Economics of Robotic Technology in Texas Wine Grape Production

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The motivation for this study centers on the labor- and cost-intensive nature of wine grape production and the potential opportunities for robotic technology to augment those production tasks that are manual labor-intensive. The objectives of this study are to: 1) develop cost of production budgets for two representative wine grape vineyards in Texas; 2) assess the economic viability of wine grape production under current operating conditions; 3) evaluate labor costs by production task; and 4) identify common production challenges and tasks that could be augmented with robotic technology development.

Introduction

In 2014, the U.S. produced an estimated 4.2 million tons of wine grapes. Wine grape acreage in the leading wine grape-producing states has increased from an estimated 521,000 acres in 2005 to 641,000 in 2014, an increase of 19 percent. There are approximately 25,000 wine grape vineyards in the U.S (The National Association of American Wineries, 2014). California led the U.S. in wine grape production with 3.89 million tons produced on 565,000 acres. Washington was the second leading state with 2.27 million tons on 48,000 acres, followed by Oregon with 58,000 tons (19,000 acres), New York with 44,000 tons, Pennsylvania with 17,600 tons, and Texas at 6th with 8,650 tons on 4,400 acres (NASS, 2014).

Grapes are among the most intensively managed fruit crops, requiring a great deal of manual labor to complete many production tasks including vine training, pruning, canopy management, and harvest. Scarcity of skilled labor has been identified as an increasing challenge for the grape industry and has constrained continued expansion (MKF Research, 2007). A reduction in the availability of skilled labor generally leads to production quantity and quality issues, higher production costs, and decreased competitiveness in global markets. With a push for stricter border reform in the U.S., there is cause for vineyards to be concerned about skilled labor availability and rising production and harvesting costs.

Machines have been developed to reduce most of the previous season’s growth, remove leaves, position shoots, and thin fruit. However, these machines do not perform any of these tasks with the selectivity that many premium wine grape producers require.

Robotic technology has made significant contributions over the last decade and offers the potential to duplicate the efficacy of skilled human labor for vineyard tasks requiring selective activity. Today’s industrial robots have dexterity, strength, reliability, speed and precision that is unparalleled by human workers. Wine grape production is primed for robotic technology as it faces a variety of production and labor issues that could affect long-term competitiveness. Mechanization will be a key factor for achieving vineyard efficiencies within the production process, as robotics can potentially allow for selective pruning, thinning, training of vines and canopy, and crop estimation.

Data and Methods

Using a grower panel process, this project includes the development of two representative wine grape vineyard budgets in Texas, which consist of a 50 acre vineyard and a 100 acre vineyard. The panels consist of 3-5 wine grape growers from a major production region within each state. Using a consensus building process, each panel provided 2015 budget information for the size of the vineyard, wine grape variety produced, cost of production, fixed costs, budgeted yield, yield distribution, budgeted price and price distribution, equipment compliment and replacement strategy, other assets, and loan terms and balances. Labor costs for various production tasks are of particular interest. The panels also provided input on the production tasks that they feel would be the most useful in terms of new technology being developed. A follow-up web conference meeting was also held to allow the panels to review the budget, validate the financial statements, and recommend further clarifications regarding production tasks and the potential for new technology.

A summary of the production cost budget for the representative wine grape vineyards is presented in Table 1, which includes subtotals for the various production tasks by budget category. The most significant difference between the two budgets lies in the budgeted yield where the 50 acre vineyard has a budgeted yield of 6 tons per acre compared to 4 tons per acre for the 100 acre vineyard. The higher yield of the 50 acre vineyard can be attributed to a more aggressive production management style with the growers on the panel. Based on the budgeted yields, the 50 acre vineyard generates gross receipts of $9,688 per acre, compared to $6,488 for the 100 acre vineyard. Both vineyards also have land rental income from dryland acres rented out (not shown in Table 1). The 50 acre vineyard has a higher cash costs per acre than the 100 acre vineyard, $4,637 compared to $4,045 per acre. Further, both the 50 acre and 100 acre vineyards have very similar non-cash overhead costs per acre, which is primarily comprised of depreciation. Using the budgeted yields and prices, the 50 acre vineyard has net returns above total costs of $2,705, compared to $100 per acre for the 100 acre vineyard.

Table 1. Production Budgets for Texas Representative Wine Grapes Vineyards ($/acre)

Vineyard Practice	TX Wine 50 ac.	TX Wine 100 ac.
Number of Acres	50	100
Budgeted Yield (Tons/ac.)	6.00	4.00
Budgeted Price ($/ton)	$1,600	$1,600
TOTAL GROSS RECEIPTS	**$9,688**	**$6,488**
OPERATING COSTS		
Floor Management - Dormant Season	$38	$38
Pruning	$1,268	$1,209
Canopy Management	$529	$529
Floor Management - Growing Season	$78	$78
Weed Management - Vine Row	$479	$293
Irrigation	$50	$50
Chemical/Pest Control	$279	$225
Harvest	$892	$630
Miscellaneous Costs	$188	$188
Cash Overhead Costs	$837	$805
TOTAL CASH COSTS	**$4,637**	**$4,045**
Non-Cash Overhead Costs	$2,346	$2,342
TOTAL COSTS	**$6,983**	**$6,387**
NET RETURNS ABOVE CASH COSTS	**$5,050**	**$2,443**
NET RETURNS ABOVE TOTAL COSTS	**$2,705**	**$100**

Economic Viability of Wine Grape Production

To evaluate the economic viability of each representative vineyard using current production methods and technology, data from the representative budgets were used to develop a projected income statement, cash flow statement, and balance sheet to estimate financial outcomes over a 10-year projection period (2015-2024). These baseline scenarios reflect the representative vineyards' current production and operating practices, projected over a 10-year planning horizon. Long-range, annual projections of inflation rate indices (Appendix Table A**)** for input prices, labor costs, equipment prices, and interest rates by the Food and Agricultural Policy Research Institute (FAPRI) at the University of Missouri form the basis for vineyard expense projections (FAPRI U.S. Baseline Briefing Book, 2015).

