50.40 per 40-pound box); and fourth, other cultivars such as "Granny Smith" and "Cripps Pink." In the model, the "other cultivars" category is omitted to avoid perfect multicollinearity (rootstock information was obtained from Washington Growers Clearing House Association, 2013; price information was obtained from the Washington State Department of Agriculture, 2011).

Additional variables include the size of the operation in acres, a binary variable to indicate whether patented cultivars[4] and organic apples are grown, use of leased land and demographic characteristics of the principal operator (the person with authority to make capital investment and orchard design decisions): age, white ethnicity, and attainment of a bachelor's degree or greater education. Patented and organic apples are associated with the financial position of the agricultural operations, given that these apples sell at premium prices. Leased land is associated with uncertainties related with the scale of the apple operation.

Results

Description of survey data

Overall, orchard operations observed in the survey averaged 93 acres. Small farms are over represented in our sample since the average for all agricultural operations in Washington is 394 acres (US Department of Agriculture, National Agricultural Statistics Service, 2012). Of the 316 respondents, only 35 respondents (11 percent) used platforms. In total, 89 percent were male, 85 percent reported white as their ethnicity, and the average age was 53 years. Men were over represented in our sample (63 percent of Washington's principal agricultural operators are men), and white ethnicity was underrepresented (90 percent of the state's principal operators are white). Our average respondent was four years younger than the state average age of 57 (US Department of Agriculture, National Agricultural Statistics Service, 2012). In terms of employment, 73 percent of the respondents had no paid job other than the orchard (compared to 39 percent for all operators in the state) (US Department of Agriculture, National Agricultural Statistics Service, 2012). For 65 percent, agriculture was also their parents' occupation; and 44 percent had at least a bachelor's degree.

Table I presents summary statistics for the orchards represented in the survey by use of platform. In general, principal operators of businesses that used platforms were four years younger and had one more year of experience in apple production than operators of orchards that did not use platforms.

In terms of orchard structure, 26 percent of the operations that used platforms had both tall spindle-shaped and traditional rounded central-leader tree systems, 23 percent used all three of the systems available (angled v-trellis, tall spindled, and rounded), and 14 percent had strictly rounded tree systems. Thus, 86 percent (30 of 35) had acreage with some form of planar structure in use. Five to six feet of unobstructed space was available in the drive row for 44 percent of the operations using platforms while 24 percent had more than six feet available. This suggests that the orchard's structure is

Variable	Use platforms ($n=35$)	No use platforms ($n=281$)	Washington State 2012 Census of Agriculture[a]
		Average (SD)	
Orchard size (acres)	221.8 (285.6)	77.5 (138.5)[b]	54.4
Years in apple production as principal operator	30.4 (23.0)	29.2 (115.4)	20.9
Age of principal operator	54.6 (13.2)	58.7 (11.4)	58.8
Platform use by type of orchard structure	*Number of farms*		
Strictly planar angled "V" or "A" shaped ($n=14$)	3	11	
Strictly planar tall spindle ($n=19$)	3	16	
Strictly round ($n=138$)	5	133	
Strictly other ($n=37$)	1	36	
Both angled and tall spindle ($n=7$)	3	4	
Both angled and round ($n=11$)	3	8	
Both tall spindle and round ($n=33$)	9	24	
Both tall spindle and other ($n=1$)	0	1	
Both round and other ($n=2$)	0	2	
Angled, tall spindle and round ($n=19$)	8	11	
Angled, round, and other ($n=1$)	0	1	
Angled, tall spindle, round, and other ($n=1$)	0	1	
Missing responses ($n=33$)	0	33	
Unobstructed space available within the drive row			
Less than 5 feet	8	34	
5-6 feet	15	79	
Greater than 5 feet	11	146	
Information sources			
Other growers	33	239	
Field days/farm tours	31	192	
Tree fruit-related conferences	30	213	
WSU extension/research	28	194	
Industry publications	28	214	
Company selling machinery/equipment	26	188	
Non-WSU extension/research	25	173	
Internet-based resources	24	163	
Family members	20	149	

Notes: [a]The 2012 Census of Agriculture information on orchard size applies to Washington apple orchards, the information on years in apple production as a principal operator, and age of principal operator applies to all Washington State agricultural firms; [b]the numbers in between parenthesis are standard deviations

Source: US Department of Agriculture, National Agricultural Statistics Service, 2012 Census of Agriculture State Data

Table I. Characteristics of apple operations by platform use

decisive when operators consider adopting platforms; a planar structure (angled or tall spindled) with five to six feet between rows is most conducive to the use of platforms.

