ECONOMIC IMPACTS OF USING VIRUS-TESTED GRAPEVINES

A Thesis

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ABSTRACT

Grapevine leafroll disease (GLRD) is one of the most important virus diseases of grapevines around the country and the world. The disease reduces yields, delays fruit ripening, reduces soluble solids and can cause irregular or undesirable flavors. One response to minimize economic losses from GLRD, is the use of virus-tested grapevines. This study constructs a cost benefit analysis of using this material in California and New York. Benefits arise from the reduction in costs and increase in yield due to the reduction of disease prevalence from planting screened material and optimally managing the disease. Virus-tested material is available to nurseries and growers from grape centers including Foundation Plant Services in Davis, California and New York State Agriculture Experiment Station in Geneva, NY. Over the period 2006-2015 in California, estimated cumulative benefits by 2015 are $1.51 billion (2002 dollars) and cumulative costs to operate Foundation Plant Services in Davis, CA, amount to $12.9 million, a benefit to cost ratio of 117. Projecting over the next ten years, by 2025 cumulative net benefits (benefits-costs) will reach an estimated $3.26 billion. Across the country in New York, benefits do not accrue until 2020 due to later adoption of virus-tested material. We estimate cumulative benefits reach $19.5 million and funding from the National Clean Plant Network (NCPN) to operate the grape center in Geneva, NY totals $2.7 million by 2025. Additionally, this thesis conducts a welfare analysis to determine the distribution of net benefits within California between grape producers and wine producers who purchase grapes to crush. The results suggest that grape growers receive most benefits because supply is inelastic relative to demand. These findings are valuable to understand the return of public and private investment in grape centers that produce virus-tested stocks for the industry, as well as help the industry understand the economic benefits of using the material, incentivizing stronger adoption.

BIOGRAPHICAL SKETCH

Jason Troendle was born August 18, 1991 in Rochester, MN. He grew up in the small town of St. Charles, MN before attending Bethel University in St. Paul. After three semesters and a year away from school serving the National FFA Organization, Jason transferred to Kansas State University in Manhattan, KS for his undergraduate in Agricultural Economics. He is a Master's of Science candidate in Applied Economics and Management at Cornell University. Jason has accepted a position as a Senior Business Analyst with Context, an agricultural consulting firm.

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Chapter I

INTRODUCTION

Viruses and related plant pathogens impose high costs on crop producers, yet no effective control besides the destruction of virus-infected material exists. Left uncontrolled, pathogens cause crop diseases that cost producers and consumers billions of dollars annually (Fuller, Alston, & Golino, 2015). Present in almost all grape and wine regions in the US (M. Fuchs, Marsella-Herrick, Loeb, Martinson, & Hoch, 2009; Golino, Weber, Sim, & Rowhani, 2008; Martin, Eastwell, Wagner, Lamprecht, & Tzanetakis, 2005) and around the world (Charles, Froud, van den Brink, & Allan, 2009; Freeborough & Burger, 2006; Martelli & Boudon-Padieu, 2006), grapevine leafroll viruses account for some of the most serious pathogens of grapes (Rayapati, Rowhani, Fuchs, Golino, & Martelli, 2014).

Grapevine leafroll disease (GLRD) causes significant yield loss (30-68%), delays fruit ripening, reduces soluble solids (Brix), increases titratable acidity, reduces tannin content in berry skin, and causes irregular or undesirable flavor profiles (Goheen & Cook, 1959; Martelli & Boudon-Padieu, 2006; Martinson, Fuchs, Loeb, & Hoch, 2008; Rayapati et al., 2014). Vegetative propagation and grafting readily transmits all grapevine leafroll-associated viruses (GLRaVs) and several species of mealybugs (Hemiptera: Pseudococcidae) and soft scale insects (Hemiptera: Coccidae) vector the viruses (Martelli & Boudon-Padieu, 2006; Tsai, Rowhani, Golino, Daane, & Almeida, 2010). Several existing studies estimate the economic impact of leafroll (S. S. Atallah, Gómez, Fuchs, & Martinson, 2012; Fuller et al., 2015; Ricketts et al., 2015).

To reduce economic losses, vineyard managers adopt different strategies to control grapevine leafroll disease. Many simply tolerate the disease without any control, despite its detrimental impact on yield and fruit quality. Other managers, spray insecticides targeting mealybugs and/or rogue (remove) and replace infected vines with healthy ones, while a few decide to replant entire infected vineyard blocks (S. S. Atallah et al., 2012). Planting vines with GLRD-tested rootstock and scion material while removing (roguing) symptomatic vines and replanting with GLRD-tested vines is the most effective management tool (Fuller et al., 2015). Several public grapevine clean plant centers established throughout the United States provide nurseries and growers these virus-screened plants. Disease management decisions depend upon a number of parameters that affect economic damages, including reduced yields, possible penalties to grape quality, and costs of controlling the disease.

To our knowledge, no studies to date conduct a cost-benefit analysis of using certified, virus-tested stock for wine grapes. This study first estimates economic benefits of planting certified, virus-tested grapevines in California and New York over the period between 2006 and 2015. We compare these benefits from a reduction of the incidence of GLRD to costs of public and private investments to operate clean plant centers that produce disease-tested grapevine stock. We project future benefits and costs to year 2025 to help evaluate the returns to the public investment over this 20-year period. Once net benefits and costs are determined, we conduct a welfare analysis to determine how grape growers or wine producers bear the costs and enjoy the benefits of the investment. These results could inform political decisions for investments in grape centers and other clean plant centers assisting in maintaining viable specialty crop industries in the United States.

1.1 Wine and Wine Grape Industry – California and New York

The United States population consumed over 3.2 million liters of wine in 2014, ranking number one in the world followed by France, Italy, and Germany (Trade Data and Analysis

(TDA), 2015a). Per resident wine consumption in the country increased from 0.26 gallons in 1934, to 2.05 gallons in 1990, to an all-time high of 2.83 gallons in 2015 (BW166/Gomberg, Fredrikson & Associates, 2016). The California wine industry alone contributed $114 billion in economic activity during 2015 (Dunham & Associates, Inc., 2016b). France, Italy, and Spain lead global wine production, followed fourth by the United States (Trade Data and Analysis (TDA), 2015a).

To support this wine demand and consumption, California, produces the most tons of grapes while cultivating the most acres on an annual basis in the U.S., according to the National Agricultural Statistical Service (NASS). In 2016, S.S. total grape production including table, raisin, and wine grapes, reached nearly 8 million tons, with California, Washington, and New York the top three producing states in terms of total tons for all grapes. California and Washington produced 3.9 and 0.25 million tons of wine grapes in 2016, respectively. Pennsylvania, Michigan, and Oregon produced over 50,000 tons of all types of grapes with Texas, Virginia, Missouri and Ohio rounding out the top ten. Table 1 shows the 2016 production by state ("USDA/NASS QuickStats," 2017).

Table 1. Top ten grape producing states in 2016 (tons)

California	6,900,000
Washington	480,000
New York	165,000
Pennsylvania	91,000
Michigan	88,000
Oregon	62,000
Texas	12,500
Virginia	9,000
Missouri	6,500
Ohio	5,000

Source: ("USDA/NASS QuickStats," 2017)

With its optimal growing conditions and the availability of irrigation water, California alone ranks fourth in wine production worldwide, only behind France, Italy, and Spain (Trade Data and

Analysis (TDA), 2015b). On average, California accounted for 89% of the U.S. production annually during 2007-2016 ("USDA/NASS QuickStats," 2017). Figure 1 shows California's production relative to the entire country showing all other states produced less than one million tons annually.

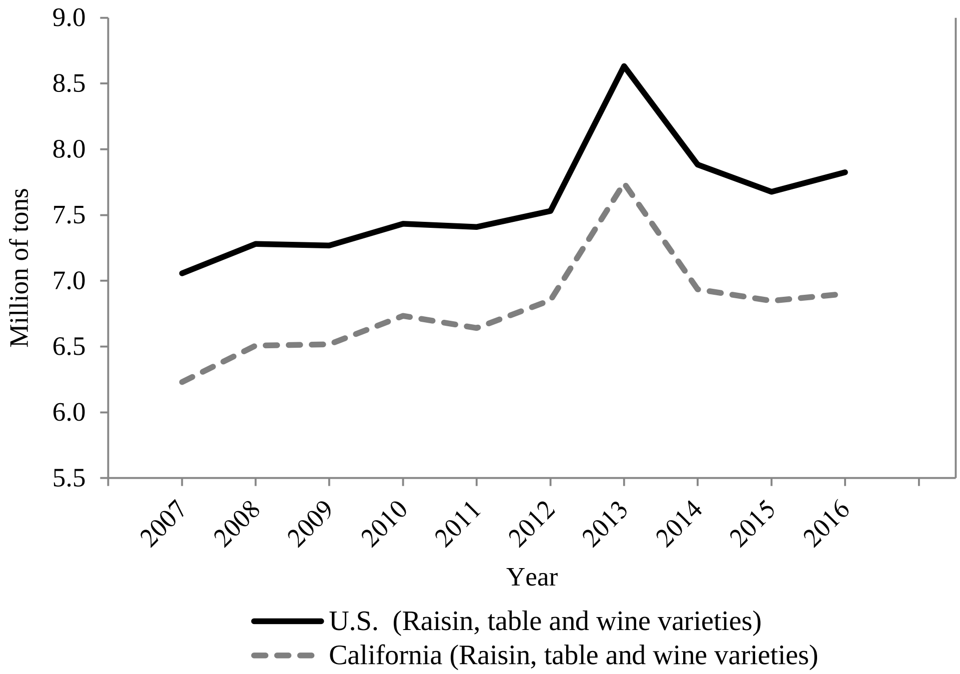

Figure 1. Grape Production

More than 110 wine grape varieties grown in the state contribute to total production. In the U.S. market in 2015, 229 million cases sold of California wine, at an estimated retail value of $31.9 billion (Dunham & Associates, Inc., 2016a).

Different soil and climate conditions in the state of New York form a market composed of different cultivars. Average annual wine grape production over 2007-2015 in the state totaled just over 44,000 tons, according to NASS (2017). Over the past decade, wine grape prices received by New York growers more than doubled from $369/ton in 2002, to $797/ton in 2015. Total grape bearing acreage (wine and juice grapes) remained constant from 2007 to 2015 at

37,000 acres statewide ("USDA/NASS QuickStats," 2017). The economic impact of the grapes, grape juice, wine, and grape products in New York during 2012 amounted to approximately $4.8 billion. Growing over time, the sector's estimated economic value in 2005 amounted to$3.14 billion and $3.76 billion in 2008 (Stonebridge Research Group LLC, 2014; Trezise, 2014). New York is an important contributor to the wine market behind California, particular in cool climate regions.

