The Economic Feasibility of Adopting Mechanical Harvesters by the Highbush Blueberry Industry

R. Karina Gallardo[1,3] and David Zilberman[2]

ADDITIONAL INDEX WORDS. **yield loss, quality loss, labor costs, net present value, sensitivity analyses**

SUMMARY. **Mechanical harvesters engineered for fresh-market highbush blueberries (*Vaccinium corymbosum)* have the potential to relieve the burden associated with relying on human labor for harvesting a crop. However, such devices must be effective and maintain fruit quality to be economically viable. Results from an empirical economic model and a series of sensitivity analyses signal that shortening the gap between prices for the fresh and processing market would increase the likelihood of adoption, especially if prices for the fresh market drop by 26% and prices for the processing market increase by 63%. If changes in prices would occur at the same time, then prices for fresh-market blueberries would have to drop by 23% and for processing blueberries would have to increase by 9%. Increases in labor wages of 61% would make mechanical harvesters more profitable than hand harvesting. A 63% reduction in yield losses due to mechanical harvest in the field must occur for mechanical harvesters to become a profitable alternative. If only quality losses (e.g., presence of bruises on the external surface of the fruit) are reduced and yield losses are kept constant, then a 43% reduction in quality losses must occur for mechanical harvesters to become a profitable alternative. If both yield and quality losses are reduced, then a 20% reduction in yield losses and 29% reduction in quality losses would be required for mechanical harvesters to become profitable. We found that a mechanical harvester in its current incarnation is not yet a proven profitable alternative for fresh-market blueberries, given all initial assumptions considered in this study. The industry urges technical improvements to decrease harvest-induced loss from mechanical harvesting in the field and loss due to presence of bruises on the fruit external surface to ensure the massive adoption of mechanical harvesters, especially for fresh-market blueberries.**

During the last century, technological innovations have played a major role in improving agricultural productivity. Economic and policy changes often drive the adoption of novel technologies. One such innovation is the mechanical harvester, which was developed in response to the need to save on labor expenses, protect against the risk of labor scarcity, and benefit from the opportunity to increase labor productivity. However, in order for producers to adopt the technology, this technology must work well and be economically viable. In addition, adoption of new technologies may be accelerated if innovations are accompanied by associated innovations or changes to government policies and regulations. For example, the tomato (*Solanum lycopersicum*) harvester was introduced in California during the 1960s, concurrent with the introduction of a new tomato cultivar (associated innovation) and subsequent end of the Bracero Program [change in government policy (Sunding and Zilberman, 2001)].

Once a technology has proven feasible, several factors affect patterns of adoption, including the inherent risks associated with the agriculture activity, investment costs, uncertainties around the innovation's performance and reliability, and appropriateness for a specific agricultural operation. This paper develops a framework for improving the understanding of the potential profitability of adopting mechanical harvesters—in their current incarnation—at highbush blueberry operations in the state of Washington. Although machine harvest is the norm for processing highbush blueberries, fresh-market highbush blueberries are typically hand harvested. Hence, there is value in developing a technology that would enable machine harvesting of these blueberries.

The highbush blueberry industry presents an interesting case for analyzing the adoption of mechanical innovations in the field. Worldwide, the highbush blueberry industry is expanding: production increased 69.4% during 2008–12 (Garner, 2013). In 2012, the United States was the world leader in cultivated highbush blueberry, with 47% of global production (Brazelton, 2013), valued at $782 million (Agricultural Marketing Resource Center, 2013). In 2014, North America (comprising the United States, Canada, Mexico, and central American countries) accounted for 60% of global production (Brazelton, 2015). Washington has seen rapid increases in production volume and—more importantly—in per-acre productivity over the past decade. In 2012, Washington was the third largest producer of highbush blueberries in the United States, with 15% of total national production, exceeded only by Michigan with 19% and Oregon with 16% (USDA, 2013). Washington was second—with 10,400 lb/acre in productivity after only California, with 11,500 lb/acre (USDA, 2015). The state produces higher average and less variable yields compared with other regions in the United States due to climatic conditions and a larger

This work was funded by the USDA National Institute of Food and Agriculture Specialty Crop Research Initiative project, Scale-Neutral Harvest-Aid System, and Sensor Technologies to Improve Harvest Efficiency and Handling of Fresh Market Blueberries (2014-51181-22383).

[1]Associate Professor, School of Economic Sciences, Puyallup Research and Extension Center, Center for Precision Agriculture and Automated Systems, Washington State University, 2606 West Pioneer, Puyallup, WA 98371

[2]Professor, Department of Agricultural and Resource Economics, University of California Berkeley, 207 Giannini Hall, Berkeley, CA 94720

[3]Corresponding author. E-mail: karina_gallardo@wsu.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922

investment in inputs and crop protection compared with other states (Brazelton, 2015).

On the consumer side, per capita highbush blueberry consumption also expanded. From 2000 to 2012, annual per capita consumption of highbush blueberries in the United States increased 400% from 0.26 to 1.3 lb (fresh) and 5% from 0.33 to 0.44 lb (processing) (USDA, 2013). Increased promotion of the health benefits of highbush blueberries increased consumption during the 1990s (DeVetter et al., 2015; U.S. Highbush Blueberry Council, 2015).

Despite the noteworthy expansion, the highbush blueberry industry in Washington, in the United States, and worldwide faces various challenges; among the most critical is the decreasing availability of agricultural labor, which generally affects labor-intensive agricultural industries (Calvin, 2012; Calvin and Martin, 2010; Martin, 2009). In general, the U.S. specialty crop agriculture and the highbush blueberry industry have benefited from the supply of migrant labor, which is unpredictable. With the U.S. 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 (Martin, 2009; Taylor et al., 2012). It is believed that the number of unauthorized immigrants from Mexico, the largest supplier of migrant labor, estimated to be living in the United States has decreased 12.9% since its peak of 12.2 million in 2007 (Passel et al., 2012). In addition, Latin America's economic growth and productivity in both the farm and nonfarm sectors have been accelerating relative to growth in the United States Finally, as the agricultural labor force ages and older workers exit, the U.S. 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 1 million workers since 2007. However, there has not yet been a widespread labor shortage (Hertz and Zahniser, 2013; Zahniser et al., 2012).

