Evaluating the Potential for Precision Mechanization in U.S. Wine Grape Production

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Abstract

The motivation for this study centers on the labor-and cost-intensive nature of wine grape production and the potential opportunities for robotic technology. The study objectives are to develop cost of production budgets for six representative wine grape vineyards in five U.S. states, assess the economic viability of wine grape production under current operating conditions, evaluate labor costs by production task, and identify common production challenges and tasks that could be augmented with robotic technology development. Investigators have worked with grower panels to develop a production budget for representative vineyards in five states, and to gather input on production tasks that the growers and technology developers feel would be most suitable for robotic technology. A stochastic simulation model was developed to assess baseline pro-forma financial statements for each vineyard size. Combined, the results help in exploring opportunities to strengthen vineyard profitability and competitiveness using robotics.

Key Words: Wine Grapes, Precision Mechanization, Robotics, Technology, Monte Carlo Simulation

Objectives

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 five representative wine grape vineyards in four U.S. states; 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

A grower panel process was used to develop six representative wine grape vineyard budgets in the following five states: California (1), Washington (1), New York (1), Oregon (1), and Texas (2). 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 each representative wine grape vineyard is presented in Table 1, which includes the budgeted yield (tons/acre), budgeted price ($/ton), gross receipts, the operating costs for the production tasks by budget category (subtotals), total cash costs, non-cash overhead (depreciation and land charge), total costs, returns above cash costs, and returns above total costs. The revenue and cost items in these budgets also represent the revenue and costs used in year one of the projected 10-year financial statements (discussed later). Oregon and California (Napa Valley), which produce wine grapes for premium wines, face the highest costs due to substantial reliance on manual labor rather than automation. For example, Oregon and California have the highest cost for canopy management ($2,015 per acre for Oregon, $1,614 for California), while canopy management in the other states ranges from $318 to $660 per acre. As the smallest vineyard, Oregon (10 acres) may lose economies of scale compared to the other representative vineyards. With 250 acres, the Washington representative vineyard is the largest. Washington also uses mechanization and automation wherever it can, and thus has the lowest costs per acre**.** Total per acre costs for the Texas and New York vineyards were similar, although differences in regional production result in different allocations of spending across categories.

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

Vineyard Practice	TX Wine 50 ac.	TX Wine 100 ac.	WA Wine	OR Wine	NY Wine	CA Wine
Number of Acres	50	100	250	10	50	30
Budgeted Yield (Tons/ac.)	6.00	4.00	4.00	3.00	4.50	4.50
Budgeted Price ($/ton)	$1,600	$1,600	$1,600	$2,600	$1,550	$6,240
TOTAL GROSS RECEIPTS	**$9,658**	**$6,458**	**$6,400**	**$7,800**	**$6,975**	**$28,080**
OPERATING COSTS						
Floor Management - Dormant Season	$38	$38	$92	$0	$180	$0
Pruning	$1,268	$1,209	$270	$942	$1,064	$1,499
Canopy Management	$529	$529	$318	$2,015	$660	$1,614
Floor Management - Growing Season	$78	$78	$92	$252	$88	$174
Weed Management - Vine Row	$479	$293	$401	$70	$270	$83
Irrigation	$50	$50	$260	$86	$0	$169
Chemical/Pest Control	$279	$225	$379	$604	$800	$639
Harvest	$892	$630	$337	$1,051	$458	$1,497
Miscellaneous Costs	$188	$188	$148	$176	$117	$88
Cash Overhead Costs	$837	$805	$768	$496	$660	$2,174
TOTAL CASH COSTS	**$4,637**	**$4,045**	**$3,065**	**$5,692**	**$4,296**	**$7,937**
Non-Cash Overhead Costs	$1,719	$1,717	$2,242	$4,269	$1,650	$8,740
TOTAL COSTS	**$6,356**	**$5,762**	**$5,307**	**$9,960**	**$5,946**	**$16,677**
NET RETURNS ABOVE CASH COSTS	**$5,021**	**$2,413**	**$3,335**	**$2,108**	**$2,679**	**$20,143**
NET RETURNS ABOVE TOTAL COSTS	**$3,301**	**$696**	**$1,093**	**-$2,160**	**$1,029**	**$11,403**

Economic Viability of Wine Grape Production

To assess 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 projection period. 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 six 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 projection period, 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 based on panel input. 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). Statewide, historical annual grape prices from 2005-2014 were provided by the panels. The sources of these data are state wine grape grower associations, or the National Agricultural Statistics Service of the United States of the Department of Agriculture's (USDA). 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 historical statewide average price data is a good approximation of the historical price risk they have faced. Stochastic prices were modeled for the two Texas vineyards, Oregon, and New York. Due to the nature of the production contracts in Washington and California, and following the panels' advice, a fixed price is used; e.g. price risk is not a major concern for growers in these two states, and price is not treated as a stochastic variable in the simulation models.

For the two Texas vineyards and New York, the deterministic price in 2015 is fixed throughout the 10-year projection period. For Washington, the deterministic price is increased by 3% every third year (2017 is the first 3% increase). For California and Oregon, the deterministic price is increased each year by 5% and 3%, respectively. The deterministic prices for year 1 (2015) for all representative vineyards can be found in Table 1.