1.2 Grapevine Leafroll Disease

The future success of modern agriculture in California, New York, the United States and globally, depends on the ability of the industry to adapt while fighting off viruses and diseases. Given its prevalence, past studies focus on the spread, effect on growth, and epidemiology of leafroll disease for grapes (GLRD) (Charles et al., 2009; M. Fuchs et al., 2009; Goheen & Cook, 1959; Golino et al., 2008; Martelli & Boudon-Padieu, 2006; Martin et al., 2005; Martinson et al., 2008; Rayapati et al., 2014; Tsai et al., 2010). While the disease affects all types of grapes – wine, raisin, juice and table – much focus has been on its affects specifically for wine grapes. According to a guide from Washington State University Extension (2008), disease symptoms vary depending on cultivar, making identification on visual signs alone a challenge for the disease. GLRD occurs more visibly pronounced in red-fruited *V. vinifera* cultivars than white-fruited cultivars. Physical signs generally begin as grapes ripen, with the appearance of red or reddish-purple discolorations in the interveinal areas of mature leaves. By the late part of the season when the disease is advanced enough, infected leaves will roll downward, hence the common name of the disease (Rayapati, O'Neal, & Walsh, 2008). Checking visual symptoms combined with testing plant material, including a woody index, lab assays such as antiserum-based ELISA (enzyme-linked immunosorbent assay), nucleic acid-based PCR (polymerase chain reaction) (Cieniewicz & Fuchs, 2015), or more recently with high frequency DNA sequencing, allows faster and more accurate diagnosis of disease. Other diseases affecting grape production such as red blotch, black rot, crown gall, grey mold, and mildew have associated economic consequences.

1.3 National Clean Plant Network

The National Clean Plant Network (NCPN) originated in 2009, with a memorandum of agreement from a push by the grape and fruit tree industries in 2005, according to their website. Meetings to explore the formation of a group devoted to focusing on foundation materials that are tested, treated and maintained as a healthy source of plant stock for growers in the United States, began the conversation. Specialty crop groups including grapes, nuts, fruit trees, citrus, and berries, voluntarily joined to create the network. Today NCPN operates under the guidance of the United States Department of Agriculture - Animal and Plant Health Inspection Service (APHIS), the Agricultural Research Service (ARS), and the National Institute of Food and Agriculture (NIFA) (University of California, 2017d).

The establishment of virus-screened wine grape stocks to produce high quality, healthy blocks in nurseries and vineyards, provides benefits to grape growers attempting to control the spread of GRLD. Virus-screened or certified stock originates from a group of centers, which comprise the National Clean Plant Network for Grapes officially established through the 2008 Farm Bill. The network provides education and outreach services in support of its mission at five clean plant centers around the country working with grapevine material. These centers include Foundation Plant Services, UC-Davis in Davis, CA; New York State Agricultural Experiment Station, Geneva, NY; Center for Viticulture & Small Fruit Research, Florida A&M University in Tallahassee, FL; Midwest Grape Tissue-Culture and Virus-Testing Laboratory –

Center for Grapevine Biotechnology, Missouri State University in Mountain Grove, MO; and Clean Plant Center Northwest – Grapes in Prosser, Washington. According to the NCPN for Grapes website, the network consists of industry members, experts in plant pathology, regulators, and clean plant centers across the industry in the United States (University of California, 2017c).

Grape material is carefully tested over a period of at least five years with state of the art equipment and technology, and, if necessary, subjected to disease-elimination therapy (microshoot tip culture) prior to release by state and federal authorities (University of California, 2017c). Introducing new certified cultivars, or certified cultivars of existing selections suitable for various regional conditions, ensures disease-tested material is available to growers and nurseries across the U.S. as a part of the program.

Foundation Plant Services (FPS) releases large quantities of certified material, not only in California, but also across the country (Foundation Plant Services UC Davis, 2006). The website states FPS has been in operation since 1958, well before the official formation of the NCPN for Grapes, with the mission to distribute virus-tested, professionally identified grape, fruit, and nut-tree propagation stock. Similarly, a long history of managing a voluntary grape certification program exists at the New York State Agricultural Experiment Station in Geneva, NY at Cornell University (University of California, 2017a). Our cost-benefit analysis uses information from these two centers.

1.4 Contribution of Thesis

As previously mentioned, a large body of literature exists about grapevine leafroll disease and its effect on grape production. Walker et al. (2004), Nimmo-Bell (2006), Atallah et al. (2012), Ricketts et al. (2015) and Fuller et al. (2015) studied these effects measured in economic costs per representative vineyard hectare under various situations. Fuller et al. (2014) also examined the welfare impacts of using certified material over a small region in California. Although virus-tested material has been available through FPS since 1958, no study has completed a comprehensive cost-benefit analysis of planting certified stock for wine grapes. Our study will compare costs of establishing and maintaining clean plant centers with benefits from virus-tested grapevines material in production. Second, we will measure the welfare change from using certified material in the industry across all of California. The results of our study highlight not only the economic costs and benefits of virus-tested material from the grape centers, but also inform policy decisions for future investment. Placing a value on direct public investment channeled through NCPN and university funding at the various grape centers, can help decision makers interested in maintaining this industry viable in the United States.

1.5 Organization of Thesis

The thesis organization is as follows: Chapter II reviews the existing economic literature on economic benefits of using virus-tested plant material and on measuring the elasticities of demand and supply for wine grapes required for the welfare analysis. Chapter III describes the empirical framework used to construct our analysis. Chapter IV covers the data description and summary statistics for the explanatory variables. Chapter V outlines our findings and results. Finally, Chapter VI touches on the implications from our findings and suggests areas of future research.

Chapter II

LITERATURE REVIEW

2.1 Grapevine Leafroll Economic Impact

Estimating economic effects of grapevine leafroll disease only began relatively recently with a few published studies examining the topic. Walker et al. (2004) calculated the impact of GLRD on gross margins using a model of virus spread under high, moderate, and low infection scenarios in New Zealand. Estimated damages amounted to $21,200 USD/ha by years 12, 15, and 17 for high, moderate and low scenarios respectively. Nimmo-Bell (2006) compared the net present value (NPV) of healthy and diseased blocks of Merlot and Sauvignon blanc in New Zealand under three different management strategies: total vine removal, roguing and replacing symptomatic vines, and rouging and replacing symptomatic vine as well as those immediately adjacent to them. They discovered roguing and replacing symptomatic vines reduces the cost (NPV/ha) of GLRD by over six fold compared to a no treatment situation.

Atallah et al. (2012) examined the economic impact of grapevine leafroll disease on *Vitis vinifera* cv. Cabernet franc in the Finger Lakes region in New York State. Three different management strategies considered were roguing, replacing the entire vineyard, and taking no action. They found the GLRD impact decreased to $3,000-$23,000 per hectare if vineyard managers rogue symptomatic vines and replace with virus-tested stock when initial disease prevalence in year three is 25% or less. If disease prevalence is over 25%, replacing an entire vineyard is the optimal response with economic losses near $25,000 per hectare. Optimally, costs per hectare associated with GLRD remain near $1,800/ha when planted originally with vines derived from certified, virus-tested stocks. They develop a decision matrix identifying an optimal disease control strategy that maximized the NPV per hectare. Additional work by

Atallah published recently examines the spatial nature of the disease and its effects on the net present value per hectare (Shady S. Atallah, Gómez, & Conrad, 2017; Shady S. Atallah, Gómez, Conrad, & Nyrop, 2015).

Ricketts et al. (2015), followed Atallah et al. (2012), but focused on Cabernet Sauvignon vines in Napa, Sonoma, and Northern San Joaquin (NSJ) Valley in California. Estimates of per hectare economic losses from grapevine leafroll disease ranged from $29,902 in NSJ with 5% initial infection, 25% yield reduction, and no quality penalty, to $226,405 for a 40% infection, 40% reduction in yield and a 10% price penalty for reduced quality in Napa. They discovered roguing symptomatic vines and replanting with certified vines in combination with application of insecticides, minimizes losses of GLRD if infection is low (≤ 25%). Full vineyard replacement should occur if disease prevalence is above this threshold similar to results in New York, although slight regional differences are present. Ricketts et al. (2015) also generates a decision matrix to assist producers in optimizing their vineyards value.

Finally, Fuller et al. (2015) constructs estimates on economic impacts from GLRD for the entire North Coast region in California – Napa, Sonoma, and Marin counties incorporating spread of the disease from neighboring vineyards. The greatest per hectare losses, $69,338, occurred when growers planted initially with unscreened vines and replanted to replace disease vines with unscreened grapevines. Planting and replanting vineyards with screened grapevines they determined minimized losses at $36,932/ha. These minimized losses although substantial, represented damages imposed by viral disease entering from neighboring blocks. Overall, the benefits of planting with certified virus-test stock is definitely worth the investment based on all past studies.

2.2 Welfare analysis

Beyond studies exploring economic costs of managing diseases in agriculture, economists are interested in not only understanding how prices and quantities are determined in the market, but also calculating how much value a market generates for society. Consumers capture this value when they purchase a good or service for less than they value the use of the item, called consumer surplus. Producers gain this value when they can sell goods and services for more than what each item cost to produce. Measured together as welfare, many papers have been published which use this is powerful tool to estimate how interventions that change the market equilibrium (i.e. new policies, regulations, or technologies) affect producer and consumer surplus (J.M. Alston, Fuller, Kaplan, & Tumber, 2013; Anderson, Lindell, Siemer, & S. A. Shwiff, 2014; Cui, Lapan, Moschini, & Cooper, 2011; Fuller et al., 2015; Khanna, Nuñez, & Zilberman, 2016; Kim, Schaible, Garrett, Lubowski, & Lee, 2008; Unnevehr, Gómez, & Garcia, 1998). Economic textbooks often contain sections on the mathematics and theory behind welfare and changes in welfare including Houck (1986) and Sanoulet and de Janvry (1995).

More specifically numerous authors have conducted studies on the returns and welfare implications of research and development in specific agriculture sectors, and across the entire industry (Julian M. Alston, Andersen, James, & Pardey, 2011; Andersen, 2015; Chavas & Cox, 1992; Griliches, 1958; Hurley, Rao, & Pardey, 2014; Jin & Huffman, 2016; Moschini & Lapan, 1997). Because of the usefulness and interest of welfare analysis for agriculture, textbooks document methods to understand the returns from agricultural research and development (J.M. Alston, Norton, & Pardey, 1995; Julian M. Alston & Pardey, 1996).