Highbush blueberry production is labor intensive, with critical masses of temporary labor needed for specific horticultural activities, such as harvest, throughout the production year. The decrease in the availability of labor could lead to crops left unharvested in the field, representing drastic economic losses to producers. For example, in 2011, in Georgia, 52% of highbush blueberry producers reported income losses due to lack of available workers (Georgia Department of Agriculture, 2012). An alternative to the industry's current labor dependence is the successful implementation of mechanical harvesters for highbush blueberries for both the fresh and processing market. However, highbush blueberries are highly susceptible to damage, and fruit picked with a mechanical harvester—in its current incarnation—tends to exhibit decreased quality and a shortened amount of time before showing decay. This situation deters the adoption of mechanical harvesters—in their current incarnation—to harvest highbush blueberries for the fresh market.

The objective of this paper is to compare net revenues realized by a highbush blueberry operation when harvesting blueberries manually and when using a mechanical harvester. The mechanical harvester improves labor productivity; reducing labor costs but—in its current incarnation—diminishes total revenue due to decreased quality and shortened amount of time before decay. We develop an economic model and present a series of sensitivity analyses to estimate the different effects of various factors (e.g., prices for the fruit in the fresh and processing market, labor wages, harvestable yield, and quality losses, among others) on the net revenues realized when manually and mechanically harvesting highbush blueberries for both the fresh and processing markets. We apply our model to the blueberry industry in the state of Washington, where mechanical harvesters are currently used mostly for blueberries for the processing market, whereas blueberries for the fresh market are, in general, picked manually because of the high proportion of fruit damaged by mechanical picking.

Review of literature

Economic studies related to the adoption of mechanical harvesters or harvest aids for labor-intensive crops are abundant. A branch of research has emphasized the effects of mechanical harvester adoption on social welfare (Brandt and French, 1983; Huang and Sexton, 1996; Kim et al., 1987; Schmitz and Seckler, 1970).

Some studies have linked mechanical harvesting and agricultural labor procurement (Cuskaden, 1973; Holt, 1982) to improve production efficiencies. In a study of platform use in Pennsylvania and Washington apple (*Malus ×domestica*) orchards, Baugher et al. (2008) found that powered platforms could improve worker productivity by 20% to 65% compared with ladders, with the greatest gains in harvest and trellis string operations. Elkins et al. (2011) examined platform harvesting of mature 'Bartlett' pear (*Pyrus communis*) orchards in California, and found that productivity for a 100% male crew paid at a per-piece rate over 5 d and two nights was 75% greater than productivity for the same crew using ladders (5.9 vs. 3.4 bins per worker per day).

A different set of studies examined the effects of mechanical harvesting on enterprise net returns. Searcy et al. (2012) estimated that Florida orange (*Citrus sinensis*) growers for the processing market would increase net returns by 17% if they increased the proportion of oranges harvested using a mechanical device from 5% to 95%. Iwai et al. (2009a) estimated that the difference in net present value of Florida oranges that were mechanically and manually harvested was 0.36%. 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%. In a study of California-grown olives (*Olea europaea*), Klonsky et al. (2012) found that the net return per acre for mechanical harvesting at 80% efficiency was 19% higher than net return per acre when manually harvesting. In an assessment of Washington sweet cherries (*Prunus avium*), Seavert and Whiting (2011) estimated an increase of 57% in the net present value when using mechanical harvesters compared with manual harvesting, leading to a break-even price reduction of \$0.17/lb when using mechanical harvesting. Morgan et al. (2011), in a field trial held in Florida, estimated that harvest costs for custom highbush blueberry were \$0.72/lb for manually picked and $0.18/lb for mechanically harvested.

In terms of the effect of mechanical harvesting on farm productivity, 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. When investigating the size of agricultural firms better positioned to adopt mechanical harvesters, Wright et al. (2006) estimated that Polish tart cherry (*Prunus cerasus*) producers would need between 23 and 53 acres to adopt an overhead mechanical harvester, whereas Michigan growers would need yields of at least 9654 lb/acre.

Over-the-row (OTR) blueberry harvesters currently available in the market include Oxbo International (Lynden, WA), Littau Harvesters (Stayton, OR), and Haven Harvesters (South Haven, MI). Other companies selling these machines are Blue-Line Equipment Co. (Union Gap, WA) and A&B Packing (Lawrence, MI), among others.

Disadvantages of the mechanical harvesters are yield losses, quality losses due to fruit bruising, and delayed harvest. Yield losses occur mainly because fruit, once knocked off the bush, misses the conveyor-belt-catchment basins and falls to the ground. Another source of yield loss is the smaller fruit-bearing canopy resulting from the excessive pruning of mature highbush blueberry bushes so they can fit the size-parameter specification of the machine harvester. A third source of yield loss is the inability of the machine harvester to differentiate between ripe and unripe blueberries. Harvested unripe blueberries are sorted out and considered cullage. Yield losses when using a mechanical harvester can often reach 30% of total yield (Rodgers, 2014).

Highbush blueberries harvested by machine are also more bruised compared with handpicked blueberries, which can reduce postharvest life in storage. There are two major reasons for this. The mechanical tines used to knock fruit off the bush are not as sensitive as a picker's hands, and the blueberries fall 12 to 18 inches onto the hard plastic fish scales of the catchment basins. As a result, the packout percentage is decreased and blueberries have a shorter shelf life. Note that the model used in this study does not capture the additional costs of a decreased shelf life due to the mechanical harvesting system and assumes that the slightest indication of a bruise on the blueberry surface will imply a shorter shelf life; hence these blueberries would be culled at the packing line. Another challenge when using mechanical harvesters is that harvest must be delayed by 5 to 7 d to minimize culling unripe blueberries. A week delay in harvesting can lead to lower farm gate prices during the early season, and can lead to overripe blueberries toward the end of season, increasing the risk of fungal infection (Rodgers, 2014). Takeda et al. (2008) asserted that some blueberry farmers have recently used machine harvesting for the fresh market to capture higher farm gate prices at lower harvesting costs.

The studies reviewed here show evidence that low rates of adoption across labor-intensive industries persist although mechanical harvesting systems are beneficial in the long run to both producers and society generally. We attribute this to financial reasons, mainly the trade-offs between annual labor savings and the upfront investment required for new machines and new plantings that are better adapted to machine harvesting. In addition, there is still uncertainty associated with the technology itself, including doubts about potential labor savings, increased plant and fruit damage, operating costs, and the costs associated with managers and workers adapting their management and working routines to the harvesters.