Regardless of whether they used platforms, respondents obtained information primarily from other growers, followed in descending order by tree fruit conferences, industry publications, field day/farm tours, WSU extension and research, companies selling machinery, non-WSU research and extension, internet-based resources, and family members.

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Table II presents summary statistics for the operations that used platforms. In general, those operations had been using platforms for seven years, had one platform in the orchard, and employed three people to work on the platform. Most used the platforms for pruning (89 percent), followed by training (66 percent), thinning of green fruit (60 percent), trellis construction (43 percent), and pheromone placement (29 percent). On average, 78 percent paid hourly wages for all of the activities. Only one company used platforms for harvesting and paid workers via a piece rate. The type of platform most often used was not self-propelled (46 percent), followed by diesel-engine self-propelled (29 percent). Operators used platforms because they increased worker productivity (91 percent), improved worker safety (89 percent), improved the quality of work (83 percent), were a recoverable purchase cost (80 percent), and because they were easy for workers to operate (80 percent). Most

General information	Average	Range
Years of use	7.4	0-50
Number of platforms in orchard	1.3	1-4
Number of people in platform	3.4	1-10
Activities where platforms are used	*Number of farms (n = 35)*	
Pruning	31	
Training	23	
Green fruit thinning	21	
Trellis construction	15	
Pheromone placement	10	
Blossom thinning	4	
Harvest	1	
Pest/disease scouting	0	
Type of platform	*Number of farms (n = 35)*	
No self-propelled (pull-behind)	16	
Diesel engine, self-propelled	10	
Other type	8	
Gas engine, self-propelled	3	
Electric, self-propelled	0	
Reasons for using platforms	*Number of farms (n = 35)*	
Increase in worker productivity	32	
Improve worker safety	31	
Improvement in quality of work	29	
Purchase cost is recoverable	28	
Easy for workers to operate	28	
Reasons for not using platforms	*Number of farms (n = 281)*	
Orchard system/architecture not suitable	184	
Purchase cost is high	150	
Steep slopes in orchard	112	
Maintenance and repair costs are high	100	
No improvement in worker productivity	95	
Limited availability at implement dealers	76	
Planning to use platforms in 12 months	*Number of farms (n = 316)*	
Yes	9	
No	307	

Table II. Average and frequencies of different characteristics for apple operations using platforms

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respondents (86 percent) agreed that the ability to employ older workers, female workers, and workers who could not perform the same task on a ladder because of some type of limitation was not a reason to use platforms. This results is in line with Elkins *et al.* (2011), which compared picking productivity for two crews, one a female crew working on platforms in which the average age was 43 and pickers were paid by the hour and the other a male crew, also working on platforms, in which the average age was 27 and pickers were paid by piece rate; the older female crew's productivity was, on average, 78 percent less than that of the younger male crew.

Among survey respondents, reasons given for not using platforms were, first, that their orchards' systems/architectures were not suitable, followed by the high cost of purchasing platforms (53 percent), steep slopes in the orchards (40 percent), high maintenance and repair costs (36 percent), a lack of improvement in worker productivity (34 percent), and the platforms' limited availability at implement dealers (27 percent). These results are somewhat similar to those of Elkins *et al.* (2011), which concluded that capital and maintenance costs, orchard renovation expenses, fruit-sorting challenges, and lack of an imminent severe labor shortage were the major barriers to widespread adoption of platforms for harvesting California pear orchards.

Interestingly, 91 percent of the respondents indicated that an increase in worker productivity was the main reason for using platforms while 34 percent of the respondents who did not use platforms believed that there would be no such improvement. Just over 97 percent of the respondents did not intend to buy a platform in the next 12 months.