Stochastic Simulation

While financial statements for a business, when presented in a deterministic mode, can provide useful information about a business or investment, this type of analysis is limited. Deterministic investment analyses that ignore risk provide only a point estimate of potential financial outcomes instead of estimates for probability distributions that show the chances of success or failure (Pouliquen, 1970; Reutlinger, 1970; Hardaker et al., 2004).

Monte Carlo simulation offers business analysts and investors an economical means of conducting risk-based economic feasibility studies for new investments and a non-destructive means of stress testing existing business under risk (Richardson et al., 2007). Stochastic models are used to generate a large sample of economic outcomes that are dependent on a defined set of risky variables. A unique feature of stochastic simulation models is that there is an explicit recognition that the independent variables have some probability distribution around their means (Paggi et al., 2007).

Richardson (2006) outlines the methodology for developing a simulation model for a production oriented business. The steps begin with defining the probability distributions for all risky variables, simulating the variables, and validating the simulation results. The stochastic values from the probability distribution are used in accounting equations to calculate production, gross revenue, expenses, cash flows, and balance sheet values for the business. Financial statement variables become stochastic by sampling stochastic values from the probability distribution. Finally, the stochastic model is simulated many times (500 iterations for example) using random values for the stochastic variables. The 500 samples provide information used to estimate empirical probability distributions for key output variables (KOVs) such as net cash income, net income, and ending cash reserves. This allows for evaluating the probability of success for a business. The stochastic model can also be used to analyze alternative management plans and/or investment strategies.

Monte Carol Simulation Model for Wine Grape Production

A stochastic simulation model was developed to evaluate the viability of the two representative wine grape vineyards. The model consists of equations necessary to develop a projected income statement, cash flow statement, and a balance sheet. The financial statements are annual for a ten-year planning horizon, 2015-2024. The model includes two risky variables - yield and price - and was developed using Simetar© (2011), a simulation add-in program designed for risk analysis in Microsoft ® Excel.

Stochastic Variables

Stochastic variables in a Monte Carlo simulation model are variables the decision maker is unable to forecast with certainty. Such variables have two components: the deterministic component, which can be forecasted with certainty, and the stochastic component, which cannot be forecasted with certainty (Richardson, Herbst, Outlaw, and Gill, 2007). To simulate stochastic yields and prices, a multivariate probability distribution was developed for each representative vineyard. Similar simulation models have been developed and used by Falconer and Richardson (2013), Outlaw et al. (2007), and Richardson and Mapp (1976) to analyze proposed business and policy changes.

Stochastic variables in the wine grape model used in this study include annual prices for grapes, and annual yields (tons/acre). Since wine grape price data for Texas is very limited, historical annual grape prices for 2005-2014 from NASS were used. Normally, statewide average price data would not be representative of the price risk that an individual grower faces. However, after reviewing the price data, each grower panel confirmed that the NASS historical price data is a reasonable approximation of the historical price risk they have faced. Panel experience is corroborated by the fact that, while most grapes are produced in the High Plains, the largest growth in wineries has occurred in Central Texas and other more populated areas. Another issue that arises with the price data for Texas is that the wine grape market is not a mature, well-developed industry; and it lacks the characteristics of well-defined, competitive market. In fact, rapid growth of Texas wineries has resulted in increased demand and prices for Texas grapes even in years with relatively high grape yields. Thus, prices and yields are not correlated in the simulation model.

Due to the lack of quality data for historical yields, each panel developed a yield distribution to represent the yield risk for their representative vineyard. Each distribution is comprised of yields (tons) per acre and the frequency of each yield where the frequency sums to ten. The price and yield distributions were used to estimate the parameters for the empirical distribution, and the stochastic variables were simulated 500 times using an empirical distribution. T-tests were conducted on the simulated prices and yields, using an alpha level of .05, to determine whether or not they simulated their respective means in each year of the 10-year planning horizon. Each tests for the yields confirmed that the simulated yields statistically reproduced their means and historic variability. As for the prices, the tests showed that the simulated prices did not statistically reproduce their means and historic variability because the simulated prices were representative of the most current year's price rather than the mean price of the historical prices and the variance is de-trending in the simulated prices and not for the historic prices.

The equations for the simulation model can be found in Appendix A. Equations (A.1) and (A.2) in Appendix A provide detail about how the random variables were simulated. Equations (A.1) was simulated as an empirical distribution, defined by the fractional deviations from trend (S_i), and cumulative probabilities ($F(S_i)$). Equation (A.2) was simulated as an empirical distribution, defined by the fractional deviations from the mean (R_i), and cumulative probabilities ($F(R_i)$).

Projected annual means for the stochastic variables over the 2015-2024 planning horizon are equal to the baseline price and yield provided by the panels. The baseline deterministic price and yield were held constant throughout the 10-year planning horizon for both Texas representative vineyards, based on panel input. The stochastic variables were simulated for 500 iterations.

