Economic Viability of Robotic Fruit Harvesters to Reduce Large Seasonal Labor Demands

Diane Charlton, Montana State University

Stephen Devadoss, Texas Tech University

R. Karina Gallardo, Washington State University

Jeff Luckstead, Washington State University

Stavros Vougioukas, UC Davis

2023 Research News Flash Session Economics – Washington State Tree Fruit Association Annual Meetings. Dec 5, 2023

Contact: R. Karina Gallardo, karina_Gallardo@wsu.edu.

Background, Objectives, & Data

- Currently, robots are in the experimental stage in apple production
  - Robots are being developed for pruning, thinning, chemical spraying, and harvesting.
- We conducted break-even analyses to determine
  1. the maximum feasible up-front cost for the robotic harvester that will yield the same profits as manual harvesting,
  2. how the economically feasible up-front cost changes for different picking speeds, robot-induced damage rates, and picking efficiency,
  3. the tradeoff between the wage rate and changes in the three robotic parameters (picking speeds, robot-induced damage rates, and picking efficiency) given an initial up-front robot cost.
- We use enterprise budget data: 2019 Cost Estimates of Establishing, Producing and Packing Gala Apples (Gallardo and Galinato 2021)

Model

Profits from manual harvest:

$$\pi_M = p \times Y\gamma_M\beta_M + p_C \times Y\beta_M \times (1-\gamma_M) - (w \times HL_M + pck_M + w \times OL + ovc + \delta \times fc),$$

p is the fresh-market apple price in \$/bin,
Y is the yield in bins/acre,
γ_M is the packout rate (% of apples sold in the fresh market),
β_M is the percent of apples the picker removes from the tree,
p_C is the price of apples sold to processors,
w is the wage rate,
HL_M is the picking rate for labor (hours per acre per worker),
$pck_m = (rc + pb \times fb) \times Y$ is the packing cost,

- rc is the receiving charge by packers,
- pb is the variable cost or packaging fee per box,
- fb is the number of boxes per bin.

OL represents other labor hours such as checkers and hauling in hour per acre,
ovc are other variable costs for horticultural management, maintenance and repair costs for buildings and machinery, fuel and lubricant costs of equipment,
$\delta \times fc$ is the annualized fixed costs discounted at the rate of δ.

Net revenue from robotic harvest (N_R), excluding the robot cost,

$$N_R = p \times Y\beta_R\gamma_R + p_C \times Y\beta_R(1-\gamma_R) - (w_R \times HL_R + pck_R + m_R + w \times OL + ovc + \delta \times fc),$$

β_R is the percent of apples the robotic harvester removes from the tree
γ_R is the packout rate for the robotic harvester
w_R is the robot operator wage rate,
HL_R is the robot operator hours per acre,
$pck_R = (rc + pb \times fb) \times Y\beta_R$ is the packing cost for robotic harvest,
m_R is the annual per acre cost of robot maintenance, fuel, and lubrication,

Model (contd.)

Profits from robotic harvest (π_R) is: $\pi_R = N_R - \delta fc_R$,

δfc_R is the discounted annualized up-front cost of purchasing the robot

We endogenously solve for the break-even robot cost such that profits from manual harvesting are equal to profits from robotic harvesting,

$$\delta fc_R = N_R - \pi_M.$$

<u>This determines the up-front robot cost that farmers could invest to earn profits equal to profits from manual harvesting</u>.

Amortizing this cost on an annual basis:

$$I = \frac{\delta fc_R}{12} \times Disc,$$

δfc_R is the annualized net revenue difference between manual and robotic harvest,

$$Disc = \frac{\left(1+\frac{i}{12}\right)^n - 1}{\frac{i}{12}\left(1+\frac{i}{12}\right)^n}$$

is the discount factor, i is the annual interest rate, and n is the number of months that the robotic harvester will be amortized.

Findings – Sensitivity Analyses of Robot Parameters

- Assuming the performance of a robotic prototype:
  - 5% robot-induced damage rate
  - Picking rate of 3 seconds per arm
  - Assuming the robot misses 10% of harvestable apples in the orchard)
- Baseline wage rate of $18.79
- The up-front robot cost is **<u>$55,332 ($461x12 monthsx10 years)</u>**, for 90 acres. This would result in equal profits from robotic and manual harvest
- The table shows different combination of picking efficiency, robot induced damage and picking speed.

		Robot-Induced Damage Rates			
		0.01	0.025	0.05	0.075
Panel 1: Time to Pick One Apple, 1 Second per Arm					
Picking efficiency	0.80	-4,899	-147,475	-385,101	-622,727
	0.85	359,233	207,746	-44,731	-297,209
	0.90	723,365	562,967	295,638	28,309
	0.95	1,087,497	918,188	636,007	353,826
Panel 3: Time to Pick One Apple, 3 Seconds per Arm					
Picking efficiency	0.80	-267,279	-409,854	-647,480	-885,107
	0.85	80,455	-71,032	-323,510	-575,987
	0.90	428,188	267,790	461	-266,868
	0.95	775,921	606,613	324,432	42,251

Findings – Sensitivity Analyses Wage and Robot Parameters

- We utilize a root-finding algorithm to calculate the robot-induced damage rate, percentage harvested, or picking speed that corresponds to a wage rate such that the net revenues from both operations are equal for an assumed annual cost of a robotic harvester of **$40,000 for a 90-acre farm**.
- By repeating this break-even analysis for various wage rates, we compute the corresponding robot-induced damage rate and then calculate the percent change in the robot-induced damage rate ($rp = \gamma_M - \gamma_R$) divided by the percent change in the wage rate:

$$\varepsilon_{rp,wage} = \frac{\%\Delta rp}{\%\Delta \text{Wage}}.$$

- Through similar analyses, we calculate the elasticity of the percentage harvested and the picking speed to the wage rate.
- For every **1% increase** in the **wage rates**, robot could have
  - **6.69% slower** than the current picking speed
  - **4.37% increase** over the current robot-induced damage rate
  - **0.22% decrease** in the picking efficiency
- Holding other parameters constant.

Conclusions

- Robot profitability is affected by robot parameters: Picking speed, robot induced damage, picking efficiency *AND* wage.
- Elasticities estimates indicate that profitability changes due to wage increases are most sensitive to (1) Picking speed, (2) Robot induced damage, and (3) Picking efficiency.
- The methodology developed in this study can be used for robotic harvest in any fruit crops.

2023 Research News Flash Session Economics – Washington State Tree Fruit Association Annual Meetings. Dec 5, 2023
Contact: R. Karina Gallardo, karina_Gallardo@wsu.edu.