Estimation results on platform adoption

Table III presents coefficient estimates of the bivariate probit model and the average marginal effects of each variable on the probability that an agricultural operation uses planar structures and platforms. The correlation coefficient (ρ in Equation (1)) between the equations is statistically significant so use of the bivariate probit model is justified. Operations in the Wenatchee area were 8 percent less likely to use a planar structure than operations in the Yakima area. This result agrees with information in the Washington Tree Fruit Acreage Report (Washington State Department of Agriculture, 2011), which noted that there were 7,178 acres (14 percent of Washington total) of apples in the Wenatchee area that had dwarf rootstocks (trees with a trellis support system, which is a planar structure) and 19,868 acres (38 percent of Washington total) of such trees in the Yakima area. Growers of "Gala" and "Fuji" apples were 16.6 percent more likely to use planar structures, and growers of "Honeycrisp" apples were 14 percent more likely than growers with other apple cultivars in their orchards. This result is consistent with numbers in the tree fruit report (Washington State Department of Agriculture, 2011), in which 53 percent of all acres of "Fuji" apples, 41 percent of all acres of "Gala" apples, and 39 percent of all acres of "Honeycrisp" apples used dwarf rootstocks while only 14 percent of "Golden Delicious" acres and 9 percent of "Red Delicious" acres did so. Relatively larger operations were slightly more likely (0.005 percent) to use planar structures. Such operations generally are in a better financial position than smaller ones to invest in planar structures. In 2009, for example, the cost of a trellis system when establishing a "Gala" orchard block was $2,000 per acre (Gallardo *et al.*, 2010).

Operations that incorporated organic apples were 17 percent more likely to use planar structures. Organic and conventional production shared some characteristics,

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Table III. Coefficient estimates and marginal effects for the bivariate model explaining the probability of using a planar structure and platforms in an apple orchard operation

Variables	Use of a planar structure		Use of platforms	
	Coefficient estimate	Marginal effect	Coefficient estimate	Marginal effect
Intercept	0.334 (0.502)[a]		–1.086 (0.678)	
Agricultural operation is located in the Wenatchee area	–0.313 (0.186)*	–0.083 (0.035)[b,c]	–0.316 (0.260)	–0.045 (0.038)
Agricultural operation is located in the Columbia Basin area	0.331 (0.233)	0.088 (0.037)	0.639 (0.275)**	0.090 (0.077)
Produce "Gala" and "Fuji" apples	0.624 (0.186)***	0.166 (0.070)	0.310 (0.262)	0.044 (0.037)
Produce "Red Delicious" and Golden delicious apples	–0.264 (0.181)	–0.070 (0.030)	–0.542 (0.242)**	–0.077 (0.065)
Produce "Honeycrisp" apples	0.530 (0.222)**	0.141 (0.059)	0.998 (0.259)***	0.141 (0.120)
Size of the agricultural operation	0.002 (0.001)**	0.0005 (0.0002)	0.001 (0.001)*	0.0002 (0.0001)
Produce apple club varieties	0.461 (0.289)	0.123 (0.051)	0.529 (0.296)*	0.075 (0.063)
Produce organic apples	0.649 (0.266)**	0.173 (0.073)	0.026 (0.291)	0.004 (0.003)
Lease land from others	–0.104 (0.178)	–0.028 (0.012)	–0.169 (0.245)	–0.024 (0.020)
Principal operator age	–0.017 (0.008)**	–0.005 (0.002)	–0.006 (0.010)	–0.001 (0.001)
Principal operator has at least a bachelor degree	0.559 (0.177)***	0.149 (0.062)	0.303 (0.225)	0.043 (0.036)
Principal operator is white	–0.636 (0.233)***	–0.169 (0.071)	–0.345 (0.330)	–0.049 (0.041)
Correlation between error terms (ρ)	0.507 (0.143)***			
Number of observations	316			
Log likelihood	–224.366			

Notes: [a]Numbers in parentheses in the column Coefficient estimate are standard errors; [b]marginal effect is the average effect of the variable on the probability that a planar system or a platform would be used in the apple orchard operation; [c]numbers in parentheses in the column Marginal effects are standard deviations. *,**,***Statistical significant at 10, 5, and 1 percent level, respectively

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such as the predominance of dwarf and semi-dwarf trees and planting densities. However, a larger share of organic production came from "Gala" and "Fuji" varieties (Slattery *et al.*, 2011). The average retail premium for organic apples was 34 percent (Lin *et al.*, 2008). Producers captured the largest premium, receiving 120 percent of the price of conventional apples (Slattery *et al.*, 2011). This indicates that producers of organic apples are in a better financial position to invest in planar orchard structures.

In terms of demographic characteristics, relatively young principal operators were 0.5 percent (or 5 percent for ten years younger operators) more likely to use planar orchard structures than older operators. Principal operators who had at least a bachelor's degree and operators who were not white were 15 and 17 percent more likely, respectively, to use planar structures. Apple production, like other agricultural activities, is marked by uncertainty on profitability due to volatility in output and input prices and factors such as weather and pests. In this context, greater education enables better access to information that could help reduce the costs associated with adoption of new technologies, leading to an increased likelihood of adoption (Wozniak, 1987).