Projected Financial Statements

Equations from the projected financial statements for a deterministic economic model comprise the majority of the equations for the Monte Carlo simulation model. The two stochastic variables in equations (A.1)-(A.2) were used as exogenous variables in the pro forma financial statement equations to incorporate risk into the model (Richardson et al., 2007). The equations for income and expenses in the income statement, cash flow statement, and the balance sheet are summarized in Appendix A as equations (A.3)-(A.58).

Income

Annual wine grape sales (A.3) were computed by multiplying the stochastic grape price by the stochastic yield and wine grape acres. Both vineyards have multi-peril crop insurance with 65 percent yield coverage and 100 percent price coverage. Crop insurance indemnity payments (A.4) were calculated when the stochastic wine grape yield is less than the guaranteed yield (yield coverage percent x average production history (APH) yield). The difference is then multiplied by the established grape price, which is specific for the wine grape variety and county where the representative vineyard is located; and wine grape acres. Land rental income (A.5), which only applies to the two Texas vineyards due to irrigation water constraints in the area, was the product of the number of acres and the rental charge per acre. Total income (A.6) equals the sum of wine grape sales, crop insurance indemnity payments when applicable, and land rental income.

Expenses

All variable costs and cash overhead costs (A.7)-(A.31) were calculated using the base cost per acre provided by the panels, adjusted annually for the projected annual inflation rates (Appendix Table 1), and the number of acres.

Interest on the operating loan is based on the vineyards borrowing 100 percent of operating funds for one-half of the year. Operating loan interest (A.32) was calculated using the annual interest rate, 50% of the year, and the number of acres. Operating interest costs also includes any interest on operating carryover debt incurred during the simulation. An annual intermediate loan equal to 50% of the total equipment assets was used for the analysis, and the intermediate loan payment and interest (A.33) was calculated using the beginning equipment loan balance, interest rate, and 5 years remaining. The beginning long-term (LT) loan balance includes 75% of the land value, 50% of buildings value, and 50% of drip irrigation system value. LT loan payment and interest cost (A.34) was derived using the LT beginning balance, interest rate, and 20 years remaining. The beginning vineyard establishment costs loan equals 30% of the total establishment costs, and the establishment loan payment and interest costs (A.35) were calculated using interest rate, and 15 years remaining. Total interest cost (A.36) is the sum of the interest costs for operating, intermediate, long term, and vineyard establishment cost loans.

Annual equipment depreciation (A.37) was calculated using the total equipment costs and annual capital replacement, multiplied by the MACRS (Modified Accelerated Cost Recovery System) fractions for an asset with a 7-year life. Annual depreciation of the buildings (A.38) was computed using the MACRS fractions for an asset with a 20-year life. Annual depreciation for the drip irrigation system (A.39) was calculated using the MACRS fractions for an asset with a 7-year life. Annual depreciation for vineyard establishment costs (A.40) was calculated using the MACRS fractions for an asset with a 10-year life. Total depreciation (A.41) is the sum of the annual depreciation for equipment, buildings, drip irrigation system, and vineyard establishment costs.

Total expenses (A.42) equal total variable costs plus total interest and depreciation. Net cash vineyard income (NCVI) (A.43) was calculated as the total income minus total variable costs and interest. Net vineyard income (A.44) was computed as NCVI minus depreciation.

Cash Flow Statement

The annual cash flows were calculated using equations (A.45)-(A.54). Total cash available (A.45) equals NCVI (A.43) plus any positive cash reserves from the previous year (A.54). In the stochastic model, ending cash reserves can be positive or negative. Positive cash reserves are a cash inflow carried forward to the following year, while negative cash reserves are cash flow deficits that require carryover financing the next year (A.49) (Richardson, Herbst, Outlaw, and Gill, 2007). Cash outflows in the cash flow statement (A.53) are the sum of cash vineyard expenses, principal portions of scheduled loan payments, any operating loan carryover, owner operator management withdrawals, federal income taxes, and self-employment and social security taxes. Ending cash reserves (A.54) equals total cash available minus total cash outflows. If ending cash reserves is negative, cash is borrowed on short-term operating loan and is reported on the balance sheet as short-term carryover debt. If ending cash is positive the following year, it is used to pay down the short-term carryover debt.

Balance Sheet

The value of total assets (A.55) was computed annually using the estimated land value, remaining market value of equipment, and ending cash reserves. The projected value of land is adjusted each year based on the projected annual inflation rate for land values (FAPRI, 2015). The market value of equipment declines at a rate equal to straight-line depreciation over the expected life, until it reaches its salvage value. Total liabilities (A.56) equal the sum of remaining long-term loan debt, intermediate loan debt, vineyard establishment costs loan debt, and any short-term loan debt. Nominal net worth (A.57) was computed by subtracting total liabilities from total assets. To calculate real net worth (A.58), nominal net worth was adjusted annually for inflation using an average inflation index based on projected inflation rates for farm inputs for by FAPRI (2015).

Results

Results for the stochastic simulation analysis are presented in Table 2 for the two Texas representative vineyards. The results include the annual mean values from the simulations for 2015-2024 for total cash receipts, NCVI, net vineyard income, ending cash reserves, short-term carryover debt, and real net worth. The mean total cash receipts range from $496,592 (TX 50 ac) to $664,830 (TX 100 ac) while the coefficient of variation is similar for each representative vineyard, 27.0% (TX 100 ac) to 27.3% (TX 50 ac).