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 using an empirical distribution. For all representative vineyards, there is no increase in the deterministic yield over the 10-year projection period, meaning the range of yield risk each year is the same.

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. Equation (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 means for the stochastic variables over the 2015-2024 study period were the baseline price and yield for year one provided by the panel of wine grape producers for each given state. The baseline deterministic price and yield were held constant throughout the 10-year projection period for New York and both Texas representative vineyards, based on panel input. For Washington, the panel advised to increase the price by 3 percent every third year to take into account the three-year contract arrangements that are common there. For Oregon, the deterministic price is increased by 3% each year. 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. Texas and New York both have multi-peril crop insurance with 65 percent yield coverage and 100 percent price coverage, while Washington and California have catastrophic (CAT) coverage with 50 percent yield coverage and 55 percent price coverage. Crop insurance indemnity payments (A.4) were calculated when the stochastic wine grape yield was less than the guaranteed yield (yield coverage percent x average production history (APH) yield). The difference was 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 include 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 costs (A.34) were 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 15-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 analyses are presented in Tables 2 and 3 for the two Texas representative vineyards (TX 50, TX 100); and Oregon, Washington, New York and California representative vineyards. Table 2 contains the 10-year mean, standard deviation, coefficient of variation, and the minimum and maxim values from the simulations for 2015-2024 for the following key output variables (KOV): total cash receipts, net cash vineyard income (NCVI), net vineyard income (NVI), ending cash reserves, short-term carryover debt, and real net worth. The 10-year mean total cash receipts vary from $89,442 (Oregon) to $1.6 million (Washington) due to the wide range in vineyard size while the coefficient of variation is relatively similar for each representative vineyard, ranging from 19.8% (California) to 27.3% (TX 100 ac). In terms of profitability, the mean NVI is negative for the TX 100 (-$29,468), Oregon (-$29,543), and New York (-$21,541); while NVI for TX 50, Washington, and California are $117,000, $264,000, and $523,000, respectively. More detail regarding these results on an annual basis can be found in the discussion of Table 3.

The annual mean results for the key output variables (KOV) for each representative vineyard are presented in Table 3. The mean total cash receipts for TX 50, TX 100, and New York are relatively stable each year because there is no annual yield or price inflation factor for these three representative vineyards. Due to the previously described price inflation factor Oregon, California, and Washington, the mean total cash receipts for these three vineyards trends up over the 10-year projection period. TX 50 has a higher mean NVI than TX 100 due to TX 50 having a 6 ton per acre deterministic yield, compared to 4 tons for TX 100. Each of the representative vineyards has a positive NCVI throughout the 10-year projection period. When depreciation is taken into account, TX 100, Oregon, and New York have a negative mean NVI throughout the projection period, except in year 1 for TX 100 and New York. TX 50, Washington, and California all show strong profits throughout the projection period.

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

	TX 50 ac.	TX 100 ac.	Oregon	Washington	New York	California
Total Cash Receipts						
Mean	$494,996	$662,107	$89,442	$1,673,331	$348,884	$1,079,562
Standard Deviation	$134,481	$180,650	$22,806	$360,004	$86,003	$213,326
Coefficient of Variation (%)	27.2	27.3	25.5	21.51	24.7	19.8
Minimum	$213,154	$284,451	$46,818	$999,940	$125,403	$648,602
Maximum	$800,414	$1,069,139	$151,323	$2,404,065	$486,729	$1,602,950
Net Cash Vineyard Income						
Mean	$199,512	$130,578	$7,501	$653,782	$78,853	$645,838
Standard Deviation	$136,236	$186,066	$21,670	$357,415	$88,528	$218,629
Coefficient of Variation (%)	68.3	142.5	288.9	54.7	112.3	33.9
Minimum	-$128,603	-$352,333	-$40,985	-$59,567	-$197,324	$204,321
Maximum	$537,107	$601,884	$66,037	$1,312,014	$244,727	$1,181,511
Net Vineyard Income						
Mean	$117,350	-$29,468	-$29,543	$264,809	-$21,541	$523,028
Standard Deviation	$136,464	$186,649	$24,854	$372,396	$89,812	$228,522
Coefficient of Variation (%)	116.3	-633.4	-84.1	140.6	-416.9	43.7
Minimum	-$185,802	-$464,092	-$79,756	-$472,462	-$284,311	$96,082
Maximum	$487,335	$502,512	$46,210	$1,082,517	$184,733	$1,097,692
Ending Cash Reserves						
Mean	$316,077	$120,185	$1,525	$1,428,157	$83,635	$1,226,228
Standard Deviation	$258,081	$186,615	$7,560	$946,557	$107,627	$829,099
Coefficient of Variation (%)	81.7	155.3	495.6	66.3	128.7	67.6
Minimum	$0	$0	$0	$0	$0	$0
Maximum	$1,399,903	$1,359,585	$132,818	$4,964,706	$535,080	$3,440,892
Short Term Carryover Debt						
Mean	$16,462	$194,541	$75,611	$6,225	$78,704	$19
Standard Deviation	$63,146	$307,536	$59,682	$45,932	$146,064	$241
Coefficient of Variation (%)	383.6	158.1	78.9	737.9	185.6	1,291.6
Minimum	$0	$0	$0	$0	$0	$0
Maximum	$1,073,496	$2,357,354	$348,632	$1,119,504	$1,267,066	$3,178
Real Net Worth						
Mean	$458,452	$311,781	$69,852	$2,197,259	$168,110	$2,762,151
Standard Deviation	$248,771	$347,606	$47,730	$824,456	$179,669	$1,223,214
Coefficient of Variation (%)	54.3	111.5	68.3	37.5	106.9	44.3
Minimum	-$579,540	-$1,429,413	-$128,589	$181,611	-$773,041	$937,734
Maximum	$1,365,101	$1,499,267	$249,938	$5,014,669	$635,645	$5,398,961