Several factors influenced use of platforms. Operators in the Columbia Basin area were 9 percent more likely to use platforms than operators in the Yakima area. On average relative to Yakima operations, Basin operations are larger (928 vs 405 acres) and have greater net cash farm incomes ($164,000 vs $71,084 per year) (US Department of Agriculture, National Agricultural Statistics Service, 2012). Growers of "Red Delicious" and "Golden Delicious" apples were 8 percent less likely to use platforms than growers of other apple cultivars; while growers of "Honeycrisp" apples were 14 percent more likely to use platforms. "Red Delicious" and "Golden Delicious" apples typically are grown on semi-dwarf and/or standard rootstocks which leads to a non-planar fruiting system in which platforms cannot be used to full capacity. "Honeycrisp" apples, on the other hand, typically are grown in some form of planar structure and thus are more conducive to use of platforms. Larger operations were 0.02 percent more likely to use platforms, likely because of their greater financial resources. Growers of a patented apple cultivar (a club variety) were 8 percent more likely to use platforms. Unlike most horticultural crops, apples can be differentiated by variety name, and consumers are willing to pay more for some varieties than for others. It is believed that limiting and controlling the number of licenses granted for new apple varieties provides an incentive to licensees to produce fruit of a higher quality than they would without limits and controls (Alston and Plakias, 2014). Consequently, producers of club varieties may be willing to invest in modern orchard structures that are more conducive to platforms.

Adoption of platforms is intrinsically related to orchard tree architectures. Planar structures require an initial capital investment that larger companies can more readily afford. In this context, we find that operators who invest in planar structures tend to produce high-value apples such as "Honeycrisp," "Gala," and "Fuji," use organic systems, and are relatively young and have more extensive education than those who do not.

Partial budget analysis

From the survey to Washington apple growers, 53 percent of respondents signaled the high cost and 34 percent indicated that lack of improvement in worker productivity were the main reasons for not using platforms. Hence, the value of platforms and in general labor-enhancing technologies boils down to gains in labor efficiencies and costs. To further investigate this, we provide partial budgets for the two technologies (ladders vs platforms) to determine the break-even efficiency gain, as well as the economic returns vary for different efficiencies. An illustration of the platforms is provided in Plate 1.

To construct the partial budget case study we used the picking efficiencies obtained by an apple operation in Eastern Washington when using platforms for harvest. A set of assumptions was made on the fixed and variable costs for the platforms (Table IV). Weestimated the annual cost of ownership of a platform at $12,045 given a 20-year lifespan. Considering that one mechanical harvester was needed for each 75 acres and that yield was 60 bins per acre in a full production year[5], the cost per bin was $2.68. We compare this information with the use of ladders using a partial budget approach (Table V). In this case study scenario a crew of eight workers picked 60 bins in ten hours, the picking rate was 0.75 bins/person/hour, and wages were piece rateat $23.5/bin (Orchard manager 2015, pers. comm., February 6). The picking rate when using platforms for harvest – for this particular case study at the time the data were collected – was 0.69 bins/person/hour. The following calculations were needed to

Plate 1.
Illustration of the platform use for this case study

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General information	
Purchase price ($/unit) (*a*)	50,000
Lifetime (years) (*b*)	20
Machine hours (hours per year) (*c*)	1,000
Fuel consumption (gasoline in gallons per hour) (*d*)	1
Salvage value ($) (*e*)	500
Interest rate (%) (*f*)	5
Costs	
Fixed costs	
Annuity[a] ($) $(a \times f/(1-((1+f)\hat{}(-b)))$	4,012
Depreciation ($) $(a-(a \times e)/b)$	2,475
Interest rate ($) $((a+(a \times e)/2) \times f)$	1,263
Taxes, insurance, and housing ($) $(0.01 \times (a-(a \times e)))$	495
Total fixed costs ($)	8,245
Variable costs	
Repairs ($) $(0.01 \times a)$	500
Fuel cost ($) $(2 \times c \times d)$	3,000
Lube cost ($) $(0.01 \times (2 \times c \times d))$	300
Total variable costs ($)	3,800
Total ownership costs ($)	12,045

Note: [a]Annuity refers to a series of equal payments on the investment

Table IV. Specifications and fixed and variable costs of a platform to be used as a mechanical harvester aid