Economic model

To develop the economic model in this study, we consulted with a number of industry representatives to make a series of realistic assumptions about the production and harvesting of highbush blueberries by both manual and mechanical harvest systems. The blueberry mechanical harvesting machine used in this study is an OTR machine, which involves a driver and three individuals located on the top of the machine, sorting fruit (hereafter these individuals are called pickers, even though their function is not to detach the fruit itself). See Fig. 1 for an illustration of the mechanical harvester used as reference in this study.

Consider a highbush blueberry operation that produces both fresh and processing blueberries. The percentage of blueberries destined for either market depends mainly on the relative prices of fresh and processing

Fig. 1. Illustration of the mechanical harvester used as reference to set up the economic model and empirical application to estimate the net revenues when mechanically and manually harvesting highbush blueberries for fresh and processing markets in Washington State as of 2014.

highbush blueberries. In both the fresh and the processing markets, the only production parameters that differ between manual or mechanical harvesting are harvesting costs, yields, and harvest-induced cullage.

Assume that we have a potential output of Q_0. In each technology, we have yield loss (the percentage of output that is culled due to harvest-induced damage in the field), $\Upsilon_{\text{loss}i}$ ($i = 0$ for manual harvesting, $i = 1$ for mechanical harvesting), and the percentage of output with bruises on the fruit's external surface (which will prevent blueberries remaining sound in long-term refrigerated storage), $Q_{\text{loss}i}$. Thus, the quantities harvested for the fresh market are represented by

$$Q_{\text{f}i} = Q_0(1 - \Upsilon_{\text{loss}i})(1 - Q_{\text{loss}i}).$$

The quantity harvested for the processing market is

$$Q_{\text{p}i} = Q_0(1 - \Upsilon_{\text{loss}i})(Q_{\text{loss}i}).$$

The price the producer gets for selling blueberries for the fresh market is P_{f} and the price for the processing market is P_{p}, hence total revenue per acre is

$$\text{TR}_i = (Q_{\text{f}i}P_{\text{f}}) + (Q_{\text{p}i}P_{\text{p}}).$$

For simplicity, we assume that the cost of mechanical harvesting includes machine rental and labor. Rental rates completely capture all costs, including ownership and return on investment. In addition, we assume that highbush blueberry operations rent at this stage because they are waiting for the technology to improve, especially to harvest fresh-market blueberries. The machinery cost per acre, M_{c} equals the annual rent, M_{r}, divided by the number of acres, M_{a}; thus, $M_c = \frac{M_r}{M_a}$.

Labor cost per acre ($L_{\text{c}i}$) for each technology i. $L_{\text{c}i}$ equals potential output minus yield loss, $Q_0(1-\Upsilon_{\text{loss}i})$ times labor cost, $L_{\text{p}i}$; thus, $L_{\text{c}i} = Q_0 (1-\Upsilon_{\text{loss}i})\, L_{\text{p}i}$. Labor cost per pound ($L_{\text{p}i}$) is the sum of the quotient of picker labor cost per hour (w_{h}) divided by picking rate per hour (q_{hi}); plus the quotient of driver labor cost per hour (w_{d}) divided by the driver output rate per hour (q_{d}). Hence, the labor cost, $L_{\text{c}i}$ equals,

$$L_{\text{c}i} = Q_0(1 - \Upsilon_{\text{loss}i})\left(\frac{w_{\text{h}}}{q_{\text{h}i}} + \frac{w_{\text{d}}}{q_{\text{d}}}\right)$$

The total cost of harvest is then represented by,

$$\text{TC}_i = \frac{M_{\text{r}}}{M_{\text{a}}} + \left[Q_0(1 - \Upsilon_{\text{loss}i})\left(\frac{w_{\text{h}}}{q_{\text{h}i}} + \frac{w_{\text{d}}}{q_{\text{d}}}\right)\right].$$

Given the preceding information, we estimate net revenue, $N_{\text{r}i}$, for each technology, which equals total revenue per acre minus harvesting cost per acre:

$$N_{\text{r}i} = \left(Q_{\text{f}i}P_{\text{f}} + Q_{\text{p}i}P_{\text{p}}\right) - \left[\frac{M_{\text{r}}}{M_{\text{a}}} + Q_0(1 - \Upsilon_{\text{loss}i})\left(\frac{w_{\text{h}}}{q_{\text{h}i}} + \frac{w_{\text{d}}}{q_{\text{d}}}\right)\right]. \quad [1]$$

Equation [1] could be rewritten as

$$N_{ri} = \{[Q_0(1 - \Upsilon_{lossi})(1 - Q_{lossi})]P_{\text{f}} + [Q_0(1 - \Upsilon_{\text{loss}i})(Q_{\text{loss}i})]P_{\text{p}}\} - \left\{\frac{M_{\text{r}}}{M_{\text{a}}} + Q_0(1 - \Upsilon_{\text{loss}i})\left(\frac{w_{\text{h}}}{q_{\text{h}i}} + \frac{w_{\text{d}}}{q_{\text{d}}}\right)\right\} \quad [2]$$

We assume that mechanical harvesting has higher Υ_{loss} and Q_{loss} compared with manual harvesting and that mechanical harvesting has a positive machine cost per acre, M_{c}, but lower labor costs, L_{c}, because of higher output per picker, q_{h}. From Eq. [2], we infer that net revenues from each harvest method depend on prices of fresh- and processing-market highbush blueberries, yield and quality loss, machine costs, number of acres in the operation, wages for pickers and drivers, and per-hour labor output. These factors can be divided into two main categories: market factors (i.e., prices for fresh and processing highbush blueberries, operation size, production volume, and labor costs) and technology factors (i.e., potential reduction in yield and quality losses, technology cost, per-hour labor output).