In regard to cash flow, all the representative vineyards have a 2015 beginning cash balance of zero. In terms of cash flow ability, TX 50, Washington, and California demonstrate strong growth in ending cash reserves, as evidenced by their mean ending cash reserves (2024) of $429,119, $2.39 million, and $2.62 million, respectively. The mean ending cash reserves for TX 100 peaks in 2020 at $150,276, but then declines to $77,567 at the end of 2024 due to inflation and new debt service associated with equipment trades in the latter years. The 10 acre Oregon representative vineyard has a mean ending cash reserves in 2024 of $2,549. The mean ending cash reserves for New York peaks in 2021 at $107,020, then declines to $71,936. All the representative vineyards, except for California, show varying levels of mean short-term carryover debt at the end of 2024, meaning there is some probability of these representative vineyards having unpaid carryover debt. These mean carryover debt levels are $31,765 (TX 50), $443,184 (TX 100), $118,477 (Oregon), $2,103 (Washington), $172,770 (New York), and $1 (California).

California shows the highest mean change in real net worth (from beginning of 2015 to the end of 2024) with a 345% increase, followed by Washington at 181%. Due to profitability and cash flow problems, real net worth for TX 100 and Oregon declined by 48% and 46%, respectively.

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

	TX 50 ac.	TX 100 ac.	Oregon	Washington	New York	California
Total Cash Receipts						
2015	$492,410	$658,367	$77,945	$1,600,010	$348,718	$842,387
2016	$493,292	$659,846	$80,333	$1,600,063	$349,032	$887,899
2017	$493,560	$660,587	$82,783	$1,647,988	$348,870	$935,844
2018	$493,744	$660,997	$85,228	$1,648,048	$349,123	$986,398
2019	$495,799	$663,003	$87,782	$1,648,038	$348,715	$1,039,626
2020	$495,427	$661,999	$90,528	$1,697,453	$348,670	$1,095,770
2021	$495,621	$662,587	$93,217	$1,697,465	$348,766	$1,154,973
2022	$496,607	$664,847	$95,921	$1,697,488	$348,894	$1,217,315
2023	$497,453	$663,562	$98,837	$1,748,341	$349,102	$1,283,058
2024	$496,045	$665,276	$101,844	$1,748,416	$348,950	$1,352,351
2015-2024 Average	$494,996	$662,107	$89,442	$1,673,331	$348,884	$1,079,562
Net Cash Vineyard Income						
2015	$229,112	$191,134	$4,550	$681,902	$106,719	$398,106
2016	$224,194	$180,989	$5,446	$665,308	$102,102	$446,392
2017	$218,381	$169,288	$6,182	$693,392	$96,544	$496,391
2018	$212,073	$156,703	$6,839	$671,686	$91,064	$549,204
2019	$207,033	$144,543	$7,537	$648,852	$84,543	$604,429
2020	$198,667	$127,163	$7,971	$671,662	$77,448	$662,490
2021	$188,563	$108,959	$8,712	$637,142	$68,562	$723,815
2022	$179,871	$93,964	$8,467	$612,649	$60,751	$788,660
2023	$173,437	$75,427	$9,371	$639,821	$54,723	$857,979
2024	$163,789	$57,614	$9,939	$615,406	$46,073	$930,912
2015-2024 Average	$199,512	$130,578	$7,501	$653,782	$78,853	$645,838
Net Vineyard Income						
2015	$179,341	$91,762	-$18,752	$441,016	$46,725	$325,086
2016	$124,661	-$17,735	-$41,122	$183,434	-$17,761	$300,343
2017	$118,985	-$29,163	-$40,266	$211,790	-$22,991	$350,432
2018	$112,844	-$41,415	-$39,480	$190,539	-$28,138	$403,371
2019	$107,873	-$53,435	-$38,703	$167,723	-$34,425	$458,627
2020	$100,121	-$70,051	-$37,731	$191,420	-$41,224	$516,803
2021	$92,115	-$86,104	-$37,483	$163,943	-$48,264	$578,148
2022	$105,342	-$45,020	-$22,205	$269,259	-$33,021	$675,501
2023	$121,025	-$12,372	-$9,796	$426,698	-$13,120	$774,875
2024	$111,191	-$31,148	-$9,888	$402,267	-$23,191	$847,092
2015-2024 Average	$117,350	-$29,468	-$29,543	$264,809	-$21,541	$523,028

Table 3 Continued.