Table 2. Summary of Stochastic Results for Representative Texas Wine Grape Vineyards

	TX 50 Ac.	TX 100 ac.
Total Cash Receipts		
Mean	$496,592	$664,830
Standard Deviation	$135,363	$179,422
Coefficient of Variation (%)	27.3	27.0
Minimum	$195,287	$283,322
Maximum	$801,912	$1,072,135
Net Cash Vineyard Income		
Mean	$200,977	$132,992
Standard Deviation	$137,170	$185,388
Coefficient of Variation (%)	68.3	139.4
Minimum	-$142,969	-$412,391
Maximum	$537,580	$601,474
Net Vineyard Income		
Mean	$137,888	$12,766
Standard Deviation	$137,421	$186,799
Coefficient of Variation (%)	99.7	1,463.2
Minimum	-$198,758	-$434,202
Maximum	$480,619	$478,925

	TX 50 Ac.	TX 100 ac.
Ending Cash Reserves		
Mean	$320,892	$136,541
Standard Deviation	$255,311	$198,959
Coefficient of Variation (%)	79.6	145.7
Minimum	$0	$0
Maximum	$1,348,820	$1,307,475
Short Term Carryover Debt		
Mean	$19,194	$202,768
Standard Deviation	$74,621	$323,347
Coefficient of Variation (%)	388.8	159.5
Minimum	$0	$0
Maximum	$1,299,484	$2,499,460
Real Net Worth		
Mean	$461,676	$320,565
Standard Deviation	$250,757	$368,796
Coefficient of Variation (%)	54.3	115.1
Minimum	-$757,217	-$1,541,139
Maximum	$1,324,938	$1,480,928

The mean results for the KOV's for each year are presented in Table 3. Mean total cash receipts for the Texas representative vineyards are relatively stable each year. The Texas 50 acre vineyard has a higher mean net vineyard income than the Texas 100 acre vineyard which is mostly attributable to the higher yield for the 50 acre vineyard.

In terms of cash flow ability, both Texas representative vineyards have a positive mean ending cash reserves at the end of 2024, with the Texas 50 acre vineyard having $401,929 in ending cash compared to $76,116 for the 100 acre vineyard. However, both the vineyards also show varying levels of mean short-term carryover debt at the end of 2024, $477,079 for the 100 acre vineyard compared to $37,165 for the 50 acre vineyard.

For real net worth, the Texas 50 acre vineyard has a higher mean change in real net worth (from beginning of 2015 to the end of 2024) with a 116% increase, compared to 8.63% for the 100 acre vineyard.

Table 3. Mean Stochastic KOVs of Representative Wine Grape Vineyards, 2015-2024

	TX 50 Ac.	TX 100 ac.
Change in Real Net Worth (%)	116.52%	8.63%
Total Cash Receipts		
2015	$494,030	$660,092
2016	$495,131	$661,553
2017	$495,289	$663,449
2018	$495,467	$664,181
2019	$496,737	$665,420
2020	$497,272	$664,349
2021	$496,174	$665,633
2022	$497,307	$667,026
2023	$499,213	$668,665
2024	$499,312	$667,928
2015-2024 Average	$496,593	$664,830
Net Cash Vineyard Income		
2015	$230,732	$192,859
2016	$226,085	$182,786
2017	$220,197	$172,422
2018	$213,867	$160,346
2019	$207,923	$147,470
2020	$200,388	$130,113
2021	$188,840	$111,798
2022	$180,410	$94,770
2023	$174,658	$78,807
2024	$166,667	$58,548
2015-2024 Average	$200,977	$132,992
Net Vineyard Income		
2015	$120,192	-$27,881
2016	$115,600	-$37,843
2017	$109,878	-$47,876
2018	$103,586	-$59,874
2019	$140,509	$12,812
2020	$175,096	$80,747
2021	$159,219	$57,495
2022	$153,885	$55,351
2023	$154,950	$57,997
2024	$145,962	$36,737
2015-2024 Average	$137,888	$12,766

Table 3 Continued.

	TX 50 Ac.	TX 100 ac.
Ending Cash Reserves		
2015	$101,239	$91,751
2016	$175,953	$133,086
2017	$244,003	$157,659
2018	$305,406	$173,548
2019	$346,430	$164,759
2020	$387,684	$166,902
2021	$410,662	$159,749
2022	$420,352	$136,225
2023	$415,260	$105,617
2024	$401,929	$76,116
2015-2024 Average	$320,892	$136,541
Short Term Carryover Debt		
2015	$15,991	$54,575
2016	$12,972	$73,056
2017	$12,153	$90,452
2018	$14,729	$116,249
2019	$15,853	$146,657
2020	$15,463	$178,809
2021	$15,960	$227,927
2022	$23,928	$291,667
2023	$27,731	$371,210
2024	$37,165	$477,079
2015-2024 Average	$19,194	$202,768
Real Net Worth		
2015	$251,529	$359,785
2016	$320,436	$374,977
2017	$389,792	$399,634
2018	$448,471	$410,817
2019	$488,570	$398,426
2020	$516,475	$365,413
2021	$540,283	$325,584
2022	$554,539	$268,814
2023	$555,409	$193,453
2024	$551,252	$108,745
2015-2024 Average	$461,676	$320,565
Beginning Real Net Worth	$213,221	$295,106
% Change	116.52%	8.63%

While the mean results for the KOV's in tables 2 and 3 are useful in providing some perspective on the economic viability of the representative vineyards, Figures 1-5 provide more insight by focusing on the risk around the means. These figures present the range of NCVI and the probability of having a cash flow deficit each year. The simulation results for NCVI, plotted against the left y-axis, are represented by percentiles in a fan graph format. For example, 95% of the simulated results for NCVI are equal to or below the 95th percentile line. The 75th (green) and 25th (blue) percentile lines provide a 50% range of variability around the mean, while the 95th (maroon) and 5th (red) percentile lines provide a 90% range of variability around the mean. The probability of having a cash flow deficit, and incurring short-term carryover debt, is plotted against the right y-axis.