Empirical application

The goal of this section is to illustrate the economic model developed in the preceding section. We obtained information on highbush blueberry manual and machine harvest efficiencies from personal interviews and follow-up consultations with industry members in Washington for the 2014 market year conditions (Table 1). The numbers used to illustrate the model should be considered as assumptions based on the consensus of realistic ranges given by a group of five experienced highbush blueberry growers across eastern and western Washington. It was not the goal of this section of the paper to conduct a survey or a census of highbush blueberry growers in the state of Washington. These numbers will vary across highbush blueberry operations within Washington State, will be different in other regions, and will vary across years within the same operation. Assume that the output price of highbush blueberries is \$2/lb for the fresh market, P_{f}, and \$0.90/lb for the processing market, P_{p}. Assume that the potential output, Q_0, is 8000 lb/acre for a full production year. Also assume that harvest-induced loss from mechanical harvesting in the field—hereafter yield loss—Υ_{loss1}, is 12% and 10% from manual harvesting, Υ_{loss0}. Assume that the percentage loss of highbush blueberries with bruises on the fruit external surface, which will prevent blueberries from remaining sound when kept in long-term refrigerated storage and hereafter considered quality loss, Q_{loss1}, is 30% for mechanical harvesting and 5% for manual harvesting, Q_{loss0}. These assumptions are consistent with previous findings in Morgan et al. (2011) and Van Dalfsen and Gaye (1999). Assume that the OTR harvester rents, M_{r}, for \$30,000/year, whereas the machine maintenance, fuel, and lubricant are at \$6500/year. Considering that one machine covers 100 acres, M_{a}, then the cost of the machine is estimated at \$365/acre (36,500 ÷ 100 = 365). Assume that the OTR harvester involves three individuals and one driver (Fig. 1). Each individual earns \$12/h, w_{h}, and picks 1000 lb of highbush blueberries per hour, q_{h1}, whereas each driver earns \$15/h, w_{d}, and harvests 3000 lb of blueberries per hour, q_{d}. For a manual harvest, each worker makes \$12/h, w_{h}, and produces 50 lb/h, q_{h0}. The total labor cost is estimated at \$0.017/lb when using the mechanical harvester and \$0.24/lb when

Table 1. Assumptions for numerical values for mechanical versus manual harvesting of highbush blueberries for fresh and processing markets, obtained from in-person interviews from highbush blueberry growers in Washington State as of 2014.

	Units[z]	Mechanical harvest (technology 1)	Manual harvest (technology 0)
Total revenue			
Output price fresh market (P_f)[y]	$/lb	2.00	2.00
Output price processing market (P_p)[y]	$/lb	0.90	0.90
Potential output (Q_0)[y]	lb/acre	8,000	8,000
Harvest-induced loss at the field with technology i ($\Upsilon_{\mathrm{loss}i}$) (%)[y]	%	12	10
Loss to bruises with technology i ($Q_{\mathrm{loss}i}$)[y]	%	30	5
Output quantity fresh market (Q_{fi})[x]	lb/acre	4,928	6,840
Output quantity processing market (Q_{pi})[w]	lb/acre	2,112	360
Total revenue (TR_i)[v]	$/acre	11,757	14,004
Harvest cost			
Cost of machinery (M_c)[u]	$/acre	365	
Labor cost–harvesting (L_{ci})[t]	$/acre	120	1,728
Total harvest cost (TC_i)[s]	$/acre	485	1,728
Net revenue (N_{ri})[r]	$/acre	11,272	12,276
Supporting calculation			
Rent of machine (M_r)[y]	$/year	36,500	
Land to be covered by one machine (M_a)[y]	acres	100	
Picking rate–picker (q_{hi})[q]	lb/h/picker	1,000	50
Picker wage (w_h)[y]	$/h	12	12
Output rate–machine driver (q_d)[y]	lb/h/driver	3,000	
Machine driver wage (w_d)[y]	$/h	15	
Labor cost (L_{ci})[p]	$/lb	0.017	0.24

[z]$1/lb = $2.2046/kg, 1 lb/acre = 1.1209 kg·ha^{-1}, 1 acre = 0.4047 ha, 1 lb = 0.4536 kg.
[y]Parameters based on assumptions made on realistic ranges given by five growers in Washington States: output price fresh market (P_f), output price processing market (P_p), potential output (Q_0), harvest-induced loss with technology i ($\Upsilon_{\mathrm{loss}i}$), loss to bruises with technology i ($Q_{\mathrm{loss}i}$), rent of machine, land to be covered by one machine, picker wage, picking rate–machine driver, and machine driver wage.
[x]Output quantity fresh market is calculated by 8000 × (1 – 0.12) × (1 – 0.30) = 4928 and 8000 × (1 – 0.10) × (1 – 0.05) = 6840.
[w]Output quantity processing market is calculated by 8000 × (1 – 0.12) × (0.30) = 2112 and 8000 × (1 – 0.10) × (0.05) = 360.
[v]Total revenue ($/acre) is calculated by (4928 × 2) + (2112 × 0.90) = 11,757 and (6840 × 2) + (360 × 0.90) = 14,004.
[u]Cost of machinery is calculated by 36,500 ÷ 100 = 365.
[t]Labor cost–harvesting is calculated by 0.017 × [8000 × (1 – 0.12)] = 120 and 0.24 × [8000 × (1 – 0.10)] = 1728.
[s]Total harvest cost when using mechanical harvest is 365 + 120 = 485.
[r]Net revenue is calculated by 11,757 – 485 = 11,272 and 14,004 – 1728 = 12,276.
[q]Picking rate–picker is calculated by 3000 ÷ 3 = 1000. Assumes that the mechanical harvester works with three pickers and one driver.
[p]Labor cost is calculated by (12 ÷ 1000) + (15 ÷ 3000) = 0.017 and 12 ÷ 50 = 0.24.

using manual labor [(12 ÷ 1000) + (15 ÷ 3000) = 0.017 and 12 ÷ 50 = 0.24 (Table 1)].

On the basis of the above assumptions and using Eq. [2], we estimate that the net revenue when using the mechanical harvester, N_{r1}, equals $11,256/acre and net revenue when harvesting manually, N_{r0}, is $12,084/acre. This gap explains—in part—why mechanical harvesters have not yet been widely adopted by producers of highbush blueberries for the fresh market; however, it shows that net returns when mechanically harvesting are not starkly different from returns when hand picking.