	TX 50 ac.	TX 100 ac.	Oregon	Washington	New York	California
Ending Cash Reserves						
2015	$86,320	$71,645	$1,842	$263,970	$38,055	$129,441
2016	$157,694	$111,660	$1,599	$535,031	$63,846	$305,661
2017	$221,807	$133,940	$1,034	$819,920	$80,584	$504,785
2018	$277,646	$144,624	$635	$1,078,005	$88,915	$727,769
2019	$323,639	$142,630	$364	$1,304,161	$91,713	$975,260
2020	$378,337	$150,276	$921	$1,630,256	$106,525	$1,261,988
2021	$417,908	$140,352	$1,780	$1,896,266	$107,020	$1,575,888
2022	$432,134	$125,469	$2,198	$2,094,786	$100,414	$1,903,370
2023	$436,160	$103,689	$2,333	$2,262,923	$87,340	$2,250,269
2024	$429,119	$77,567	$2,549	$2,396,255	$71,936	$2,627,846
2015-2024 Average	$316,077	$120,185	$1,525	$1,428,157	$83,635	$1,226,228
Short Term Carryover Debt						
2015	$17,067	$56,377	$17,952	$21,850	$24,317	$186
2016	$14,614	$78,209	$33,830	$10,442	$33,479	$1
2017	$13,464	$98,971	$49,822	$5,882	$42,111	$1
2018	$13,863	$125,545	$66,559	$5,719	$51,184	$1
2019	$13,659	$157,318	$84,025	$6,522	$64,574	$1
2020	$10,667	$175,224	$87,359	$3,859	$73,657	$1
2021	$13,199	$204,462	$90,891	$1,749	$84,671	$1
2022	$14,936	$262,934	$99,270	$1,610	$106,146	$1
2023	$21,388	$343,190	$107,924	$2,515	$134,134	$1
2024	$31,765	$443,184	$118,477	$2,103	$172,770	$1
2015-2024 Average	$16,462	$194,541	$75,611	$6,225	$78,704	$20
Real Net Worth						
2015	$235,533	$337,878	$105,099	$1,121,917	$118,857	$1,070,167
2016	$300,916	$348,906	$86,482	$1,371,077	$135,469	$1,242,876
2017	$367,374	$368,890	$78,248	$1,678,946	$162,410	$1,654,173
2018	$423,564	$375,422	$70,984	$1,947,232	$181,764	$2,072,582
2019	$470,101	$369,025	$64,574	$2,173,010	$192,932	$2,491,647
2020	$512,540	$354,137	$61,820	$2,398,880	$195,526	$2,904,022
2021	$548,688	$329,001	$60,438	$2,606,517	$195,054	$3,341,894
2022	$571,626	$283,602	$59,884	$2,784,028	$187,095	$3,810,775
2023	$577,299	$214,417	$56,619	$2,897,335	$168,116	$4,273,652
2024	$576,875	$136,535	$54,369	$2,993,643	$143,876	$4,759,727
2015-2024 Average	$458,452	$311,781	$69,852	$2,197,259	$168,110	$2,762,151
Beginning Real Net Worth	$233,029	$344,933	$105,359	$1,133,379	$126,182	$1,071,445
% Change	145.00%	-48.00%	-46.00%	181.00%	57.00%	345%

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 1-6 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. To illustrate, 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 a good financial position if their probability of having a cash flow deficit is less than 25%, and the probability of experiencing a decline in real net worth over the 10-year projection period is less than 25%. A vineyard is considered to be in marginal financial position if these probabilities are between 25% and 50% and in poor financial position if these probabilities are greater than 50%.

The probability of TX 50 (Figure 1) having a cash flow deficit ranges between 8% and 27% over the 10-year projection period, and is below 15% the last 9 years. TX 50 has a 12% probability of losing real net worth over the 10-year projection period. This representative vineyard is in good financial condition. For TX 100 (Figure 2), NCVI declines over the 10-year projection period while the probability of having a cash flow deficit is on an increasing trend, ranging from 41% to 75% and is greater than 50% the last 5 years. With a 67% probability of losing real net worth, TX 100 is considered to be in poor financial condition. NCVI for Oregon (Figure 3) is relatively flat over the 10-year projection period but is not at a level to cash flow the vineyard. The probability of having a cash flow deficit ranges between 78% and 96%, while the probability of losing real net worth is 79%; indicating the Oregon vineyard is in poor financial condition. Washington (Figure 4) generates a mean NCVI in the $600,000 to $700,000 range with variability around the mean ranging from slightly below zero (5th percentile) on the low side, to $1.3 million on the high side (95th percentile). The probability of incurring a cash flow deficit is 16% or less each year while the probability of losing real net worth is 1%; indicating this vineyard is in good financial condition. NCVI for New York (Figure 5) is on a declining trend while the probability of having a cash flow deficit increases from 27.4% in 2015 to 46.8% in 2022; then climbs to over 50% in 2023 and 2024. New York also has a 43% probability of losing real net worth. This vineyard is in marginal financial condition, but it is on the verge of being in poor financial condition. With California's strong profit growth over the 10-year projection period, it has a low, 6% probability of incurring a cash flow deficit in 2015, which declines to 1% the remainder of the projection period. With California also have just a 1% probability of experiencing a decline in real net worth. California is in good financial position.