Directly related to our study, returns from research and development in the Australian grape and wine industry were studied by Zhao et al. (2003) to determine how producers and consumers bear the costs and benefits from this additional investment. They find that foreign consumers take a much larger share of the benefits than costs with the program studied and producer levies. Alston et al. (2013) estimate changes from Pierce's disease (PD) on welfare in California relative to different baseline scenarios. They estimate the "most likely" outbreak scenario results in losses four times the cost of the current prevention program, amounting to $126,474 of producer surplus loss and $58,987 consumer surplus loss per year. Anderson et al. (2014) estimated the welfare impact of bird damage and its control for California wine grape production. They found eliminating all bird control results in a decrease of producer and consumer surplus of 6.6% and 11.5%, respectively.

Fuller et al. (2015) calculate benefits of having the virus-screening program for grapevine leafroll-associated virus-3 (GLRaV-3) for the entire North Coast region in California. They construct welfare measures to determine the additional value generated from using virus-tested material and who captures this value. They estimate potential benefits of $52.7 million per year for the north coast region, with a 100% adoption rate. Using a range of elasticities and infection rates, producer surplus was $37.6-$51.9 million and consumer surplus was $0.74-$15.0 million. The large difference in benefits between the groups results from the fact that supply is inelastic relative to demand. Their study begins to answer the economic welfare implications from using virus-tested material between grape producers (producer surplus) and grape crushers (consumer surplus) in a specific California region. Researchers in many fields continue to explore welfare changes in the markets because knowledge about who wins and who loses influences decision-making and public policy.

2.3 Elasticities in the Wine Grape Market

Elasticity, the percentage change in quantity demanded or supplied due to a one percent change in price, is very important with regard to how market changes affect this welfare distribution. Numerous factors including number of producers, inventory and excess capacity, length of production period, factor mobility, substitutes and compliments, influence supply and demand functions and their own-price elasticities.

Agricultural supply analysis has often used a planting-time measure of the price farmers expect to receive under the assumption these expected prices are exogenous with respect to quantity. This assumes that this future price equals a producer's rational expectation of post-harvest prices. Nerlove (1958) suggests including a lagged price and lagged dependent variable as explanatory variables based on a supply model with adaptive expectations. More recent work has continued to debate this strong assumption of the exogeneity of expected prices (Choi & Helmberger, 1993; Hendricks, Janzen, & Smith, 2015; Roberts & Schlenker, 2013). Specific to wine grapes, Volpe et al. (2010) estimated supply elasticities from a system of simultaneous equations for eight California wine grapes, four red and four white, using a regional systems of equations across four different growing regions. They found wine grape supply is inelastic with respect to prices received. Alston et al. (2013) completed parametric simulations to generate region specific elasticities. Own-price elasticity for wine grapes ranged from 0.8 to 4.7, becoming more elastic the more years allowed for price adjustment. Fuller and Alston (2012) are the first and only, to model the demand elasticity for California wine grapes based on three regions, aggregated according to average wine grape price. Own-price demand elasticity is most elastic, -9.5 for high-price wine grapes to least elastic, -2.6 for low price wine grapes, over the 25-year study period.

Given the body of past literature, our study estimates hectares in production to calculate total benefits of virus-tested material specifically in California and New York over 2006 to 2015. By modeling an additional estimation of elasticity of supply for wine grapes coupled with existing estimated elasticities, we construct a welfare analysis to determine the distribution of benefits. The strength of our study results from combining past studies with new data and knowledge of the lifecycle of certified material. Finally, we use this framework to make predictions about future costs and benefits by 2025.

Chapter III

METHODOLGY

3. 1 Benefits

The benefits from using virus-tested material begin when these vines produce a crop of grapes for wine production. The time lag between this production and the initial request for a certified cultivar, results in a challenge to provide accurate estimates of producing hectares in the field. A clean plant center carefully tests a cultivar for a minimum of five years, possibly longer if disease-elimination therapy is required once it receives a request. Once material becomes certified – free of any known viruses or diseases – the center distributes cuttings and plants primarily to nurseries upon request (Foundation Plant Services, 2008). Nurseries increase material quickly to generate mother blocks or increase blocks that undergo frequent testing to ensure no reintroduction of viruses and diseases. These blocks grow at nurseries in California for two years, in New York for three years, until reaching a size capable of producing cuttings to graft for broad distribution to vineyards. Upon acquisition of certified vines, vineyards plant vines that start producing valuable fruit after year three and reach maximum fruit production in year five. For grape production from certified vines to occur – five or more years at the grape center, two or three years growing in nurseries and another three years growing in the field – the process on average lasts over 10 years. Vineyard managers and nursery operators must inherit the risk of making decisions today about future demands and needs, due to this time lag. Understanding the process of how grapevines become certified and move into production, is critical to calculating our stream of benefits.

We base our estimates on following the lifecycle of known clean plant material distributed from the centers and nurseries. Foundation Plant Services records from 2006 through 2015 contain the number of both certified cuttings and certified plants distributed to nurseries (Foundation Plant Services UC Davis, 2006). With a set of general assumptions about the productivity of material and time needed for plants to mature, we could use these numbers to estimate certified vines in nurseries. Upon further investigation in touring nurseries and talking to operation managers, no general method to increase material quickly for their own increase blocks is widespread. The larger nurseries only need a few mist propagated certified plants to generate thousands of mother plants. Fortunately, the California Department of Food and Agriculture (CDFA) began collecting the number of acres of certified material at participating nurseries in California starting in 2009 that we use to overcome this variability. Surveyed nursery hectares serve as our basis to estimate certified material distributed by nurseries.

Once we estimate appropriate certified nursery mother plants, predictions about vines sold to vineyards and therefore in production, are possible. Assuming nurseries sell all possible vines that then become productive vines in the field, is an unrealistic expectation. Changing cultivar demand, propagation mortality, field loss, and market saturation contribute to less than the maximum vines sold from each participating nursery. Rootstock and scion material at nurseries also generate slightly different amounts of plant material available for cuttings depending upon varieties. We consider these factors in our calculations and can approximate an adoption rate of material across the state based upon our estimation. Additionally, Foundation Plant Services requires user fees for each propagative unit sold, exchanged or retained for your own use during the preceding calendar year (University of California, 2017b). This means anyone who purchases grapevine material from FPS is required to sign the "FPS Grower Agreement" holding them accountable to report and pay the appropriate user fees for their certified material. We use this measure to help validate our assumptions about vine sales from nurseries to vineyards. On the other side of the country in New York because only three main nurseries exist, rather than use the above method like California, we survey these nurseries to provide current and estimated future acres of certified mother blocks and annual certified vine sales to get a measure for benefits.

Once we calculate the number of hectares of planted virus-tested vines, relying on the past studies (Fuller, Alston, and Golino 2015; Ricketts et al. 2015; Atallah et al. 2012), benefits are estimated. Within California, well-known production regions include Sonoma, North San Joaquin Valley (NSJ), and Napa. Each of these viticulture regions has a different average number of vines per hectare, cost of land, land preparation costs, operating cost, etc. which in turn affects the NPV we apply to each hectare of estimated producing certified grapevines (Ricketts et al., 2015). Within our study, the first benefits from vines in production began accruing in 2008, due to the time lag of the first material planted in 2006, because harvest happens three growing seasons later. Benefits result from calculating net income per representative hectare, by discounting future cash flows over 25 years – average lifespan of vineyard – to their present value under a variety of scenarios. By comparing the difference in net income of a hectare affected by grapevine leafroll to a hectare planted with certified vines, we estimate the economic cost of GLRD or the economic benefit of using virus-tested grapevines. We must keep in mind that in our analysis net present values are discounted benefits over the future 25 years, so 25 years must pass before all actual benefits occur. Therefore, we will not realize all benefits from our study period until 2050, since vineyards plant virus-tested vines in 2025.

Similar to the past ten years when certified vines sales increased from 25 million in 2006 to 33 million in 2015, we argue that sales of certified material will continue to grow in the future.

Looking ahead, we estimate the total number of producing vines by the year 2025 with a range of assumptions incorporating average nursery hectare growth rates.

3. 2 Costs

An analysis, including costs, will account for the investments from private and public sources to develop and distribute the virus-tested certified stock. The major center, Foundation Plant Services (FPS) at the University of California Davis, distributes most of the certified clean stock across the entire country, making the center the ideal candidate to use for projecting the present value of future costs of maintaining the program. Given the center has been established for a few decades, costs of the center and program are well documented (Foundation Plant Services UC Davis, 2006). Costs to operate the center include salaries, benefits, contract labor, capital investments and equipment, program support, general operating expenses and miscellaneous expenses. These costs are directly offset by public investment in the form of user fees, NCNP funding, gifts and awards, and CDFA Nursery Assessments. We used past costs to project future costs estimating a similar growth trajectory for FPS.

At the New York State Agricultural Experiment Station part of Cornell University in Geneva, NY, the National Clean Plant Network supports a grape center. Given the center is part of the experiment station, operations are combined with other programs so direct expenses are not know for the grape program alone. We have approved NCPN funding for the center from proposals since 2009 to 2015 as well as an initial USDA funds to begin the center in 2008, which we use as a measure for public investment for our study. While this may underrepresent actual expenses, these funds account for a large portion of the operation costs. FPS and the grape center at Geneva are the primary sources for nurseries and vineyards to acquire certified cultivars in both states.

In attempting to match costs to benefits of virus-tested material, we must mention a few caveats relative to California. FPS has been in operation and grown mother plants in their foundation vineyard for years before our study period began in 2006. The costs associated with creating this virus-tested material could have occurred any year after the program began in 1958, since mother plants may have been planted 5, 10, 20 years ago. We are confident based on records of operating costs and certified material sold from our period and back to 1999 at FPS, benefits of planted material from these certified plants outweighs the costs over the lifetime of the center. Because of the challenge of matching today's benefits to specific past year's costs, our cost measure is the annual investments in the grape centers, which support continued access to certified stocks, certification programs, and other mission aligned activities for the industry. Finally, despite distributing virus-tested material outside of the state, we do not remove a portion of the costs for this material while comparing it to benefits only in the boundary of California. This causes our costs to be slightly relative to the benefits since our cost-benefit analysis only accounts for in-state benefits.