Sensitivity analyses

Market factors: prices of fresh and processing highbush blueberries. We estimated the effect of changes in the price of blueberries for both the fresh and processing markets on differences in net revenues when using the mechanical harvester, N_{r1}, and harvesting manually, N_{r0} (e.g., the likelihood of adopting mechanical harvesters) (Table 2). We assumed that prices increase/decrease at a rate of 2% per year, based on the fact that blueberry prices have increased at an average of 2% annually for the last 15 years (USDA, 2015). For all the prices included in the sensitivity analyses, manual harvest leads to higher revenues than mechanical harvest. We estimated that a blueberry grower would be indifferent toward harvesting mechanically or manually—all else constant—if the price of blueberries for the fresh market fell to $1.48/lb, a decrease of 26%. Growers would be indifferent, if—all else constant—prices for the processing market increased to $1.47/lb, an increase of 63%. If both fresh and processing blueberry prices would change simultaneously, growers would be indifferent if prices for fresh blueberries decreased to $1.55/lb and prices for processing blueberries increased to $0.98/lb (Table 2).

Market factors: production volume. We estimated the effects of production volume, Q_0, on the difference in net revenue between harvesting mechanically, N_{r1}, and manually, N_{r0}. For 1993–2012, output in Washington was 4500 to 8750 lb/acre, increasing at an average rate of 4% per year (USDA, 2015). Results from our model, show that increases in production volume (pounds per acre)—all else constant—would deter the adoption of mechanical harvesters (Table 3). The higher the yields, the more production destined to the fresh market, hence the lower the probability of using mechanical harvesters in their current incarnation.

Market factors: labor cost. For the last 10 years, the nominal minimum wage in Washington

Table 2. Effect of a decrease/increase in highbush blueberry prices for the fresh/processing market on the net revenue when mechanically (N_{r1}) and manually (N_{r0}) harvesting highbush blueberries for fresh and processing markets in Washington state as of 2014.

Price of highbush blueberries ($/lb)[z]		Net revenue ($/acre)[z]		
Fresh market	Processing market	Mechanical harvest	Manual harvest	Difference
2.00	0.90	11,272	12,276	1,004
1.96	0.92	11,113	12,009	896
1.92	0.94	10,959	11,747	789
1.88	0.96	10,809	11,491	682
1.84	0.97	10,664	11,241	577
1.81	0.99	10,523	10,995	472
1.77	1.01	10,387	10,755	368
1.74	1.03	10,255	10,520	265
1.70	1.05	10,128	10,290	163
1.67	1.08	10,004	10,065	61
1.48	0.90	8,685	8,685	0
2.00	1.47	12,476	12,481	5
1.55	0.98	9,237	9,237	0

[z]$1/lb = $2.2046/kg, $1/acre = $2.4711/ha.

Table 3. Effect of the production volume on net revenue when mechanically (N_{r1}) and manually (N_{r0}) harvesting highbush blueberries for fresh and processing markets in Washington state as of 2014.

	Net revenue ($/acre)[z]		
Output (lb/acre)[z]	Mechanical harvest	Manual harvest	Difference
4,500	6,181	6,905	724
4,680	6,443	7,181	739
4,867	6,715	7,469	754
5,062	6,998	7,767	769
5,264	7,293	8,078	785
5,475	7,599	8,401	802
5,694	7,918	8,737	820
5,922	8,249	9,087	838
6,159	8,593	9,450	857
8,000	11,272	12,276	1,004
8,750	12,363	13,427	1,064

[z]1 lb/acre = 1.1209 kg·ha^{-1}, $1/acre = $2.4711/ha.

increased at an average rate of 3% per year (State of Washington, 2015). We built the sensitivity analyses assuming an increase in picker wages at 3% annually and estimated that the grower would be indifferent between mechanical and manual harvesting, all else constant, if both picker and driver wage increased to $19/h (picker) and $24/h (driver) (Table 4).

Among factors that could potentially impact labor supply and wage rates are the potential changes in immigration regulations. Zahniser et al. (2012) explored the effects of immigration reform on agricultural wages in the United States and estimated that an expansion in the H2A program (from positions in 2005 to ≈156,000 in 2020 for the entire United States) would lead to a 4.4% decrease in real wages over the 15-year period. In contrast, a reduction in the agricultural labor supply (by 2.1 million people in absolute terms over the first 5 years) would lead to a 3.9% increase in real wages. Both potential changes to immigration regulations as simulated in Zahniser et al. (2012) fall short of making mechanical harvesting in its current incarnation more profitable than manual harvesting.

TECHNOLOGY FACTORS: POTENTIAL REDUCTIONS IN YIELD AND QUALITY LOSSES. We analyzed the impact of yield loss (e.g., harvest-induced loss from mechanical harvesting in the field), Y_{loss1}, and quality loss (e.g., loss due to bruises that will prevent blueberries from remaining sound when kept in long-term refrigerated storage), Q_{loss1}, due to the use of a mechanical harvester on the difference in the net revenue when mechanically, N_{r1}, and manually harvesting, N_{r0}. Reductions in yield losses, Y_{loss1}, while keeping quality losses, Q_{loss1}, constant would decrease the difference in the net revenue when harvesting mechanically, N_{r1}, and manually, N_{r0} (Table 5). We expect the grower to be indifferent between harvesting with a machine or manually if yield losses decrease from 12% to 4.4%, all else constant.

Reductions in quality losses, Q_{loss1}, while keeping yield losses, Y_{loss1}, constant would decrease the difference in the net revenue when mechanically, N_{r1}, and manually harvesting, N_{r0} (Table 6). We estimated that if quality losses decrease from 30% to 17% (all else constant) the grower would be indifferent between harvesting mechanically or manually.

Reducing both yield, Y_{loss1}, and quality losses, Q_{loss1}, would decrease the difference in net revenue when mechanically, N_{r1}, and manually harvesting, N_{r0}, leading to adoption (Table 7). For the grower to be indifferent between mechanical and manual harvesting, yield loss, Y_{loss1}, would have to be at no more than 9.6% and quality loss, Q_{loss1}, at 21.30%, all else constant.

TECHNOLOGY FACTORS: TECHNOLOGY COST. We estimated that decreasing the rental cost would increase savings from using a mechanical harvester, but it is still not more profitable than manual harvesting. Even if rental price falls to zero, manual harvesting appears more profitable than mechanical harvesting by $639/acre, all else constant. This result implies that gains accrued due to savings in labor costs when using a mechanical harvester to pick blueberries, are higher than the cost of the mechanical harvester itself (when renting the machine).