Figure 1. TX 50 Representative Vineyard

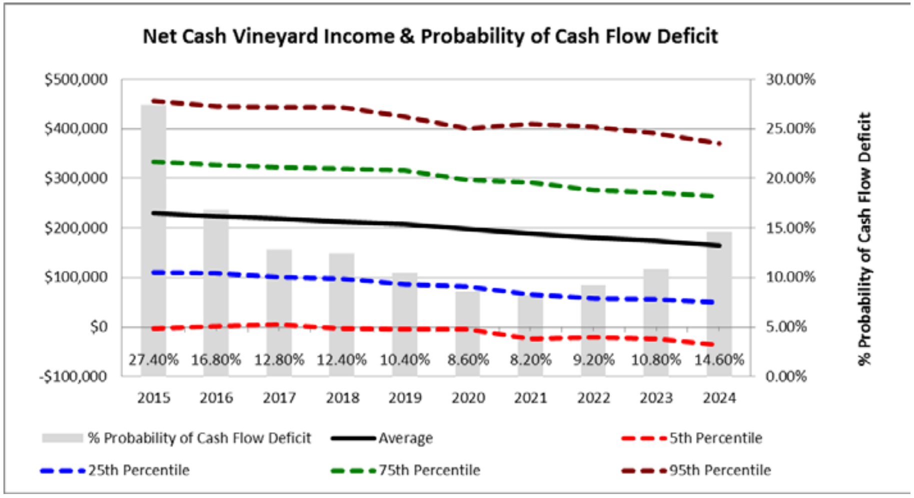


Figure 2. TX 100 Representative Vineyard

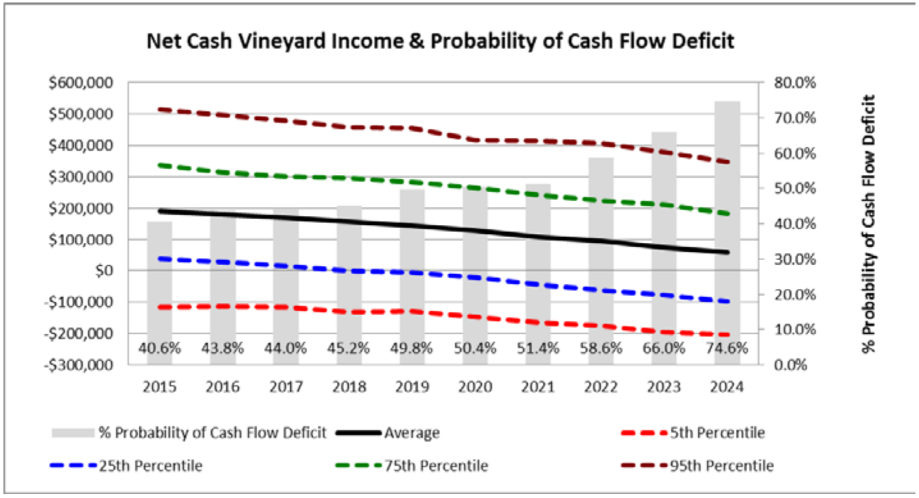


Figure 3. Oregon Representative Vineyard

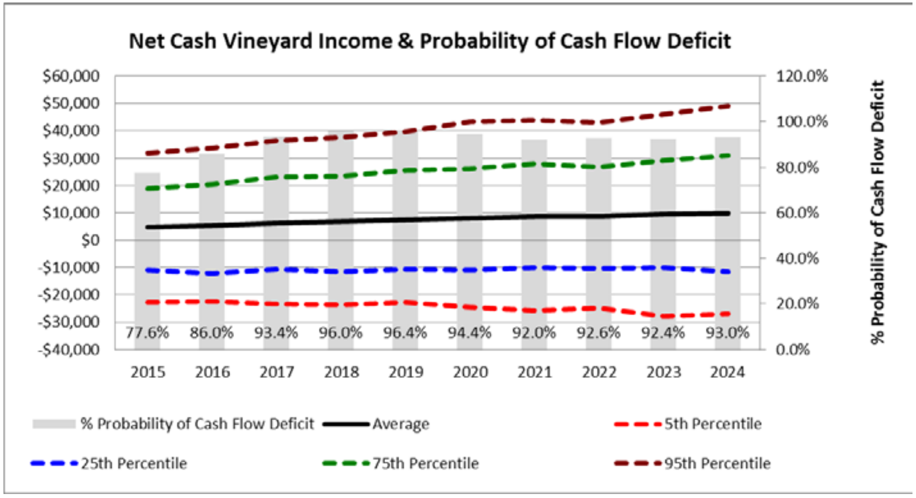


Figure 4. Washington Representative Vineyard

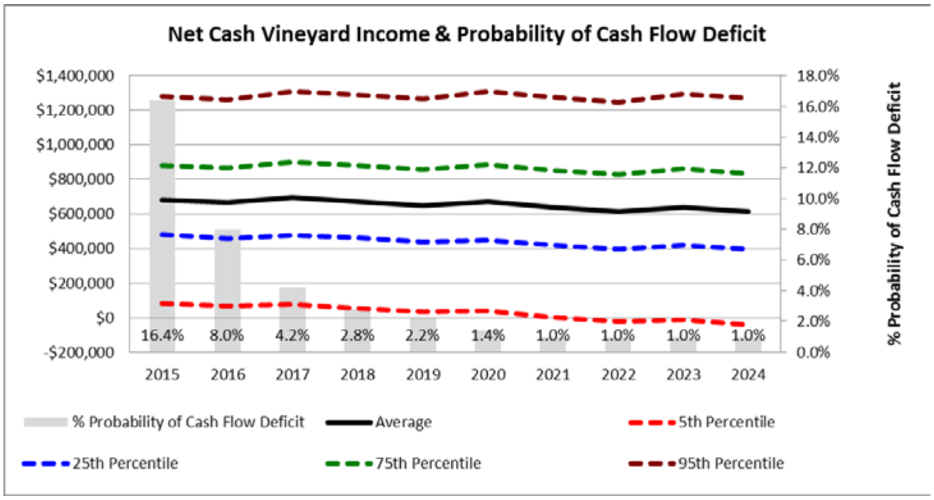


Figure 5. New York Representative Vineyard

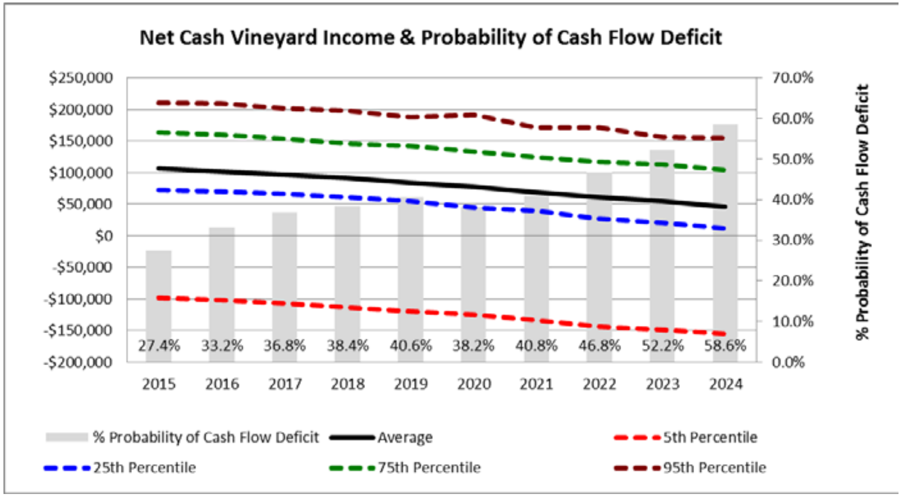
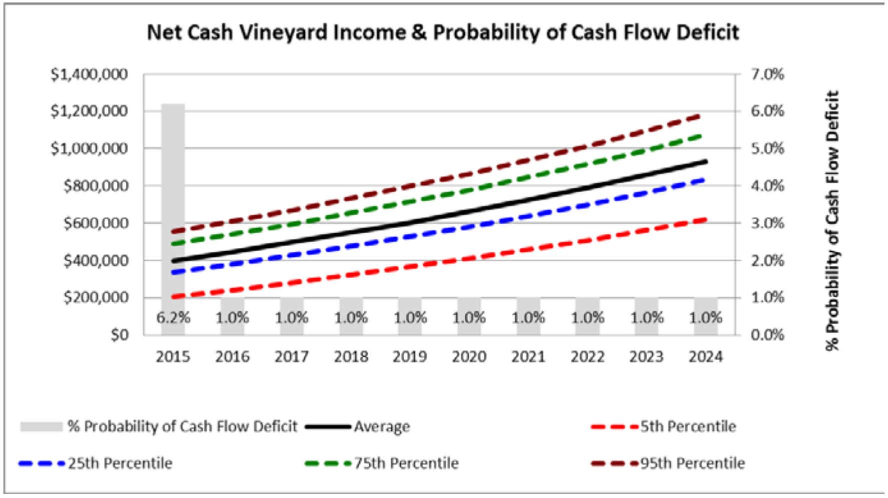


Figure 6. California Representative Vineyard



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 that are presented in terms of labor usage (hours) in Table 4, and labor costs in Table 5. Washington, which relies on less labor than the other vineyards, has the lowest labor usage per acre (82.7 hours) and labor cost per acre ($997.60), while Oregon has the highest labor usage per acre (250.5 hours) and labor cost per acre ($3,953.00). 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, like Washington, equipment operator hours and costs are a significant portion of total labor costs.