3.3 Welfare Analysis

One can view the any additional benefits from planting virus-tested certified material as a supply shift, changing welfare. With this shift producers capture part of the additional welfare and the rest goes towards consumers. In our setting, grape growers are the producers and wine producers who crush grapes are the consumers. Distribution of welfare will be highly dependent upon the elasticities of the supply and demand curves relative to each other another.

We use a measure of distribution from a demand and supply model implemented by Alston et al. (1995) and used by Fuller et al. (2015) corresponding to the economic surplus or gross-annual benefits from a technological change. The appendix presents a full model. The share of total annual benefits distributed between wine grape buyers (consumer surplus) and wine grape growers (producer surplus) results from equations (1) and (2):

$$\text{Consumer surplus} = \frac{\varepsilon}{\varepsilon + \eta} \tag{1}$$

$$\text{Producer surplus} = \frac{\eta}{\varepsilon + \eta} \tag{2}$$

where ε is the elasticity of supply or the percentage increase in quantity supplied due to a 1% increase in price and η is the absolute value of elasticity of demand or the percentage reduction in quantity demanded due to a 1% increase in price.

The elasticities of supply and demand play a key role in determining the relative change in welfare for producers of wine grapes and those who purchase them for wine. When supply is inelastic relative to demand as it is for most agricultural commodities, producers bear a greater share of the total gains than when supply is elastic relative to demand. Given the perennial nature of wine grape and the lag time between planting decisions and harvest, our intuition would lead us to believe supply would be inelastic relative to demand therefore producers would face greater losses or gains in welfare than consumers (Fuller et al., 2015). Understanding the distribution of welfare could assist in continuing to incentivize the use of certified material from either or both participants in the market.

3.4 Elasticity Framework

We assume wine grape producers maximize their incomes through crush decisions that are independent across growing regions. The study uses a model for the own-price elasticity of supply for wine grapes in California similar to Volpe et al. (2010). The model removes lagged dependent variables and acreage from the specification to avoid introducing additional potential endogeneity beyond expected price. Using a log-linear functional form allows for straightforward interpretation of the coefficients as elasticity estimates. Equation (3) presents the crush equation for a given region:

$$lncrush_{r,t} = \beta_1 + \beta_2 lneprice_{r,t} + \beta_3 lnwages_{r,t} + \beta_4 t$$
$$+\beta_5 lnbloom_{r,t} + \beta_6 lnharvest_{r,t} + \varepsilon_{r,t-1} \tag{3}$$

where the dependent variable *lncrush* is the log of tons crushed in region *r* in time *t*. *Lneprice* is the logarithm of expected prices received in that time period, using a naïve specification of the previous year's price. *Lnwages* are log of hourly wages paid to on-farmer laborers, *t* represents a time trend, *lnbloom* are the log of weather variables related to conditions at the time of the bloom for grapevines, *lnharvest* are the log of weather variables related to conditions at the time of harvest.

We recognize a possible dependency between error terms leading to auto correlation across years. This means the error term should be modeled as $\varepsilon_t = \rho\varepsilon_{t-1} + \mu_t$. Constructing and performing a Durbin Watson test determines if autocorrelation in the residuals exists. We discover autocorrelation exists and to overcome it, apply a Prais-Winsten model containing an AR(1) error term. Hashimoto (1988) noted this estimator performs considerably better than the Cochrane-Orcutt estimator and the full-maximum likelihood estimator. Our estimates for supply elasticity combined with secondary estimates from additional sources (J.M. Alston et al., 2013; Fuller & Alston, 2012; Volpe, Green, Heien, & Howitt, 2010), are incorporated into a sensitivity analysis to determine a range of possible distributions of welfare from virus-tested material.

Chapter IV

DATA DESCRIPTION

By using multiple data sources, we are able to build upon the existing literature and focus on the period 2006-2015 while projecting future costs and benefits for the period 2016-2025 for New York and California.

4.1 Certified Grapevine Benefits and Costs

A data set is compiled from the Foundation Plant Services at University of California Davis (Foundation Plant Services UC Davis, 2006; Golino, 2017) and the California Department of Agriculture (California Department of Food and Agriculture, 1977a) to estimate total certified acreage in production across the state as described above. Table 2, column one shows the annual quantity of certified material distributed from FPS to nurseries and vineyards including both cuttings and propagated plants. During 2006-2015, the annual average number of plants and cuttings distributed amounted to just over 25,000. We derive vines sold from total user fee income, knowing the fee amount for each vine sold from original FPS material. This provides an estimate of the amount of plant material sold from nurseries to vineyards in the second column. Finally, the third column in Table 2 shows the hectares of current registered certified increase blocks at nurseries around California collected by the CDFA with an average of 863 hectares. Larger nurseries purchasing and dissolving acres at smaller nurseries causes slight fluctuations in nursery hectares over this time.

Table 2. Certified material in California

Year	Certified material[1] released from FPS	Vines sold	Registered hectares[2] at nurseries
2006	18,821	25,665,972	n/a
2007	37,100	21,727,948	n/a
2008	16,550	23,558,258	n/a
2009	23,522	16,026,519	826
2010	30,361	17,608,665	836
2011	21,723	12,133,515	781
2012	19,962	25,659,444	855
2013	15,680	34,526,145	836
2014	18,459	32,848,946	939
2015	49,250	33,043,108	934

[1]Includes both cuttings and propagated plants
[2]Includes plants in increase blocks, certified field blocks, screenhouses, and greenhouses
[3]User fee changed causing delay in collecting user fees during reporting year
Source: (Dayyani, 2017; Foundation Plant Services UC Davis, 2006; Golino, 2017)

Overall, we can see user fee estimates steadily increasing, particularly since 2012, perhaps due to the discovery of red blotch and renewed attention to the importance of using certified material.

From this data, we estimate certified vines growing in the field by making a number of assumptions from personal interviews and survey questions combined with using multiple measures – user fee data and hectares of certified material at nurseries. First, in terms of mother plant productivity at the nurseries, we assume that an average rootstock generates 125 cuttings and scion 250 buds. We apply a conservative successful propagation rate of 60% to all possible cuttings after talking to nursery managers. As previously mentioned, it is unrealistic to assume nurseries sell all possible vines due to changes in demand from year to year, so we estimate half of all possible scion buds sell annually. There is also a shrinkage or loss rate factored in whenever material moves location i.e. FPS to nursery or nursery to vineyard field, of 10%. These are our assumptions for number of vines sold which cause our estimates to align fairly well with estimated vines sold from user fees over the last eight years.

Our estimates include a final set of assumptions to determine under what regional conditions these vines will enter into production. We assume that from all sold vines in the state of California approximately 10% are in Napa County or similar production conditions, 10% in Sonoma County or similar conditions, and the final 80% in conditions similar to North San Joaquin Valley. These regions align with our use of Ricketts et al. (2015) estimates for the benefits of planting certified vines.

We apply net present values calculated from Ricketts et al. (2015) model, to acreage estimates to calculate the benefits. Each year, vineyards plant more certified vines adding benefits to the overall economic impact. The NPV calculations used account for production costs gathered by the University of California Cooperative Extension and additional surveys, average prices, and a premium on certified vines under various scenarios. These measures (see appendix) are from an average Cabernet Sauvignon vine over a 25-year productive life. While only Cabernet Sauvignon is modeled, this variety had the second highest crush volume in 2015 about 12% of total crush, only behind Chardonnay at 16% (California Department of Food and Agriculture, 1977b). For net present value measurements in our study, a 5% discount rate is used and we report all dollars in 2002 real dollars.

To estimate certified material in New York and the northeast, we surveyed the three primary nurseries serving the region. Certified material appeared much later in New York than the west coast, with most planted nursery acres starting last year (2016) and continuing over the next few years. Total estimated hectares of certified mother blocks at these three nurseries will be approximately 36 hectares by the year 2022. Cuttings will be available from some mother plants prior to 2022, with the first certified material sold to vineyards in 2018. Therefore, with this distribution, benefits will begin to occur in the field in 2021 and continue into the future. Similar to California we then utilize NPV measures for a 25-year productive life of a vineyard from Atallah et al. (2012) to calculate estimated benefits from certified vines in production assuming a shrinkage or loss rate of 10%.

All grape centers producing virus-tested certified material incur costs from operation – Foundation Plant Services and Cornell University are of interest for our study. Unlike benefits, costs derived from accounting records, require far fewer calculations and assumptions. Table 3 notes annual expenses for the grape program at Foundation Plant Services in the first column and approved NCPN funds for Cornell University to the right. We recognize the New York center has received some matching funds available at Cornell from the NY State Department of Agriculture and Markets and contributions from nurseries. Due to accounting challenges, we use only NCPN investment as a measure of expenses in this case, knowing they underestimate the total investment in the center.

Table 3. Nominal expenses at NCPN Grape Centers

Year	FPS Expenses, California	Cornell NCNP Funds, New York
2006	$1,007,096	n/a
2007	$1,175,720	n/a
2008	$1,479,449	$100,000[1]
2009	$1,806,862	$264,325
2010	$1,923,567	$299,895
2011	$2,497,427	$318,804
2012	$2,464,810	$350,659
2013	$2,418,317	$142,635
2014	$2,769,401	$392,779
2015	$2,614,326[2]	$288,253

[1]Funds from USDA-APHIS
[2]Expense not available – midpoint estimate used
Sources: (Foundation Plant Services UC Davis, 2006; Marc Fuchs, 2009)

From Table 3, average annual operation expenses were just over $2 million in California and annual NCPN funding in New York averaged nearly $300,000 over the past seven years. We anticipate based upon past trends, these costs rising slowly over the next ten years provided the program and mission remain similar to today.

4.2. California Wine Grape Supply

To generate a supply elasticity estimate for California wine grapes, we use data on crush, acres, prices, wages, and weather. The California Department of Food and Agriculture collects annual production data, broken into 17 grape growing districts (see map in appendix). Final Grape Crush Reports contain tons crushed and is our dependent variable. Gross grower returns in dollars per ton our independent variable of interest contained in these reports, we will call price (California Department of Food and Agriculture, 1977b). Expected price (*Eprice)* which enters the model is simply the previous year's price in $/ton ($eprice = price_{t-1}$). The California Grape Acreage Reports provides total bearing acreage for weighting our data where needed (California Department of Food and Agriculture, 1977a). Production data is available from 1976-2016, but data on wages of farm workers is only available for the period of 1991-2014. We use 24 annual observations that overlap during the period. A graphical depiction presented in Figure 2, shows our dependent variable, tons crushed. The figure stacks tons crushed by district for the top three producing districts and all other districts to visual see statewide production.