TECHNOLOGY FACTOR: PICKING RATE. The effect of increases in picking rate when using the mechanical harvester was negligible in these analyses. However, changes in picking rate when manually harvesting would be more significant; in fact, the

Table 4. Effect of picker wage and machine driver wage on net revenue when mechanically (N_{r1}) and manually (N_{r0}) harvesting highbush blueberries for fresh and processing markets in Washington state as of 2014.

Picker wage ($/h)	Driver wage ($/h)	Net revenue ($/acre)[z]		
		Mechanical harvest	Manual harvest	Difference
12.0	15.0	11,272	12,276	1,004
12.4	15.5	11,269	12,224	956
12.7	15.9	11,265	12,171	906
13.1	16.4	11,261	12,116	855
13.5	16.9	11,257	12,059	802
13.9	17.4	11,253	12,001	748
14.3	17.9	11,249	11,941	692
14.8	18.4	11,245	11,879	634
15.2	19.0	11,240	11,815	575
15.7	19.6	11,236	11,749	514
19.3	24.1	11,199	11,225	25

[z]$1/acre = $2.4711/ha.

Table 5. Effect of yield losses due to use of mechanical harvesters on net revenue when mechanically (N_{r1}) and manually (N_{r0}) harvesting highbush blueberries for fresh and processing markets in Washington state as of 2014.

Yield loss with mechanical harvester (%)	Quality loss with mechanical harvester (%)	Net revenue ($/acre)[z]		
		Mechanical harvest	Manual harvest	Difference
0.12	0.30	11,272	12,276	1,004
0.11	0.30	11,404	12,276	872
0.10	0.30	11,537	12,276	739
0.09	0.30	11,669	12,276	607
0.08	0.30	11,801	12,276	475
0.07	0.30	11,933	12,276	343
0.06	0.30	12,066	12,276	210
0.05	0.30	12,198	12,276	78
0.044	0.30	12,276	12,276	0

[z]$1/acre = $2.4711/ha.

grower would be indifferent between manual and mechanical harvesting if an individual picker's rate—when manually harvesting—fell from 50 to 32 lb/h, all else constant.

INTEGRATING MARKET AND TECHNOLOGY FACTORS. By integrating market and technology factors, we found that more conservative changes (compared with changes previously discussed) would be needed to make the grower indifferent between manual and mechanical harvesting in its current form. For example, a decrease in yield from 8000 to 7834 lb/acre; a decrease in yield loss when using mechanical harvester from 12% to 11%, a decrease in quality loss from 30% to 28%; a decrease in fresh price from $2/lb to $1.75/lb; an increase in processing price from $0.90/lb to $0.95/lb; a decrease in the cost of renting the mechanical harvester from $365/acre to $361/acre; an increase in picker wage from $12/h to $12.6/h; in increase in picking rate when mechanically harvesting from 1000 to 1003 lb/picker per hour; or a decrease in picking rate when manually harvesting from 50 to 48 lb/picker per hour.

Efforts are under way to improve yield and especially quality loss when using mechanical harvesters, which would make these machines more feasible for adoption. One example is changing the design of the harvesting machine by shortening the height from which fruit drops to less than 15 inches and cushioning the machine–fruit contact surface with a foam sheet (Van Dalfsen and Gaye, 1999). Another example is the development of highbush blueberry cultivars that bruise less after impacting with the hard surface of the machine and modifying horticultural practices such as crown restriction (Takeda et al., 2013). Other important advancements include the development of a prototype for a semimechanical harvesting based on the integration of a self-propelled harvest platform with improved handheld shakers and a novel highbush blueberry catching system (Li, 2014). Coupled with improvements in a sensor called berry impact recording device, this prototype would enable quantifying the magnitude and the location of the mechanical impact originated during the harvest and handling, leading to improvements in the quality of mechanically harvested fresh-market highbush blueberries (Yu et al., 2011, 2012, 2014).

Conclusions

We developed an empirical model and conducted a series of sensitivity analyses to improve the understanding of the economic feasibility of adopting mechanical harvesters for the highbush blueberry industry. Market factors affecting net revenues from mechanically and manually harvesting blueberries are prices for fresh and processing blueberries and picker wages; technology factors are yield and quality loss. Mechanical harvesters are currently used primarily for highbush blueberries intended for the processing market; the technology is not fully developed for the fresh market given the large proportion of harvester-induced damage. Shortening the gap between prices for the fresh and processing markets would increase the likelihood of adoption of harvesters in their current incarnation, especially if prices for the fresh market dropped by 26% (e.g., from $2/lb to $1.48/lb) and prices for the processing market increased by 63% (e.g., from $0.9/lb to $1.47/lb), all else constant. If changes in prices would occur at the same time, then prices for fresh-market blueberries would have to drop by 23% (e.g., from $2/lb to $1.55/lb) and for processing blueberries would have to increase by 9% (e.g., from $0.9/lb to $0.98/lb). Increases in labor wages would increase the likelihood of adoption; if picker and driver wages increased by 61% [e.g., from $12/h to $19/h (picker) and from $15/h to $24/h (driver)], then growers would find mechanical harvesters more profitable than the alternative. Finally, decreasing the current levels of harvester-induced yield and quality

Table 6. Effect of quality losses due to the use of mechanical harvesters on net revenue when mechanically (N_{r1}) and manually (N_{r0}) harvesting highbush blueberries for fresh and processing markets in Washington state as of 2014.

Yield loss with mechanical harvester (%)	Quality loss with mechanical harvester (%)	Net revenue ($/acre)[z]		
		Mechanical harvest	Manual harvest	Difference
0.12	0.30	11,272	12,276	1,004
0.12	0.27	11,504	12,276	772
0.12	0.24	11,737	12,276	539
0.12	0.21	11,969	12,276	307
0.12	0.18	12,201	12,276	75
0.12	0.17	12,434	12,276	0

[z]$1/acre = $2.4711/ha.

Table 7. Effect of product quality losses due to the use of mechanical harvesters on net revenue when mechanically (N_{r1}) and manually (N_{r0}) harvesting highbush blueberries for fresh and processing markets in Washington state as of 2014.