Following the work of Richardson et al. (2015), the representative vineyards are considered to be in good financial position if their probability of having a cash flows deficit is less than 25%. Vineyards are considered to be in marginal financial position if the probability is between 25% and 50%, and poor financial position if the probability is greater than 50%.

The probability of the Texas 50 acre vineyard (Figure 1) having a cash flow deficit ranges between 9.8% and 23.2% over the 10-year planning horizon, and indicates the vineyard is in good financial condition. For the Texas 100 acre vineyard (Figure 2), NCVI declines over the 10-year planning horizon while the probability of having a cash flow deficit is on an increasing trend, ranging from 38.4% to 74.6% and is greater than 50% the last 4 years. This vineyard is in marginal to poor financial condition.

Figure 1. TX 50 Ac. Representative Vineyard

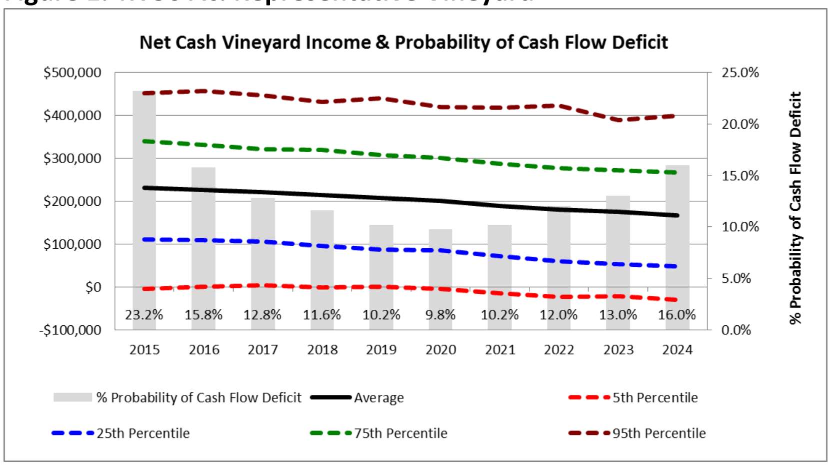
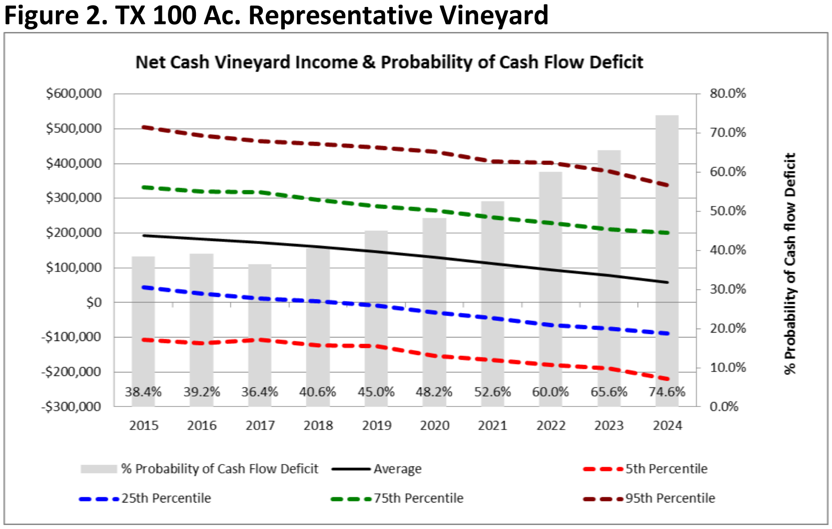


Figure 2. TX 100 Ac. Representative Vineyard



Wine Grape Vineyard Labor Requirements and Cost

In order to assess production tasks that may lend themselves to robotic technology development, labor usage and costs for each task was provided by the vineyard panels. Production tasks are performed by both field labor and equipment operator labor (primarily tractor drivers). The research team has developed a preliminary list of production tasks that have the potential for robotic technology. These tasks are grouped into several vineyard production task categories and are presented in terms of labor hours in Table 4 and labor costs in Table 5. The 50 acre vineyard has a labor usage of 135.5 hours per acre and labor cost of $1,782.42 per acre. The 100 acre vineyard, which relies on less labor than the 50 acre vineyard, has a labor usage of 114.50 hours per acre and a labor cost of $1,538.19. There appear to be substantial potential labor savings from applying robotic technology to pruning and canopy management. Equipment operator hours are included in each category in Tables 4 and 5. Considering the idea that unmanned tractors could potentially be new technology for vineyards, equipment operator hours - per acre and total for the vineyard - were summed and reported at the bottom of Table 4 while the associated costs is reported at the bottom of Table 5. For those vineyards that rely more on mechanization, equipment operator hours and costs are a significant portion of total labor costs.