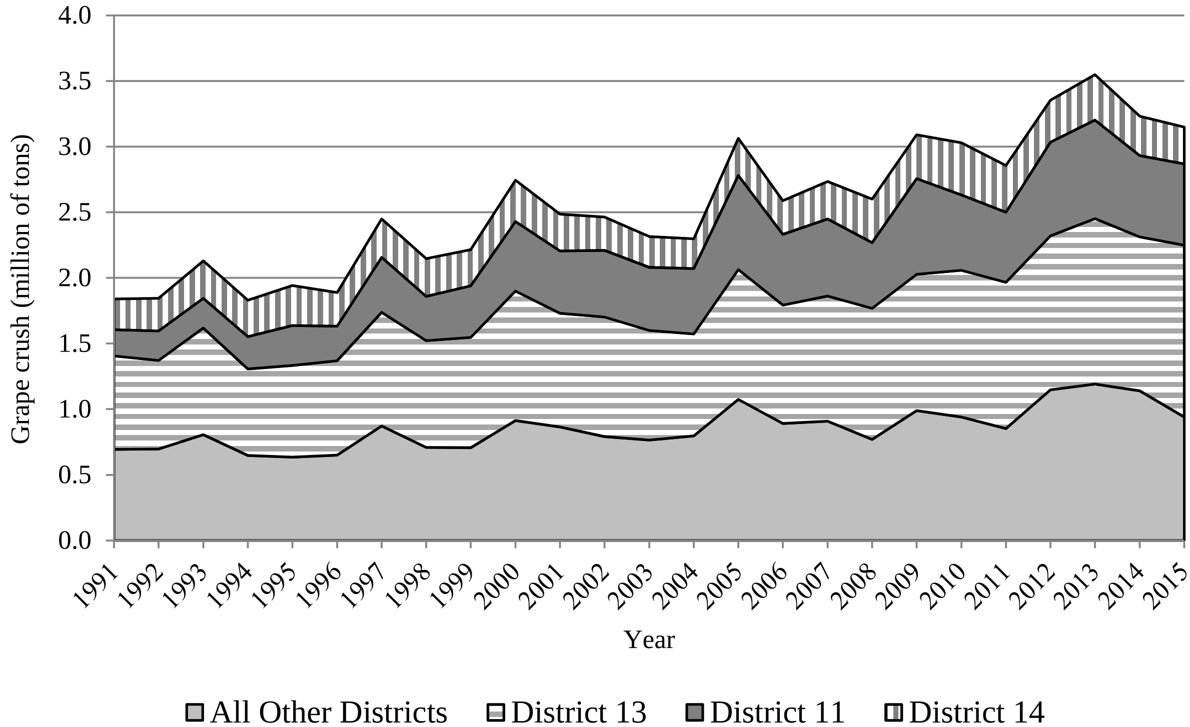

Figure 2. Grape Crush - Top 3 Districts and State Total, California (1991-2015)

Acreage, highly correlated with tons crushed, follows a similar growth pattern over this period. Statewide price, weighted average grower returns per ton, began at $344/ton in 1991, increasing to $679/ton in 20015 and an all-time high in 2012 at $773/ton. Upon closer inspection slow price increases occurred over our period of analysis with the exception of Districts 3 and District 4 – the premium wine grape market – where prices increased more rapidly. Separating the districts into distinct growing regions that influence grape quality, we see strong variation in prices received by growers. We segregate into a high quality region composed of crush districts 3 and 4, mid quality region including districts 1, 2, 5-11, and 15-17, while the low quality region captures production from districts 12-14. For the regions, an average district price received more than one standard deviation above the average state price over our period of interest results in becoming part of the high quality region, while the low region is over one standard deviation below. Fuller and Alston (2012), who estimate the elasticity of demand use similar segmentation for the state based on high, medium, and low quality grapes based on price. During 1991-2015 the weighted average price for high, mid, and low quality grapes was \$2,126, \$716, and \$266 respectively (see figure in appendix).

The California Employment Development Department provides monthly agricultural wages according to six agricultural regions in the state (see map in appendix). We calculate region-year average wages for fruit and tree nut laborer from reported monthly dollars per hour wages. To match to districts, we weight according to acreage to get appropriate values. The North Coast region averaged the highest wage at \$9.50/hr. during 1991-2015, compared to the lowest at \$7.80/hr. in the San Joaquin region (California Employment Development Department, 1991).

Monthly, county-level weather data is obtained from the National Oceanic and Atmospheric Administration (NOAA) to generate bloom and harvest weather variables (Lawrimore, 2016). A study by Lobell, Cahill and Field (2006) forecasted crop yields using a variety of weather variables for California specialty crops. They determined the models with the best prediction for wine grape yields (R^2cv= 0.59) include total rainfall during the September of the year prior to harvest, the average minimum temperature in April, and the total precipitation in June in the year of harvest. We follow their study and include these three variables in our model for each growing district. Table 4 shows the annual statewide averages for our three variables: the extreme minimum temperature experienced during April in degrees Fahrenheit, total June precipitation during the year of harvest in inches, and total September precipitation from the year prior to harvest in inches. June and September are in the dry period of the year with a majority of rainfall in California occurring in the winter months (see Table 4). The minimum April temperature reached below 30 degrees Fahrenheit once across this period in 1999, and June of 2011 had an abnormally large average rainfall of over an inch.

Table 4. Annual average weather variables for California (1991-2014)

Year	Average minimum April temperature (°F)	Average total June precipitation (in.)	Average total September precipitation *(t-1)* (in.)
1991	35.16	0.35	0.26
1992	39.31	0.53	0.09
1993	37.88	0.85	0.01
1994	37.48	0.02	0.00
1995	34.87	0.71	0.18
1996	36.57	0.11	0.02
1997	35.18	0.38	0.09
1998	33.17	0.36	0.47
1999	29.78	0.14	0.36
2000	37.66	0.27	0.11
2001	31.03	0.17	0.24
2002	34.40	0.01	0.19
2003	33.27	0.01	0.03
2004	36.99	0.02	0.06
2005	35.22	0.75	0.19
2006	35.92	0.02	0.14
2007	35.10	0.02	0.03
2008	32.45	0.00	0.30
2009	33.34	0.15	0.03
2010	33.56	0.06	0.11
2011	31.68	1.43	0.06
2012	32.52	0.12	0.07
2013	36.87	0.36	0.04
2014	36.52	0.01	0.49

Source: (Lawrimore, 2016)

For our study, we use annual measures of weather variables by district. Across districts and years, in 1997 District 2 had the record high minimum temperature in April of 45.1 degrees and 2011 the low of 20.5 degrees. The wettest June of the harvest year and September of the pre-harvest year occurred in 2005 and 1998 with 3.28 inches and 2.24 inches of rainfall respectively. For these measures, we average individual station data in each county and then weight according to acreage to generate district values.

Chapter V

RESULTS

5.1 California Cost-Benefit Ratios

We calculate total benefits by multiplying the amount of virus-tested hectares in production with the benefits per hectare. Calculated benefits result from comparing the net present value of a healthy hectare in each viticulture region to a hectare with varying parameters of grapevine leafroll incidence and its associated costs. Leaning on Ricketts et al. (2015) NPV approach, we model various disease control strategies for each level of yield reduction, initial infection, and possible price penalty caused from GLRD. We select the strategy that maximizes NPV or reduces the damage from GLRD, assuming vineyard managers act optimally. If vineyard managers do not select the optimal strategy to control GLRD, actual benefits will be greater than our calculations making the estimate a lower bound. From the assumptions presented in the previous section for costs, vines, hectares and benefits, Table 5 shows our annual cost and benefit estimates.

Table 5. Estimated nominal costs and benefits *(shaded represent actual values)*

Year	FPS Expenses[1], California	Vines in Production (mil)	Field Hectares	Annual benefits[1]
2006	$1,007,096	n/a	n/a	n/a
2007	$1,175,720	n/a	n/a	n/a
2008	$1,479,449	23.10	10,908	$348,633,611
2009	$1,806,862	19.56	9,234	$295,141,479
2010	$1,923,567	21.20	10,012	$320,003,479
2011	$2,497,427	14.42	6,811	$217,696,139
2012	$2,464,810	15.85	7,483	$239,187,211
2013	$2,418,317	10.92	5,157	$164,815,547
2014	$2,769,401	23.09	10,905	$348,544,927
2015	$2,614,326[2]	31.07	14,673	$468,985,719
2016	$2,459,250	29.56	13,960	$446,203,493
2017	$2,659,250	29.74	14,043	$448,840,890
2018	$2,859,250	26.56	14,273	$456,197,998
2019	$3,059,250	27.16	12,823	$409,864,397
2020	$3,259,250	27.75	13,104	$418,831,684
2021	$3,459,250	28.34	13,385	$427,798,970
2022	$3,659,250	28.94	13,665	$436,766,257
2023	$3,859,250	29.53	13,946	$445,733,544
2024	$4,059,250	30.13	14,226	$454,700,830
2025	$4,259,250	30.72	14,507	$463,668,117

[1]All values are in nominal dollars
[2]Expense not available – midpoint estimate used.
Source: (Foundation Plant Services UC Davis, 2006; Golino, 2017)

First, we employ expenses from the Foundation Plant Services or the costs of developing and supporting a wide number of virus-tested cultivars from 2006 to 2016 as seen in the first column of the table. Projected expenses increase by $200,000 a year, which averages to approximately 6.75% annually over the next ten years. Expenses reach $4.2 million by 2025, $1.8 million higher than present day (2015), with total expenses over our 20-year study amounting to $53.74 million nominal dollars.

Based on mother plant productivity, propagation mortality, and demand, we estimate the number of new producing certified vines annually. The average number of vines sold over the next ten years, is approximately 32 million annually, up 7 million compared to the average of 24 million over the last ten years. We use user fee numbers to verify that these estimates seem appropriate based on known sales. Note the second column displays producing vines result from vines sold by nurseries three growing periods prior - i.e. 23.10 million producing vines in 2008 were sold in 2006. The table also presents the number of hectares of virus-tested, certified grapevines added to production across California.

We conservatively use a 20% initial infection, 25% yield reduction, and no price penalty as the most likely situation to generate net present values for the hectares over our study three regions. The last column of Table 5 presents the annual benefits from this assumed scenario. While we only present one scenario, economic losses due to GLRD over the lifetime of a 1-ha block of Cabernet Sauvignon ranged from $10,163 in NSJV with a 5% initial infection, 25% yield reduction, and no quality penalty to $139,299 in Napa County with a 40% initial infection, 40% yield reduction and a 10% price penalty for reduced quality. The appendix contains a complete table showing net present values per hectare from varying affects due to GLRD.