Yield loss with mechanical harvester (%)	Quality loss with mechanical harvester (%)	Net revenue ($/acre)[z]		
		Mechanical harvest	Manual harvest	Difference
0.12	0.30	11,256	12,084	828
0.11	0.27	11,652	12,084	432
0.10	0.24	12,013	12,084	71
0.09	0.21	12,343	12,084	259
0.08	0.18	12,644	12,084	560
0.07	0.15	12,917	12,084	833
0.06	0.12	13,165	12,084	1,081
0.05	0.09	13,390	12,084	1,306
0.096	0.13	13,595	12,084	1,511
0.05	0.12	13,780	12,084	1,696

[z]$1/acre = $2.4711/ha.

losses (e.g., presence of bruises on the fruit external surface) would foster harvester adoption. If only yield losses are reduced and quality losses are kept constant, then a reduction of 63% in yield losses (e.g., from 12% to 4%) must occur for mechanical harvesters to become a profitable alternative. If only quality losses are reduced and yield losses are kept constant, then a reduction of 43% in quality losses (e.g., from 30% to 17%) must occur for mechanical harvesters to become a profitable alternative. If both yield and quality losses are reduced, then a reduction of 20% in yield losses (e.g., from 12% to 10%) and 29% in quality losses (e.g., from 30% to 21%) would be required for mechanical harvesters to become profitable.

We show evidence that prices (e.g., blueberry and labor) and yield and quality losses are determinant factors for mechanical harvester adoption. Given that blueberry prices and labor wages could be driven by myriad factors, the one factor to encourage adoption that can be controlled by innovators is decreasing yield and quality losses induced by mechanical harvesters in their current incarnation. In an environment in which labor supply is uncertain and costs are constantly increasing, it would be beneficial to blueberry growers to mitigate labor-associated risks by fully implementing mechanical harvesters for both fresh and processing blueberries. The blueberry industry is concerned about labor challenges, and is supporting efforts to develop machine-harvesting technologies for fresh-market fruit. This technology in its current incarnation is not yet a proven profitable alternative for fresh-market blueberries, given all initial assumptions considered in this study, which might vary from operation to operation or from region to region in the United States. The industry urges technical improvements to decrease harvest-induced loss from mechanical harvesting in the field and loss due to presence of bruises on the fruit external surface to ensure the massive adoption of mechanical harvesters, especially for fresh-market blueberries.

This study is a premier effort to analyze the economics of adopting mechanical harvesters by the blueberry industry. However, further analyses are warranted to have a more thorough understanding of this complex issue. For example, this study assumes that the decision to allocate blueberries in the fresh or processing market is driven by the prices in each market. Although this assumption is realistic, it might not necessarily apply to all blueberry operations in North America, some operations might have an ex ante plan of how to allocate their blueberry production. Another potential caveat is that our study does not consider other potential gains accrued when using mechanical harvesting; for example, the fact that blueberries are presorted in the field. Finally, we assumed blueberry operations rent the mechanical harvesting machine. Although this is true for some operations, one must consider that an increasing number of businesses are investing in buying these machines, and thus ownership risks must be accounted.

Literature cited

Agricultural Marketing Resource Center. 2013. Blueberries profile. 13 Aug. 2015. <http://www.agmrc.org/commodities-products/fruits/blueberries/>.

Baugher, T., J. Schupp, K. Lesser, R.M. Harsh, C. Seavert, K. Lewis, and T. Auvil. 2008. Mobile platforms increase orchard management efficiency and profitability. Acta Hort. 824:361–364.

Brandt, J.A. and B.C. French. 1983. Mechanical harvesting and the California tomato industry: A simulation analysis. Amer. J. Agr. Econ. 65:265–272.

Brazelton, C. 2013. 2012 World blueberry acreage and production. North American Blueberry Council, Folsom, CA.

Brazelton, C. 2015. 2014 World blueberry statistics and global market analysis. North American Blueberry Council, Folsom, CA.

Calvin, L. 2012. The economics of harvest mechanization for fruit crops. Intl. Symp. Mechanical Harvesting Handling Systems Fruits Nuts. 2–4 Apr. 2012, Lake Alfred, FL. 20 Feb. 2016. <http://www.crec.ifas.ufl.edu/harvest/pdfs/presentations/Calvin_session_8.pdf>.

Calvin, L. and P. Martin. 2010. Labor-intensive U.S. fruit and vegetable industry competes in a global market. U.S. Dept. Agr. Econ. Res. Serv., Amber Waves 8. 20 Feb. 2016. <http://www.ers.usda.gov/amber-waves/2010-december/labor-intensive-us-fruit-and-vegetable-industry-competes-in-a-global-market.aspx>.

Cuskaden, C.M. 1973. Labor productivity in apple harvesting. Amer. J. Agr. Econ. 55:633–636.

DeVetter, L.W., D. Granatstein, E. Kirby, and M. Brady. 2015. Opportunities and challenges of organic highbush blueberry production in Washington State. HortTechnology 25:796–804.

Elkins, R.B., J.M. Meyers, V. Duraj, J.A. Miles, D.J. Tejeda, E.J. Mitcham, W.V. Biasi, L. Asin, and J. Abreu. 2011. Comparison of platform versus ladders for harvest in northern California pear orchard. Acta Hort. 909:241–249.

Garner, D. 2013. An analysis of the supply and demand fundamentals that underscore the global blueberry market, and an exploration of the potential market size. DGC Asset Mgt., Northampton, UK.

Georgia Department of Agriculture. 2012. Report on agricultural labor. As required by House Bill 87. January 2012. 20 Mar. 2016. <http://agr.georgia.gov/AgLaborReport.pdf>.

Hertz, T. and S. Zahniser. 2013. Is there a farm labor shortage? Amer. J. Agr. Econ. 95:476–481.

Holt, J.S. 1982. Labor market policies and institutions in an industrializing agriculture. Amer. J. Agr. Econ. 64:999–1006.

Huang, S. and R.J. Sexton. 1996. Measuring returns to an innovation in an imperfectly competitive market: Application to mechanical harvesting of processing tomatoes in Taiwan. Amer. J. Agr. Econ. 78:558–571.

Iwai, N., R.D. Emerson, and F.M. Roka. 2009a. Labor cost and value of citrus operations with alternative technology: Enterprise DCF approach. Southern Agr. Econ. Assn. Annu. Mtg. 31 Jan.–3 Feb. 2009, Atlanta, GA. 20 Feb. 2016. <http://purl.umn.edu/46836>.

Iwai, N., R.D. Emerson, and F.M. Roka. 2009b. Harvest cost and value of citrus operations with alternative technology: Real options approach. Agr. Appl. Econ. Assn. Annu. Mtg. 26–29 July 2009, Milwaukee, WI. 20 Feb. 2016. <http://purl.umn.edu/49942>.