If new technology can be developed and made available commercially to growers, it would most likely carry a price that would necessitate a capital purchase whereby a grower would secure a loan, incur annual payments and interest cost, and the technology would be depreciated over several years. These types of decisions are usually evaluated using net present value (NPV) to compare the NPV of the cash outflows for using manual labor to the NPV of the cash outflows associated with purchasing new technology. To provide some insight into the NPV of projected labor costs for each production task (not categories) that could offer the potential for new technology, the 10-year projected labor costs for each task were discounted at a 5% discount rate. The resulting NPVs per acre for each task are presented in Table 6 which shows significant variation, depending on the task, and the representative vineyard. In general, the tasks with highest NPVs are finish spur pruning, cane pruning, tie canes, tie cordons, shoot positioning/green, and contract manual harvest.

Table 4. Equipment Operator and Field Labor Hours by Production Task Category for Potential Robotic Technology Development (2015)

	TX Wine 50 ac.	TX Wine 100 ac.
Floor Management - Dormant Season	0.60	0.60
Pruning	54.00	49.00
Canopy Management	42.10	42.10
Floor Management - Growing Season	1.80	1.80
Weed Management - Vine Row	24.20	8.20
Irrigation	0.00	0.00
Chemical/Pest Control	1.80	1.80
Harvest	11.00	11.00
Total Labor Hours per Acre	**135.50**	**114.50**
Total Vineyard Acres	50	100
Total Labor Hours	**6,775**	**11,450**
Equipment Operator Hours per Acre (1)	23.5	23.5
Equipment Operator Vineyard Labor Hours (1	1,175	2,350

(1) Equipment operator labor hours are not in addition to total vineyard labor hours (it is included in total vineyard labor hours).

Table 5. Equipment Operator and Field Labor Costs by Production Task Category for Potential Robotic Technology Development (2015)

	TX Wine 50 ac.	TX Wine 100 ac.
Floor Management - Dormant Season	$12.25	$12.25
Pruning	$707.13	$648.98
Canopy Management	$499.29	$499.29
Floor Management - Growing Season	$36.75	$36.75
Weed Management - Vine Row	$318.36	$132.28
Irrigation	$0.00	$0.00
Chemical/Pest Control	$36.76	$36.76
Harvest	$171.88	$171.88
Total Labor Costs per Acre	**$1,782.42**	**$1,538.19**
Total Vineyard Acres	50	100
Total Labor Costs	**$89,121.00**	**$153,819.00**
Equipment Operator Labor Cost per Acre (1)	$480	$480
Equipment Operator Labor Costs (1)	$23,993	$47,986

(1) Equipment operator labor hours are not in addition to total vineyard labor hours (it is included in total vineyard labor hours).

Table 6. Net Present Value (NPV) Per Acre for Selected Vineyard Practices for Precision Mechanization

Vineyard Practice	Tx 50 ac. NPV per ac.	Tx 100 ac. NPV per ac.
Remove Cover Crop	$109	$109
In-row Herbicide and Insecticide	---	---
In-row Pre-emergent Herbicide	---	---
Hilling-Up	---	---
Take-Away (de-hilling)	---	---
Pre-Prune (mechanical)	$543	$543
Finish Spur Prune	$4,641	$4,126
Cane Prune	---	---
Tie Canes (Cane-trained)	---	---
Tie Cordons	---	---
Pull/Rake Brush	$905	$905
Shred Brush	$181	$181
Trellis Maintenance and Repair	---	---
Cordon/Shoot Thinning	---	---
Sucker Removal w/ Herbicide	$109	$109
Sucker Removal - manual	$825	$825
Disbudding	---	---
Shoot Positioning/green tying	$2,578	$2,578
Move Catch Wires Up	$413	$413
Move Catch Wires Down	$413	$413
Leaf Pulling - manual	---	---
Leaf Pulling - mechanical	$91	$91
Cluster Thinning	---	---
Hedging	---	---
Mowing Vineyard Floor	---	---
Till Alleyway - mechanical	$217	$217
Plant Winter Cover Crop	$109	$109
Pre-emergent Herbicide	$109	$109
Post-emergent Herbicide	$435	$435
Hoeing/Hand Pulling	$2,063	$413
Post-emergent Herbicide (Spot Spray)	$217	$217
Crop Estimation	---	---
Green Thinning	---	---
Irrigation Management	---	---
Fungicides	$272	$272
Insecticides	$54	$54
Bird & Rodent Control	---	---
Hedging to Facilitate Machine Harvest	$181	$181
Contract Manual Harvest	NA	NA
Bin Handling and Hauling	$724	$724
Harvest Support Labor (unskilled)	$619	$619
Total	**$15,807**	**$13,641**
Equipment Operator Labor Costs NPV per Acre	$4,256	$4,256

Summary and Conclusions

Representative wine grape grower panels in four states provided important input regarding wine grape production costs in their respective regions and production tasks that have potential to be automated with robotic technology. Under current production tasks and technology, Monte Carlo simulation model results indicate that two of the vineyards are in good financial condition, one is in marginal-to-poor financial condition, one is in marginal condition but is at risk of being in poor condition, and one is in poor condition. These results are an indication that most of the growing areas are in need of improved financial conditions that could potentially come from new technology.

Equipment operator and field labor usage and cost data provided by the grower panels show a slight difference between the Texas representative vineyards with labor hours per acre ranging from 114.50 to 135.50, and labor costs ranging from $1,538.19 to $1,782.42 per acre. Equipment operator labor and costs alone was the same for both the Texas 50 acre and 100 acre vineyards. The NPV of labor costs over 10-years was presented for production tasks that may be conducive for robotic technology. For Texas growers, several production tasks have a NPV of more than $2,000, ranging from $2,063 for hoeing and hand pulling to $4,641 for finish spur pruning. This analysis provides important insight for technology developers in identifying and prioritizing the production tasks to focus on for new technology development, and for determining a price range to facilitate adoption by wine grape growers.