Based on this model, from 2006 – 2015 the cumulative expenses for the Foundation Plant Services center amounted to nearly $13 million (2002 real dollars), while the cumulative benefits were around $1.51 billion (2002 real dollars). The investment in virus-tested, certified stock, with a benefit to cost ratio of 117.2 (1.51 bil/12.9 mil), has clearly paid dividends. Even if we use the most conservative situation with a 5% initial infection rate, 25% yield reduction, and no price penalty, the benefit to cost ratio is still 40.5 (522.3 mil/12.9mil). Under any of our estimated scenarios accounting for costs and benefits up to the present day (2015), there is a high return on our public investment, providing evidence of the value created from activities of Foundation Plant Services in Davis, CA.

Over the 20-year period of our study, we perform a sensitivity test for our cost-benefit analysis. Adjusting parameters – levels of yield reduction, possible price penalty for fruit quality, and initial infection rates – net benefits (cumulative benefits minus cumulative costs) range between $509 million to $5.41 billion (see appendix for full table). Costs to operate the center remain the same regardless of the scenario at just over $26 million by year 2025. While the net benefits may appear very large in magnitude, we must keep in mind the California industry generates over $114 billion in economic activity a year (Dunham & Associates, Inc., 2016b) and in 2016, $2.51 billion of grapes were sold from vineyards for wine production. These net benefits may be small relative to the industry over a 20-year period, but they have generated a large return on our investment.

By 2015, strictly based on calculated user fee vines distributed, approximately 75,000 hectares or 31% of all 2015 wine bearing grape acres in California were planted with certified vines. Because we only capture benefits from material distributed since 2006, the first year these plants generate production is 2008, so this number only captures benefits over eight years. With the projection of the additional ten years after 2015, planted material reaches 211,000 acres or 86% of current bearing acres by 2025. If the average lifespan of a vine is approximately 25 years, an annual average statewide vineyard replacement rate of 4% is expected or 80% over 20 years. This assumes approximately similar amounts of material from each year class are producing in the field. This means our estimated 86% adoption rate or replacement rate of current bearing acres by 2025 seems reasonable for a 20-year period.

5.2 New York Cost-Benefit Ratios

Estimation for the benefits in New York follows a similar projection as in California, with one major difference being quantity and timing of plant material. Given the much smaller market, only three nurseries produce wine grapevines. In the state and in the northeast, virus-tested, certified vines have more recently gained interest from nurseries and producers. We use estimated vines sales from surveys, to determine the economic benefits of avoiding GLRD from the use of certified material. Our study uses NPV estimates per hectare from Atallah et al. (2012), again selecting the optimal strategies for vineyard managers to maximize the value of their given producing hectares. With these optimal strategies, GLRD impact per hectare is $5,207, $17,016, and $22,823 when initial infection is 5, 20 and 40% respectively. Table 6 displays costs, vines, hectares and estimated benefits for material distributed and grown in the state of New York.

Table 6. Estimated nominal costs and benefits *(shaded represent actual values)*

Year	Cornell Expenses, New York[1]	Vines in Production	Field Hectares	Annual benefits[1]
2008	$100,000[2]	n/a	n/a	n/a
2009	$264,325	n/a	n/a	n/a
2010	$299,895	n/a	n/a	n/a
2011	$318,804	n/a	n/a	n/a
2012	$350,659	n/a	n/a	n/a
2013	$142,635	n/a	n/a	n/a
2014	$392,779	n/a	n/a	n/a
2015	$288,253	n/a	n/a	n/a
2016	$297,253	n/a	n/a	n/a
2017	$306,253	n/a	n/a	n/a
2018	$315,253	n/a	n/a	n/a
2019	$324,253	n/a	n/a	n/a
2020	$333,253	90,000	45	$1,464,788
2021	$342,253	451,800	227	$3,138,832
2022	$351,253	976,500	490	$7,323,941
2023	$360,253	1,305,000	654	$12,555,328
2024	$369,253	1,485,000	745	$14,647,883
2025	$378,253	1,485,000	745	$16,740,437

[1]All values are in nominal dollars
[2]Funds from USDA-APHIS
Source: (Marc Fuchs, 2009)

Investment in certified material through NCPN funding for the center in Geneva averaged approximately $300,000 per year with one outlier year in 2013. Projected investment increases by $9,000 a year, resulting in a $340,000 average over the next ten years, which seems reasonable considering two past years (2012, 2014) exceeded this amount. The earliest producing mother blocks in nurseries generated vines for sale to vineyards starting in 2018, while they reach full production capacity by 2022. Vines in production start generating benefits beginning three growing seasons later. Selecting a moderate level of yield reduction of 30%, three different initial infection levels of 5%, 20% and 40% (replacement is optimal strategy if infection is greater than 25%) are simulated. Projected total benefits, assuming a 20% initial infection, reach $19.5 million (2002 real dollars) by the year 2025. Even after only five years of vine distribution, a benefit to cost ratio of 7.22 (19.5 mil/2.7 mil) shows the immediate impact using certified, virus-tested stock with net benefits of $16.8 million in New York. Lower the initial infection to 5% or raising it to more than 25%, results net benefits range from $3.2 million to $23.5 million respectively. In the simulation by 2025, nearly 6 million certified vines are sold, resulting in 2,905 hectares of producing vines or 19% of the total 2015 wine bearing acreage in the state.

5.3 California Welfare Analysis

To this point our analysis has been a cost-benefit study focused on benefits per hectare of using GLRD-tested grapevines compared to costs of producing this material at grape centers under a set of given assumptions. We essentially derive the "gross-annual net benefits" from using certified material that as mentioned, we interpret similar to an economic surplus measure from a technological change in the supply and demand framework. We estimate the distribution of net benefits in California between wine grape crushers and wine grape producers, using the equations (1) and (2). Again, we use no price penalty for reduction in fruit quality and a 25%

yield reduction due to grapevine leaf roll, with three initial infection rates of 5, 20 and 40% to determine a range of distributions. Net economic benefits are heavily dependent upon the initial infection rate of the average hectare of vineyard in the state of California. Different supply and demand elasticities for wine grapes, also highly influences distribution of these benefits.

5.3.a Elasticity Estimates

To generate a supply elasticity estimate used to understand the distribution of the additional welfare, we use a model with data from the districts across California. The following three results in Table 7 come from equation (3) running all districts together and districts separated by grape quality reflected in average prices received.

Table 7. California grape supply ordinary least squared estimates (1991-2014)

	All	High	Mid	Low
ln(expected price)	0.435***	1.029***	0.442***	0.427***
	(0.000)	(0.000)	(0.000)	(0.000)
ln(wage)	0.167	1.873*	-0.00783	0.213
	(0.551)	(0.016)	(0.982)	(0.645)
time trend	1.252	-0.00838	0.197	0.00669
	(0.495)	(0.724)	(0.597)	(0.671)
ln(min. temp)	0.360**	0.352	0.395*	0.130
	(0.004)	(0.370)	(0.019)	(0.336)
ln(precip)	0.00881*	-0.0117	0.0112*	0.00588
	(0.033)	(0.431)	(0.040)	(0.239)
ln(precip t-1)	0.00128	0.00779	0.000988	-0.00102
	(0.753)	(0.539)	(0.854)	(0.839)
_cons	-1393.3	14.63	-364.5	-3.728
	(0.492)	(0.755)	(0.600)	(0.905)
N	374	46	264	69
F-statistic	6.254	89.04	4.156	32.44
Durbin-Watson statistic (original)	0.156	0.846	0.236	0.573
Durbin-Watson statistic (transformed)	2.461	2.138	2.429	2.873

*** p<0.01, ** p<0.05, * p<0.1
t-statistics in parentheses

Within the Prais-Winsten regression, the original and transformed Durbin-Watson statistics show an autoregressive error term is present in the model. An original Durbin-Watson statistic equal to two indicates no autocorrelation with a test statistic range of zero to four. A statistic less than two as in our case is evidence of positive serial correlation meaning successive error terms are on average close in value to one another or positively correlated. As in the past study, using an AR(1) model seems reasonable (Volpe et al., 2010).

With the model specification as log-linear, coefficients are simply to interpret. The coefficient on the expected price means that a 1% increase in expected price results in a .44% increase in crush. This own-price elasticity aligns with past estimates of supply being inelastic most likely due to the perennial nature of the crop, time lag between planting and production, as well as the use of contracts. Oczkowski (2014) estimated a supply elasticity of 0.83 and Volpe et al. (2010) estimates between 0.378 and 1.180. Our results suggest differences in the elasticity of supply for high quality grapes or highest priced grapes, compared to mid and low quality.

As for the other independent variables, it is unknown if we should expect a positive or negative coefficient on wages. A negative coefficient means crush decreases as wage increases, most likely the result of less labor hired due to higher cost per unit. On the other hand, as wages increase if more mechanization occurs i.e. electric clippers, mechanical harvesting, etc. productivity increases and therefore total crush, a positive coefficient could result. Our model does not give a strong indication of either, as the coefficients are not statistically different from zero. We expected a positive time trend as yields and technology improve over time. The model should result in a positive coefficient on average minimum temperature, since having a higher average minimum temperature would promote more growth and better production. These coefficients have the expected sign and are slightly statistically significant. We expect a positive coefficient for precipitation given California is generally dry and rain should increase production. Precipitation coefficients are mostly positive, but barely statistically significant even at the 10 percent level. Overall, our model follows our intuition.

Estimating supply elasticities can be sensitive to assumptions and data, so we combine our estimate with secondary estimates from other mentioned studies. Alston et al. (2013) estimated a range of 0.1 in the short run and 2.8 in the long run, Volpe et al. (2012) 0.378 and 1.18, and we estimated 0.435 from the above model. We focus on our derived value of 0.435 for the main analysis. Fuller and Alston (2012) estimated a number of elasticity of demand values and we will use the value of -7 as in Fuller et al. (2015). By using a range of additional supply elasticities, 0.1, 1.18 and 2.8, we can determine the sensitivity of total distribution of net benefits between grape growers (producer surplus) and wine producers (consumer surplus). Table 8 shows the results of our welfare distribution. Based on three initial infection rates in California, total cumulative net benefits range from $509 million to $1.58 billion by 2015.