Kim, C.S., G. Schaible, J. Hamilton, and K. Barney. 1987. Economic impacts on consumers, growers and processors resulting from mechanical tomato harvesting in California: Revisited. J. Agr. Econ. Res. 39:39–45.

Klonsky, K., P. Livingston, R. DeMoura, W.H. Krueger, U.A. Rosa, J.A. Miles, S. Castro-Garcia, E. Fitcher, J.X. Guinard, S.M. Lee, K. Gloze, C. Crisosto, J.K. Burns, and L. Ferguson. 2012. Economics of mechanically harvesting California black ripe table olives. Intl. Symp. Mechanical Harvesting Handling Systems Fruits Nuts. 2–4 Apr. 2012, Lake Alfred, FL. 20 Feb. 2016. <http://www.crec.ifas.ufl.edu/harvest/>.

Li, C. 2014. Scale neutral harvest aid system and sensor technologies to improve harvest efficiency and handling of fresh market highbush blueberries. Grant proposal submitted to the National Institute of Food and Agriculture, Grant No. 2014–51181–22383. 18 Mar. 2016. <https://portal.nifa.usda.gov/web/crisprojectpages/1004552-scale-neutral-harvest-aid-system-and-sensor-technologies-to-improve-harvest-efficiency-and-handling-of-fresh-market-highbush-blueberries.html>.

Martin, P.L. 2009. Importing poverty? Immigration and the changing face of rural America. Yale Univ. Press, New Haven, CT.

Morgan, K., J. Olmstead, J. Williamson, G. Krewer, F. Takeda, D. MacLean, R. Shewfelt, C. Li, A. Malladi, and P. Lyrene. 2011. Economics of hand and mechanical harvest of new "crispy" flesh cultivars from Florida. Blueberry Educ. Session. 7 Jan. 2011, Savannah, GA.

Moseley, K.R., L.A. House, and F.M. Roka. 2012. Adoption of mechanical harvesting for sweet orange trees in Florida: Addressing grower concerns on long-term impacts. Intl. Food Agribus. Mgt. Rev. 15:83–98.

Passel, J., D. Cohn, and A. Gonzalez-Barrera. 2012. Net migration from Mexico falls to zero—and perhaps less. 17 Sept. 2015. <http://www.pewhispanic.org/2012/04/23/net-migration-from-mexico-falls-to-zero-and-perhaps-less>.

Rodgers, A.D. 2014. Determining willingness to adopt mechanical harvesters among southeastern blueberry farmers. MS Thesis, Mississippi State Univ., Starkville.

Schmitz, A. and D. Seckler. 1970. Mechanized agriculture and social welfare: The case of the tomato harvester. Amer. J. Agr. Econ. 52:569–577.

Searcy, J., R. Roka, and T. Spreen. 2012. The impact of mechanical citrus harvester adoption on Florida orange juice growers. Agr. Appl. Econ. Assn. Annu. Mtg. 12–14 Aug. 2012, Seattle, WA. 20 Feb. 2016. <http://purl.umn.edu/124711>.

Seavert, C. and M.D. Whiting. 2011. Comparing the economics of mechanical and traditional sweet cherry harvest. Acta Hort. 903:725–730.

State of Washington. 2015. History of Washington minimum wage. 20 Oct. 2015. <http://www.lni.wa.gov/WorkplaceRights/Wages/Minimum/History/default.asp>.

Sunding, D. and D. Zilberman. 2001. The agricultural innovation process: Research and technology adoption in a changing agricultural sector, p. 207–261. In: B.L. Gardner and G.C. Rausser (eds.). Handbook of agricultural economics. Vol. 1A. Elsevier, Amsterdam, The Netherlands.

Takeda, F., G. Krewer, E.L. Andrews, B. Mullinix, and D.L. Peterson. 2008. Assessment of the V45 blueberry harvester on rabbiteye blueberry and southern highbush blueberry pruned to v-shaped canopy. HortTechnology 18:130–138.

Takeda, F., G. Krewer, C. Li, D. MacLean, and J.W. Olmstead. 2013. Techniques for increasing machine harvest efficiency in highbush blueberry. HortTechnology 23:430–436.

Taylor, J.E., D. Charlton, and A. Yúnez-Naude. 2012. The end of farm labor abundance. Appl. Econ. Perspect. Policy 34:587–598.

U.S. Department of Agriculture (USDA). 2013. Economics, statistics and market information System. U.S. blueberry industry. 13 Aug. 2015. <http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1765>.

U.S. Department of Agriculture (USDA). 2015. Non-citrus fruits and nuts 2014 summary. 4 Nov. 2015. <https://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1113>.

U.S. Highbush Blueberry Council. 2015. History of blueberries. 14 Aug. 2015. <http://www.blueberrycouncil.org/about-blueberries/history-of-blueberries/>.

Van Dalfsen, K.B. and M.M. Gaye. 1999. Yield from hand and mechanical harvesting of highbush blueberries in British Columbia. Appl. Eng. Agr. 15:393–398.

Wright, R.T., L. Martinez, and S. Thornsbury. 2006. Technological leapfrogging as a source of competitive advantage. Southern Agr. Econ. Assn. Annu. Mtg. 4–8 Feb. 2006, Orlando, FL. 20 Feb. 2016. <http://purl.umn.edu/35433>.

Yu, P., C. Li, G. Rains, and T. Hamrita. 2011. Development of the berry impact-recording device sensing system: Hardware design and calibration. Comput. Electron. Agr. 79:103–111.

Yu, P., C. Li, F. Takeda, and G. Krewer. 2014. Visual bruise assessment and analysis of mechanical impact measurement in southern highbush blueberries. Appl. Eng. Agr. 30:29–37.

Yu, P., C. Li, F. Takeda, G. Krewer, G. Rains, and T. Hamrita. 2012. Quantitative evaluation of a rotary blueberry mechanical harvester using a miniature instrumented sphere. Comput. Electron. Agr. 88:25–31.

Zahniser, S., T. Hertz, P. Dixon, and M. Rimmer. 2012. The potential impact of changes in immigration policy on U.S. agriculture and the market for hired farm labor: A simulation analysis. U.S. Dept. Agr., Econ. Res. Serv. ERR-135.