	Amount ($/bin)		Amount ($/bin)
Additional revenue	0	Additional costs	2.68
Reduced costs	–2.04	Reduced revenue	0
Harvest cost when using ladders	23.50		
Harvest cost when using platform	25.54		
Total additional revenue and reduced costs (*g*)	–2.04	Total additional costs and reduced revenue (*h*)	2.68
Net change in profit (*g*–*h*)	–4.72		

Table V. Partial budget – costs and saving of using platforms vs ladders when harvesting apples

complete the budget: first, convert the piece rate wage to an hourly rate $(23.5 \times 0.75 = 17.63)$; second, estimate the man-hours to pick one bin in one hour $(1 \div 0.69 = 1.45)$; third, estimate the costs for picking a bin $(17.63 \times 1.45 = \$25.54)$. This implied an additional cost of $2.04/bin compared to harvest using ladders $(25.54 - 23.5 = 2.04)$. Considering that the cost of owning and operating a platform was $2.68/bin, the total additional cost was $4.72/bin (Table V). The question then was how much the picking rate needed to improve to transform the additional labor costs to cost savings. We estimated that using a platform should reduce the harvest cost to $20.82/bin $(23.5 - 2.68 = 20.82)$. This implied that the picking rate had to improve to at least 0.846 bins/person/hour in order to cover the additional costs of using a platform $(17.63 \div 20.82 = 0.846)$. This equated to an improvement in efficiency of 13 percent. We present two simulations. First, we present the different worker-hours and costs to pick one bin of apples at different picking rates (Figure 1). Second, we illustrate the different picking cost savings at various levels of platform efficiencies (Figure 2).

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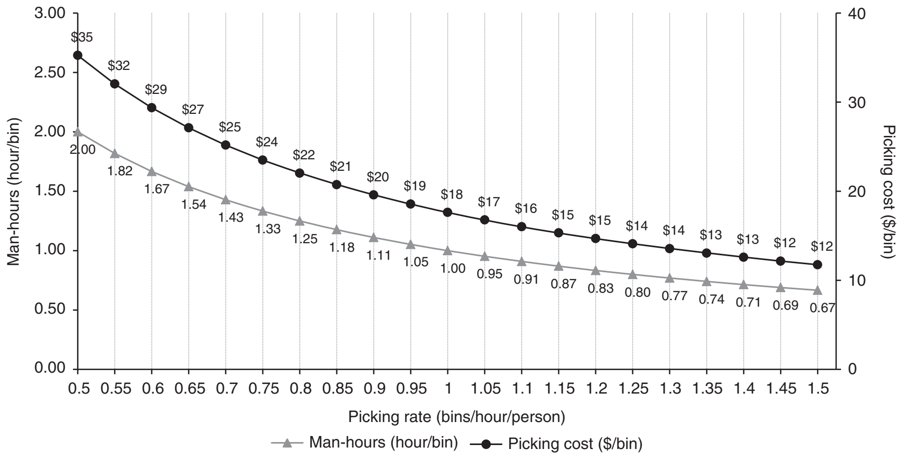

Figure 1.
Employee-hours (hours/bin) and picking cost ($/bin) to pick a bin of apples at various picking rates (bin/hour/person)

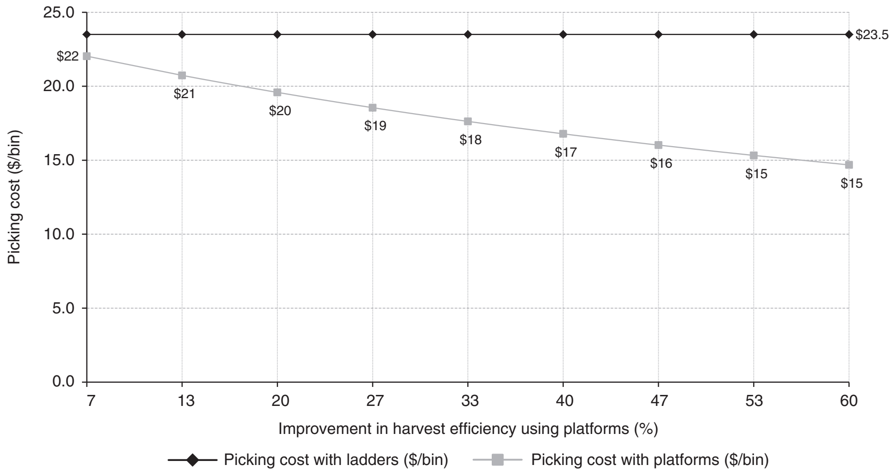

Figure 2.
Comparison between picking cost with ladders and with platforms at different platform efficiency improvements