Table 8. Discounted net benefits of using certified material (2006-2015)

	(in millions of 2002 dollars)
Initial Infection 5%	$\varepsilon = 0.435$, $\eta = -7$
Consumer surplus (ΔCS)	29.81
Producer surplus (ΔPS)	479.63
Total (ΔTS)	509.44
Initial Infection 20%	
Consumer surplus (ΔCS)	87.76
Producer surplus (ΔPS)	1,412.17
Total (ΔTS)	1,499.92
Initial Infection 40%	
Consumer surplus (ΔCS)	92.46
Producer surplus (ΔPS)	1,487.88
Total (ΔTS)	1,580.34

Source: Authors' calculations based on welfare analysis

Since supply is inelastic relative to demand, producers or grape growers should capture most of the benefits compared to consumers or wine producers who buy grapes to crush. Maintaining the same demand elasticity and using the additional supply elasticity estimates across the three initial infection rates, wine grape producers capture net benefits with a range of $363 million up to $1.55 billion while net benefits for consumers/wine producers ranged from $7.18 million up to $451 million. If we estimate the distribution over the entire period 2006-2025, producer net benefits range from $830 million up to $3.44 billion while net benefits for the consumer ranged from $16.3 million up to $997 million. The appendix contains full tables of these ranges. Table 9 displays the distribution of net benefits for one year – in the most recent year of 2015.

Table 9. Distribution of economic benefits of using certified material (2015)

	(in millions of 2002 dollars)
Initial Infection 5%	ε = 0.435, η = -7
Consumer surplus (ΔCS)	4.94
Producer surplus (ΔPS)	79.55
Total (ΔTS)	84.49
Initial Infection 20%	
Consumer surplus (ΔCS)	14.47
Producer surplus (ΔPS)	232.86
Total (ΔTS)	247.33
Initial Infection 40%	
Consumer surplus (ΔCS)	15.24
Producer surplus (ΔPS)	245.30
Total (ΔTS)	260.55

Source: Authors' calculations based on welfare analysis

Given producers capture a majority of the economic surplus from planting certified vines, strong incentives should exist for their continued adoption by vineyard managers. This incentive is a little less direct for wine producers who are one-step removed from production, but encouraging vineyards to use virus-tested vines will help them capture net benefits. The gain in total surplus or net benefit helps the entire wine grape industry in California.

Chapter VI

CONCLUSION

6.1 Discussion

This study builds on research conducted in California (Fuller et al., 2015; Ricketts et al., 2015) and in New York (S. S. Atallah et al., 2012) by estimating a cost-benefit analysis of using virus-tested grapevines. These past studies focus on estimating the per-hectare economic impact of GLRD under various management strategies in each state often recommend an optimal strategy for disease control. This study contributes to this body of work by considering the costs of having certified, virus-tested material available for nurseries and producers in combination with the benefits from the estimated amount of certified material in production. We conduct our analysis over 2006 to 2015, with projections extending to 2025. Finally, we employ a welfare analysis framework to measure how wine grape producers and wine makers capture net economic benefits.

This research offers insight for industry and policy makers on the use of virus-tested, certified wine grape stock, a public good. A program like the National Clean Plant Network with centers similar to those in California and New York provide net benefits to all those in the wine grapevine supply chain. A large portion of funding to ensure grapevines can undergo thorough testing and “clean” stocks are available comes from public investment. This public investment comes from federal agencies (USDA/NCPN), state agencies (CDFA), as well as nurseries and producers (user fees), allowing the grapevine centers to fulfill their mission. Not only is value generated from this investment in terms of material distributed, but also the repository of a wide range of cultivars at foundation vineyards ensures diversity and protection against disease and pests for the future. The development of a certified program combined with education and outreach can assist in the adoption of using this available material.

Once planted, virus-tested grapevines generate well-documented benefits for vineyards attempting to manage grapevine leafroll disease one of the most prominent diseases affecting production across the country and world. This knowledge should generate a continued push to educate grape growers and increase clean plant material available to encourage adoption and realization of benefits available. Once producers understand benefits aligned with a desire to maximize profits, there should be strong adoption not only across California and in New York, but also in all states growing wine grapes. Our study and Fuller et al. (2015), use welfare analysis to document that private industry - grape producers and wine producers - capture benefits from these programs. Overall, virus-tested grapevines contribute great value to the entire U.S. wine and grapevine industry.

While this study helps understand the cost and benefits of using certified material and how the industry benefits, future research could help address some limitations. First, we must use net present value estimates per grapevine hectare keeping in mind a few caveats, as both Atallah et al (2012) and Ricketts et al. (2015) note. In each study, they assume averages across a diverse group of growers, terrains, climates, and markets in each state to create a representative vineyard for analysis. Additionally, both past studies noted that the patterns of disease spread used in their models, which is crucial to understand economic losses associated with the disease, were either averages or best available information based on limited disease knowledge. More work on evaluating the spread of GLRD in California and New York vineyards with the varying ecological, biological and production factors, could change net present value estimates and ultimately total benefits.

Other challenges arise when we scale the economic impact of virus-tested material over an entire region or state. Net present value estimates incorporate the income and production costs for only one cultivar, Cabernet franc and Cabernet Sauvignon in New York and California respectively. By focusing solely on one cultivar, the model may understate or overstate the economic impacts of GLRD depending on how similar or dissimilar other cultivars are relative to those studied particular in terms of prices received. Similarly, we make the assumption all additional hectares outside of our direct study regions – Napa County, Sonoma County, and North San Joaquin region in California and the Finger Lakes region in New York – grow under like conditions. Even in accounting for this geographic variability in a more complex analysis, the main results showing total benefits from planting certified material outweighing the total costs of operating the grapevine network, should not be affected.

Lastly, welfare distribution is highly dependent upon relative elasticities between wine grape supply and demand. Additional studies on the derived demand from wine producers purchasing grapes for crush, given only one set of demand elasticity estimates exists, could improve estimate confidence. Because supply and demand modelling includes both price and quantity, estimates are likely to be biased. One future method to employ to help overcome this challenge would be to introduce an instrumental variable in a 2SLS framework. An appropriate instrumental variable should affect the price of a ton of grapes in region *r* in time *t* without correlation with any unobserved attributes in that same period. Future work could explore additional specifications to solve some of these econometric challenges. Exploring the use of a variety of other exogenous weather variables could improve significance and overcome endogeneity as suggested by Hendricks et al. (2015). Overall, our specification using expected prices in the supply framework, while perhaps not as robust as we hope, produces results consistent with intuition and past studies.

6.2 Conclusion

This research provides an actual and projected cost benefit analysis of the economic impact of certified, virus-tested grapevines in combatting grapevine leafroll disease over the period between 2006 and 2025. In California the top grape producing state in the country, estimated cumulative net benefits are $3.26 billion by 2025 (25% yield reduction, 20% initial incidence, and no price penalty). Cumulative net benefits range from $1.1 billion to $3.43 billion with varying initial incidence of disease of 5% and 40%. At the same time costs to operate Foundation Plant Services, the main grape center supplying certified material to nurseries and produces, cost just over $26 million to operate. Assuming the most likely scenario of a moderate initial infection rate of 20%, the cost-benefit ratio is 117.2 ($3.2 bil/$26.3 mil). From these estimated net benefits, a welfare analysis shows grape producers capture most of the surplus from planting virus-tested vines, with small portions going to wine producers who crush grapes. In the state of New York, the third largest grape producer, projected cumulative net benefits range from $3.2 million to $23.5 million by 2025. The grape center at Cornell is smaller with costs just exceeding $2.7 million. These results add to the current body of literature and suggest that the use of certified virus-tested grapevines provide benefits beyond the costs, aiding the entire industry in the United States.

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Figure 3. Map and Definitions of California Grape Pricing Districts