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Appendix A

Equations for Simulation Model for Wine Grape Production in the U.S.

Stochastic Variables

(A.1) $Grape\ Price_t = Mean\ Price_t \times [1 + Empirical(S_{i,}\ F(S_i)]$

(A.2) $Grape\ Yield_t = Mean\ Yield_t \times [1 + Empirical(R_{i,}\ F(R_i)]$

Income

(A.3) $Wine\ Grape\ Sales_t = Grape\ Price_t \times Grape\ Yield_t \times Number\ of\ Acres$

(A.4) $Crop\ Insurance\ Indemnity\ Payment_t = (Guaranteed\ Yield_t - Grape\ Yield_t) \times Established\ Price$ *[When grape yield is less than the guaranteed yield] x Number of Acres*

(A.5) $Land\ Rental\ Income_t = Number\ of\ Acres \times Rate\ per\ Acre\ for\ Land\ Rental$

(A.6) $Total\ Income_t = Wine\ Grape\ Sales_t + Crop\ Insurance\ Indemnity\ Payment_t + Land\ Rental\ Income_t$

Expenses

(A.7) $Fertilizer\ Cost_t = Fertilizer\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.8) $Fungicide\ Cost_t = Fungicide\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.9) $Insecticide\ Cost_t = Insecticide\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.10) $Herbicide\ Cost_t = Herbicide\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.11) $Tying\ Material\ Cost_t = Tying\ Material\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.12) $Soil\ Sampling\ Cost_t = Soil\ Sampling\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.13) $Trellis\ Repair\ Cost_t = Trellis\ Repair\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.14) $Vine\ Cost_t = Vine\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.15) $Rodent\ Control\ Cost_t = Rodent\ Control\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.16) $Propane\ Cost_t = Propane\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.17) $Seed\ Cost_t = Seed\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.18) $Irrigation\ Cost_t = Irrigation\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.19) $Custom\ Contract\ Cost_t = Custom\ Contract\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.20) $Machinery\ Labor\ Cost_t = Machinery\ Labor\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.21) $Non\ Machinery\ Labor\ Cost_t = Non\ Machinery\ Labor\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.22) $Fuel\ Cost_t = Fuel\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.23) $Lube\ Cost_t = Lube\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.24) $Machinery\ Repair\ Cost_t = Machinery\ Repair\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.25) $Buildings\ \&\ Tools\ Maintenance\ \&\ Repair\ Cost_t = Buidlings\ \&\ Tools\ Maintenance\ \&\ Repair\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.26) $Management\ Cost_t = Management\ Cost_{t-1} \times (1 + Inflation\ Rate_t) \times Number\ of\ Acres$

(A.27) $Crop\ Insurance\ Cost_t = Crop\ Insurance\ Cost_{t-1}$ x (1 + $Inflation\ Rate_t$) x $Number\ of\ Acres$
(A.28) $Liability\ Insurance\ Cost_t = Liability\ Insurance\ Cost_{t-1}$ x (1 + $Inflation\ Rate_t$) x $Number\ of\ Acres$
(A.29) $Property\ Insurance\ Cost_t = Property\ Insurance\ Cost_{t-1}$ x (1 + $Inflation\ Rate_t$) x $Number\ of\ Acres$
(A.30) $Property\ Taxes\ Cost_t = Property\ Taxes\ Cost_{t-1}$ x (1 + $Inflation\ Rate_t$) x $Number\ of\ Acres$
(A.31) $Office\ Cost_t = Office\ Cost_{t-1}$ x (1 + $Inflation\ Rate_t$) x $Number\ of\ Acres$
(A.32) $Operating\ Interest_t = Total\ Variable\ Cost_t$ x $OP\ Interest\ Rate_t$ x $Fraction\ of\ Year$ X $Number\ of\ Acres$
(A.33) $Intermediate\ Loan\ Interest_t = Equipment\ Beginning\ Debt\ Balance_t$ x $Fixed\ Interest\ Rate_t$
(A.34) $Long\ Term\ Loan\ Interest_t = Land,\ Buildings,\ and\ Drip\ Irrigation\ System\ Beginning\ Debt\ Balance_t$ x $Fixed\ Interest\ Rate_t$
(A.35) $Establishment\ Costs\ Loan\ Interest_t = Vineyard\ Establishment\ Costs\ Beginning\ Debt\ Balance_t$ x $Fixed\ Interest\ Rate_t$
(A.36) $Total\ Interest\ Cost_t = Operating\ Interest_t + Intermediate\ Loan\ Interest_t + Long\ Term\ Interest_t + Establishment\ Cost\ Loan\ Interest_t$
(A.37) $Equipment\ Depreciation_t$ = ($Equipment\ Cost$ x $MACRS_t$ + $Capital\ Replacement$ x $MACRS_t$) x $Number\ of\ Acres$
(A.38) $Buildings\ Depreciation_t$ = ($Buildings\ Cost$ x $MACRS_t$) x $Number\ of\ Acres$
(A.39) $Drip\ Irrigation\ Depreciation_t$ = ($Drip\ Irrigation\ System\ Cost$ x $MACRS_t$) x $Number\ of\ Acres$
(A.40) $Establishment\ Costs\ Depreciation_t$ = ($Establishment\ Costs$ x $MACRS_t$ + $Capital\ Replacement$ x $MACRS_t$) x $Number\ of\ Acres$
(A.41) $Total\ Depreciation_t = Equipment\ Depreciation_t + Buildings\ Depreciation_t + Drip\ Irrigation\ System\ Depreciation_t + Establishment\ Costs\ Depreciation_t$
(A.42) $Total\ Expenses_t = Total\ Variable\ Cost_t + Total\ Interest\ Cost_t + Total\ Depreciation_t$
(A.43) $Net\ Cash\ Vineyard\ Income_t = Total\ Income_t – Total\ Variable\ Costs_t – Total\ Interest\ Cost_t$
(A.44) $Net\ Vineyard\ Income_t = Total\ Income_t – Total\ Expenses_t$