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

	TX Small Wine	TX Large Wine	OR Wine	WA Wine	NY Wine	CA Wine
Floor Management - Dormant Season	0.60	0.60	0.00	1.20	5.00	0.00
Pruning	54.00	49.00	57.50	18.50	62.17	52.00
Canopy Management	42.10	42.10	136.50	39.00	48.15	72.00
Floor Management - Growing Season	1.80	1.80	6.50	2.10	0.70	3.00
Weed Management - Vine Row	24.20	8.20	2.00	6.40	3.00	1.00
Irrigation	0.00	0.00	4.00	10.00	0.00	3.30
Chemical/Pest Control	1.80	1.80	20.00	3.50	2.90	8.00
Harvest	11.00	11.00	24.00	2.00	22.50	0.00
Total Labor Hours per Acre	**135.50**	**114.50**	**250.50**	**82.70**	**144.42**	**139.30**
Total Vineyard Acres	50	100	10	250	50	30
Total Vineyard Labor Hours	**6,775**	**11,450**	**2,505**	**20,675**	**7,221**	**4,179**
Equipment Operator Hours per Acre (1)	23.5	23.5	22.5	12.3	17.05	14
Equipment Operator Vineyard Labor Hours (1)	1,175	2,350	225	3,075	853	420

(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 Small Wine	TX Large Wine	OR Wine	WA Wine	NY Wine	CA Wine
Floor Management - Dormant Season	$12.25	$12.25	$0.00	$16.80	$92.50	$0.00
Pruning	$707.13	$648.98	$883.00	$206.50	$837.69	$1,123.20
Canopy Management	$499.29	$499.29	$1,923.00	$486.00	$637.99	$1,568.00
Floor Management - Growing Season	$36.75	$36.75	$117.00	$29.40	$12.95	$84.00
Weed Management - Vine Row	$318.36	$132.28	$28.00	$74.90	$55.50	$28.00
Irrigation	$0.00	$0.00	$56.00	$110.00	$0.00	$71.28
Chemical/Pest Control	$36.76	$36.76	$316.00	$49.00	$53.67	$224.00
Harvest	$171.88	$171.88	$630.00	$25.00	$300.00	$0.00
Total Labor Costs per Acre	**$1,782.42**	**$1,538.19**	**$3,953.00**	**$997.60**	**$1,990.30**	**$3,098.48**
Total Vineyard Acres	50	100	10	250	50	30
Total Vineyard Labor Costs	**$89,121**	**$153,819**	**$39,530**	**$249,400**	**$99,515**	**$92,954**
Equipment Operator Labor Cost per Acre (1)	$480	$480	$395	$172	$315	$392
Equipment Operator Labor Costs (1)	$23,993	$47,986	$3,950	$43,050	$15,773	$11,760

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

If new technology can be developed – and made available commercially to growers - to perform some of these tasks that are currently performed by humans, 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 (rather than 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 representative vineyard. In general, the tasks with highest NPVs are finish spur pruning, cane pruning (applicable to Oregon and New York), cane tying (Oregon), cordon tying, shoot positioning/green tying, and contract manual harvest. For the total NPV of all labor, which takes into account the size of each vineyard, the NPVs of the labor expense cash outflows over 10 years are $15,807 for TX 50, $13,641 for TX 100, $35,057 for Oregon, $8,847 for Washington, $17,651 for New York, and $27,446 for California. The equipment operator labor portion of these NPVs range from $1,527 for Washington to $4,256 for TX 50 and TX 100.

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.	Oregon NPV per ac.	Washington NPV per ac.	New York NPV per ac.	California NPV per ac.
Remove Cover Crop	$109	$109				
In-row Herbicide and Insecticide				$74		
In-row Pre-emergent Herbicide				$74		
Hillinp-Up					$328	
Take-Away (de-hilling)					$492	
Pre-Prune (mechanical)	$543	$543		$62		$2,490
Finish Spur Prune	$4,641	$4,126		$1,317		$7,471
Cane Prune			$2,873		$4,302	
Tie Canes (Cane-trained)			$2,235			
Tie Cordons			$2,235	$390	$2,438	
Pull/Rake Brush	$905	$905		$62		
Shred Brush	$181	$181	$239		$197	
Trellis Maintenance and Repair			$248		$492	
Cordon/Shoot Thinning			$1,862	$1,171	$1,163	$1,916
Sucker Removal w/ Herbicide	$109	$109		$124	$814	
Sucker Removal - manual	$825	$825	$3,104			$2,873
Disbudding			$3,725			
Shoot Positioning/green tying	$2,578	$2,578	$869		$1,616	
Move Catch Wires Up	$413	$413	$2,483	$488	$930	$3,256
Move Catch Wires Down	$413	$413		$293	$930	
Leaf Pulling - manual			$497			
Leaf Pulling - mechanical	$91	$91	$479	$124	$205	$497
Color Set						$3,448
Cluster Thinning			$3,725	$2,111		$1,916
Hedging			$310			
Mowing Vineyard Floor			$479	$186	$115	$248
Till Alleyway - mechanical	$217	$217	$479			$497
Plant Winter Cover Crop	$109	$109	$80	$74		
Pre-emergent Herbicide	$109	$109				
Post-emergent Herbicide	$435	$435	$248	$186	$427	$216
Hoeing/Hand Pulling	$2,063	$413				
Post-emergent Herbicide (Spot Spray)	$217	$217			$66	
Crop Estimation				$29		
Green Thinning				$449		
Irrigation Management			$497	$976		$632
Fungicides	$272	$272	$1,117	$372	$476	$1,490
Insecticides	$54	$54	$319	$62		$497
Bird & Rodent Control			$1,366			
Hedging to Facilitate Machine Harvest	$181	$181				
Contract Manual Harvest			$5,587		$2,661	
Bin Handling and Hauling	$724	$724		$124		
Harvest Support Labor (field)	$619	$619		$98		
Total	**$15,807**	**$13,641**	**$35,057**	**$8,847**	**$17,651**	**$27,446**
Equipment Oper. Labor Costs NPV per Acre	$4,256	$4,256	$3,503	$1,527	$2,798	$3,444