Discussion

In this paper we present results of a survey conducted in 2010, and a case study illustrating costs of harvesting apples with platforms and with ladders. Since 2010 to date, circumstances related to labor-enhancing machines in agriculture have evolved. An orchard manager in November 2013 expressed that he believes his operation had not maximized picking efficiencies using platforms (Warner, 2013). By November 2014, platforms had been adapted to be used at night, increasing the number of hours the machine is used and the number of acres one platform covers, reducing the ownership costs (Mullinax, 2014). As of the agricultural employment, the estimated average annual agricultural employment increased from 2007 to 2013 by 12 percent, due to increases in demand for seasonal labor. Washington growers felt a generalized shortage of seasonal labor in 2013 exceeding 8 percent as of June-September 2013 (Washington State Employment Security Department, 2013). This shows that

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labor-enhancing machine efficiencies are improving through time, however the improvement seems not to suffice the increasing specialty crop agriculture labor needs.

Conclusions

The US specialty crop sector is facing critic labor-related challenges associated with higher labor costs that are related to an unpredictable and, at times, inadequate supply of workers. Changes in labor supply have been attributed to macroeconomic conditions in the USA and Latin America, especially Mexico. In the face of these challenges, labor-enhancing technologies that improve the productivity of agricultural workers are receiving significant attention in terms of research and development.

We assess the value of using mechanical platforms, one of several labor-enhancing mechanisms available, for Washington apple production (harvesting). As of 2010, platforms had not been widely adopted in Washington – 11 percent of the 316 apple operations covered by our survey used them. We found that the primary reason for investing in platforms was increased labor productivity. The primary impediment to their adoption was an incompatibility between platforms and the tree structure and architecture of existing orchards. The ideal is planar tree structures with wide driving spaces between rows. The choice of tree structure will impact the economic performance of the orchard for the next 15-30 years (typical lifetime of an orchard). Along with the type of rootstock, the type of orchard system structure will affect the tree precocity (how soon it will produce fruit) and productivity, and hence the length of the payback period of the investment. Another key issue influenced by the choice of tree structure is the uniformity of the location of the fruit within the tree, which is crucial for maximizing the efficiency of labor-enhancing technologies. Orchard operations most likely to invest in planar structures are relatively large, produce high-value varieties (such as "Honeycrisp," "Gala", and "Fuji"), use organic systems, and have relatively young and educated principal operators. Similarly, operations producing high-value fruit, such as "Honeycrisp" and controlled or patented varieties, and relatively large operations are more likely to invest in platforms.

The results of our comparison of the cost of harvesting apples using platforms vs ladders under several production assumptions indicated that the cost of using a platform was \$2.68 per bin. To break even, platforms must reduce worker-hours during picking by 13 percent. The faster the picking rate, the fewer worker-hours needed and the smaller the harvest cost.

A caveat to our study is the lack of reliable time-series data on costs and savings accrued when using labor-enhancing technologies such as platforms for apple production. The modeling of the financial feasibility ought to include uncertainties associated with apple production and marketing, underscoring the need of further research to analyze deeper these aspects.

Notes

1. Apple trees are not grown on their own roots, they are propagated on rootstocks (Wilson, 2000). Rootstocks are divided into three groups dwarf, semi-dwarf, and standard (Washington State Department of Agriculture, 2011). Dwarf rootstocks control the amount of wood in the tree, directing its energy into fruit production. The more dwarfing the rootstock, the better suited for high-density plantings (> 1,000 trees per acre). Dwarf rootstocks require some type of support for the trees given the narrow canopy, thus they are associated with fruiting walls or planar systems (Wilson, 2000). In this study we consider two types of planar systems: angled v-trellis and tall spindle.

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2. Although the data was collected in 2010, some circumstances and economics hold in 2015.
3. Our initial sample size represents 25 percent of all the apple industry in Washington State. In Washington State, there were 3,052 apple orchards in 2007 and 2,832 in 2012 (US Department of Agriculture, National Agricultural Statistics Service, 2007, 2012).
4. Patented cultivars are cultivars over which there is some degree of control in acreage, packing, sales, and/or marketing; they are also known as club varieties.
5. We measure apple volume in bins. The capacity of a bin in pounds varies with the size of the bin; we assume a capacity of 825 pounds.

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