Cashflow Statement

(A.45) $Total\ Cash\ Available_t = Net\ Cash\ Vineyard\ Income_t + Positive\ Cash\ Reserves_{t-1}$
(A.46) $Principal\ Payment\ Long\ Term\ Loan_t = Fixed\ Annual\ Payment – Long\ Term\ Loan\ Interest_t$
(A.47) $Principal\ Payment\ Intermediate\ Term\ Loan_t = Fixed\ Annual\ Payment – Intermediate\ Loan\ Interest_t$
(A.48) $Principal\ Payment\ Establishment\ Costs_t = Fixed\ Annual\ Payment – Establishment\ Costs\ Loan\ Interest_t$
(A.49) $Carryover\ Loan\ Payment_t$ = ($Beginning\ Debt\ Balance_{t-1}$ + ($Beginning\ Debt\ Balance_{t-1}$ x $Interest\ Rate$) – ($Beginning\ Debt\ Balance_{t-1}$ x $Interest\ Rate$)
(A.50) $Owner\ Operator\ Management\ Withdrawls_t = Owner\ Operator\ Management\ Withdrawls_{t-1}$ x (1+ $Inflation\ Rate_t$)
(A.51) $Federal\ Income\ Taxes_t = Positive\ Net\ Vineyard\ Income_t$ x $Income\ Tax\ Rate$
(A.52) $Self\text{-}Employment\ and\ Social\ Security\ Taxes_t$ = ($Positive\ Net\ Vineyard\ Income_t$ x $Self\text{-}Employment\ Tax\ Rate$) + ($Positive\ Net\ Vineyard\ Income_t$ x $Medicare\ Tax\ Rate$)
(A.53) $Cash\ Outflows_t = Cash\ Vineyard\ Expenses_t + Principal\ Payment\ Long\ Term\ Loan_t$ +

Principal Payment Intermediate Term Loan$_t$ + *Principal Payment Establishment Cost*$_t$ + *Operating Loan Carryover*$_{t-1}$ + *Owner Operator Management Withdrawls*$_t$ + *Federal Income Taxes*$_t$ + *Self-Employment and Social Security Taxes*$_t$

(A.54) *Ending Cash Reserves*$_t$ = *Total Cash Available*$_t$ – *Cash Outflows*$_t$

Balance Sheet

(A.55) *Assets*$_t$ = *Land Value* + *Book Value Farm Machinery*$_t$ + *Positive Ending Cash*$_t$

(A.56) *Liabilities*$_t$ = *Long Term Loan Debt*$_t$ + *Intermediate Loan Debt*$_t$ + *Establishment Costs Debt*$_t$ + *Short Term Loan Debt*$_t$

(A.57) *Nominal Net Worth*$_t$ = *Assets*$_t$ – *Liabilities*$_t$

(A.58) *Real Net Worth*$_t$ = (*Inflation Rate Year 1* ÷ *Inflation Rate*$_t$) x *Nominal Net Worth*$_t$

Table A. Projected Inflation Rates for Machinery and Other Farm Operations

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Machinery Prices	-0.81%	1.41%	1.64%	3.22%	3.51%	3.23%	2.61%	2.38%	2.07%	1.64%
Fertilizer	-5.29%	-1.64%	-0.48%	1.47%	3.26%	3.25%	1.10%	-1.00%	-0.54%	-0.81%
Herbicides	-0.95%	1.80%	2.82%	3.47%	4.00%	4.97%	3.35%	2.16%	2.79%	2.34%
Insecticides	-0.85%	0.54%	1.76%	2.70%	3.36%	4.10%	2.60%	1.54%	2.00%	1.50%
Fuel & Lube	-22.56%	6.72%	7.79%	7.99%	7.21%	8.59%	7.34%	4.51%	4.66%	4.64%
Wages	1.60%	3.09%	3.30%	3.48%	3.49%	3.34%	3.36%	3.35%	3.32%	3.33%
Supplies	1.60%	1.50%	1.88%	1.75%	1.85%	1.91%	1.73%	1.57%	1.58%	1.58%
Repairs	1.60%	1.50%	1.88%	1.75%	1.85%	1.91%	1.73%	1.57%	1.58%	1.58%
Taxes	0.27%	1.71%	2.11%	2.08%	3.26%	3.71%	3.18%	2.72%	3.10%	2.96%
Land	-3.50%	-3.50%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Interest	1.98%	3.88%	6.54%	2.63%	1.71%	2.52%	2.46%	1.60%	2.36%	2.31%

Source: Food & Agriculture Policy Research Institute, University of Missouri (2015).