Summary and Conclusions

Representative wine grape grower panels in five 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 three 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 two are in poor condition. These results are an indication that one-half of the growing areas evaluated in this study are in need of improved financial conditions that could potentially come from new technology. Also, managers of vineyards in areas that are in good financial condition (in this study) expressed an interest in robotic technology due to concerns about labor availability.

Equipment operator and field labor usage and cost data provided by the grower panels show a wide range across the representative vineyards with labor hours per acre ranging from 82 to 250 hours, and labor costs ranging from $997 to $3,953 per acre. Equipment operator labor and costs alone is also significant, especially for those vineyards that rely more on mechanization. The NPV of labor costs over 10 years was presented for production tasks that may be conducive for robotic technology. Considering all six representative vineyards, there are 12 production tasks that have a NPV of more than $2,000; ranging from $2,235 for tying canes to $7,471 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*$_t$ x [1 + *Empirical*(S_i, $F(S_i)$)]
(A.2) *Grape Yield*$_t$ = *Mean Yield*$_t$ x [1 + *Empirical*(R_i, $F(R_i)$)]

Income

(A.3) *Wine Grape Sales*$_t$ = *Grape Price*$_t$ x *Grape Yield*$_t$ x *Number of Acres*
(A.4) *Crop Insurance Indemnity Payment*$_t$ = (*Guaranteed Yield*$_t$ – *Grape Yield*$_t$) x *Established Price [When grape yield is less than the guaranteed yield] x Number of Acres*
(A.5) *Land Rental Income*$_t$ = *Number of Acres* x *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*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.8) *Fungicide Cost*$_t$ = *Fungicide Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.9) *Insecticide Cost*$_t$ = *Insecticide Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.10) *Herbicide Cost*$_t$ = *Herbicide Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.11) *Tying Material Cost*$_t$ = *Tying Material Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.12) *Soil Sampling Cost*$_t$ = *Soil Sampling Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.13) *Trellis Repair Cost*$_t$ = *Trellis Repair Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acre*s
(A.14) *Vine Cost*$_t$ = *Vine Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.15) *Rodent Control Cost*$_t$ = *Rodent Control Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.16) *Propane Cost*$_t$ = *Propane Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.17) *Seed Cost*$_t$ = *Seed Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.18) *Irrigation Cost*$_t$ = *Irrigation Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.19) *Custom Contract Cost*$_t$ = *Custom Contract Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.20) *Machinery Labor Cost*$_t$ = *Machinery Labor Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.21) *Non Machinery Labor Cost*$_t$ = *Non Machinery Labor Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.22) *Fuel Cost*$_t$ = *Fuel Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.23) *Lube Cost*$_t$ = *Lube Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.24) *Machinery Repair Cost*$_t$ = *Machinery Repair Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.25) *Buildings & Tools Maintenance & Repair Cost*$_t$ = *Buidlings & Tools Maintenance & Repair Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *Number of Acres*
(A.26) *Management Cost*$_t$ = *Management Cost*$_{t-1}$ x (1 + *Inflation Rate*$_t$) x *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-Employment and Social Security Taxes*$_t$ = (*Positive Net Vineyard Income*$_t$ x *Self-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) $\textit{Assets}_t = \textit{Land Value} + \textit{Book Value Farm Machinery}_t + \textit{Positive Ending Cash}_t$

(A.56) $\textit{Liabilities}_t = \textit{Long Term Loan Debt}_t + \textit{Intermediate Loan Debt}_t + \textit{Establishment Costs Debt}_t + \textit{Short Term Loan Debt}_t$

(A.57) $\textit{Nominal Net Worth}_t = \textit{Assets}_t - \textit{Liabilities}_t$

(A.58) $\textit{Real Net Worth}_t = (\textit{Inflation Rate Year 1} \div \textit{Inflation Rate}_t) \times \textit{Nominal Net Worth}_t$

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).