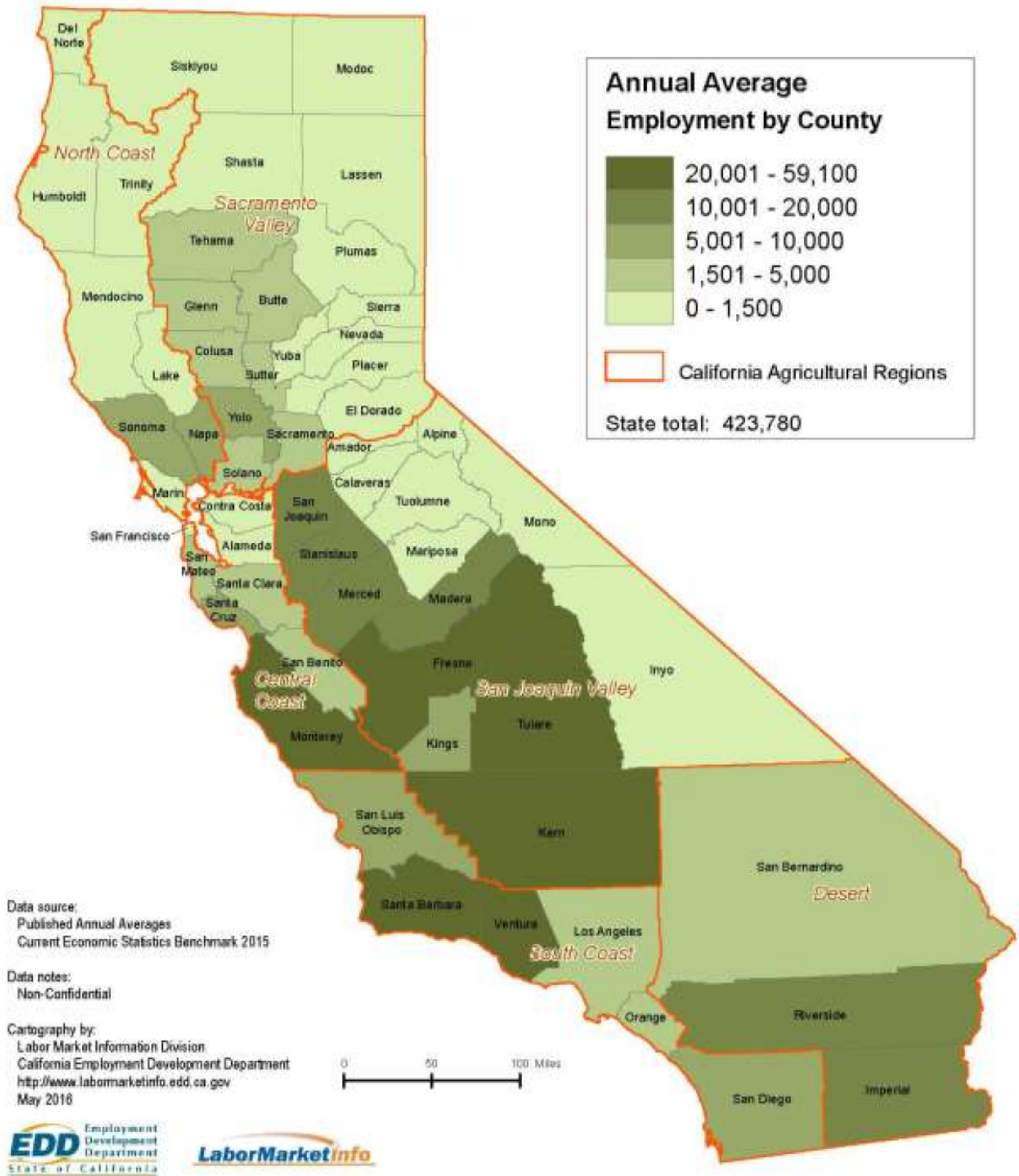


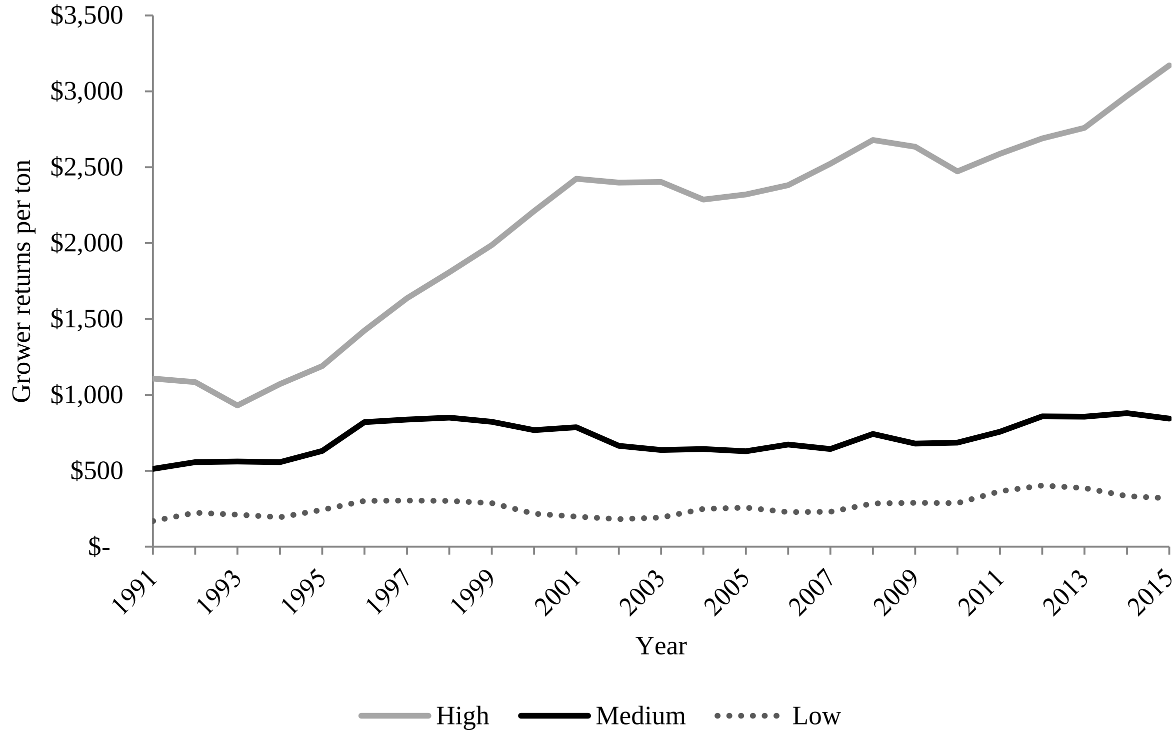
Figure 4. California Agricultural Employment 2015 Annual Average

Figure 5. Grape Clean Plant Centers

Table 10. California wine bearing acres by region as percentage of annual bearing acres (2013-2015)

	2015	2014	2013
North San Joaquin Valley (NSJV)	15.9%	14.4%	15.8%
Napa	7.9%	7.4%	8.0%
Sonoma	10.4%	9.6%	10.5%
Other	65.8%	68.6%	65.7%
NSJV + Other	81.7%	83.0%	81.5%

Source: (California Department of Food and Agriculture, 1977a; "USDA/NASS QuickStats," 2017)



Source: (California Department of Food and Agriculture, 1977b)

Figure 6. Grower returns by quality (1991-2015)

Table 11. Optimal GLRD control decision matrix for a cabernet sauvignon vineyard according to California region, yield reduction, price penalty and initial infection level generated from Ricketts et al. (2015)

	Disease onset in year 3, no price penalty			***Disease onset in year 3, 10% quality penalty***		
Annual yield reduction	**Napa County**	**Sonoma County**	**NSJV Region**	**Napa County**	**Sonoma County**	**NSJV Region**
25% Yield Reduction						
5% Initial Infection	RRVC[1]	RRVC	RRVC	RRVC	RRVC	RRVC
20% Initial Infection	RRVC	RRVC	Replace	RRVC	RRVC	Replace
40% Initial Infection	Replace[2]	Replace	Replace	Replace	Replace	Replace
40% Yield Reduction						
5% Initial Infection	RRVC	RRVC	RRVC	RRVC	RRVC	RRVC
20% Initial Infection	RRVC	RRVC	Replace	RRVC	RRVC	Replace
40% Initial Infection	Replace	Replace	Replace	Replace	Replace	Replace

[1]*RRVC=Rouge, replant, and vector control*
[2]*Replace=Total vineyard replacement*

Table 12. Net present value per hectare under optimal GLRD management for a cabernet sauvignon vineyard in California over 25 years. Presented are different yield reduction scenarios, quality penalties, and three initial infection levels beginning in year 3 generated from Ricketts et al. (2015)

	Disease onset in year 3, no price penalty			*Disease onset in year 3, 10% quality penalty*		
Annual yield reduction	***Napa County***	***Sonoma County***	***NSJV Region***	***Napa County***	***Sonoma County***	***NSJV Region***
25% Yield Reduction						
5% Initial Infection	*$21,562*	*$13,261*	*$10,163*	*$75,826*	*$40,511*	*$28,337*
20% Initial Infection	*$71,467*	*$40,910*	*$28,634*	*$121,913*	*$66,216*	*$45,109*
40% Initial Infection	*$90,806*	*$44,939*	*$28,999*	*$138,766*	*$69,182*	*$45,437*
40% Yield Reduction						
5% Initial Infection	*$21,562*	*$13,261*	*$10,163*	*$75,826*	*$40,511*	*$28,337*
20% Initial Infection	*$71,467*	*$40,910*	*$28,853*	*$121,913*	*$66,216*	*$45,306*
40% Initial Infection	*$91,398*	*$45,338*	*$29,436*	*$139,299*	*$69,541*	*$45,831*

Note: some results are similar given roguing scenarios are essentially fixed for each region given the yield impacts. More information can be found in Ricketts et al. (2015) published paper.

Table 13. Net benefits for varying scenarios in California (2002 dollars)

	Initial Infection 5%	**Initial Infection 20%**	**Initial Infection 40%**
		25% Yield Reduction, No Price Penalty	
2015	509,437,737	1,499,922,257	1,580,339,182
2020	840,519,689	2,471,176,649	2,603,568,843
2025	1,109,935,122	3,264,565,276	3,439,498,582
		40% Yield Reduction, No Price Penalty	
2015	509,437,743	1,508,883,777	1,601,295,614
2020	840,519,698	2,485,930,201	2,638,069,889
2025	1,109,935,133	3,284,059,535	3,485,085,726
		25% Yield Reduction, 10% Price Penalty	
2015	1,497,649,628	2,401,270,673	2,469,745,219
2020	2,467,435,168	3,955,086,836	4,067,818,021
2025	3,259,621,559	5,225,295,039	5,374,249,735
		40% Yield Reduction, 10% Price Penalty	
2015	1,497,649,628	2,409,336,051	2,488,606,008
2020	2,467,435,168	3,968,365,049	4,098,868,963
2025	3,259,621,559	5,242,839,893	5,415,278,165

Table 14. Optimal GLRD control decision matrix in a Cabernet franc vineyard in New York based on yield reduction, GLRD prevalence and a quality penalty generated from Atallah et al. (2012)

Yield reduction	Penalty level	
30% reduction	**10%**	**None**
≤25% infection	rogue	rogue
>25% infection	replace vineyard	indifferent
<30% reduction		
≤25% infection	rogue	rogue
>25% infection	replace vineyard	do not control
50% reduction		
≤25% infection	rogue	rogue
>25% infection	replace vineyard	replace vineyard

Table 15. Net present value per hectare under optimal GLRD management for a cabernet franc vineyard over 25 years in New York. Presented are results from 30% yield reduction scenarios, no quality penalties, and three initial infection levels beginning in year 3 generated from Atallah et al. (2012)

5% Initial Infection	$5,207
20% Initial Infection	$17,016
40% Initial Infection	$22,823

Table 16. Distribution of economic benefits of using certified material (2015) (in millions of 2002 dollars)

Initial Infection 5%	ε = 0.1	ε = 0.435	ε = 1.18	ε = 2.8
Consumer surplus (ΔCS)	7.18	29.81	73.49	145.55
Producer surplus (ΔPS)	502.26	479.63	435.95	363.88
Total (ΔTS)	509.44	509.44	509.44	509.44
Initial Infection 20%				
Consumer surplus (ΔCS)	21.13	87.76	216.37	428.55
Producer surplus (ΔPS)	1,478.80	1,412.17	1,283.55	1,071.37
Total (ΔTS)	1,499.92	1,499.92	1,499.92	1,499.92
Initial Infection 40%				
Consumer surplus (ΔCS)	22.26	92.46	227.97	451.53
Producer surplus (ΔPS)	1,558.08	1,487.88	1,352.37	1,128.81
Total (ΔTS)	1,580.34	1,580.34	1,580.34	1,580.34

Table 17. Discounted economic benefits of using certified material (total by year 2025)

	(in millions of 2002 dollars)			
Initial Infection 5%	ε = 0.1	ε = 0.435	ε = 1.18	ε = 2.8
Consumer surplus (ΔCS)	15.23	63.26	155.97	308.92
Producer surplus (ΔPS)	1,065.98	1,017.95	925.24	772.29
Total (ΔTS)	1,081.21	1,081.21	1,081.21	1,081.21
Initial Infection 20%				
Consumer surplus (ΔCS)	44.74	185.86	458.26	907.64
Producer surplus (ΔPS)	3,132.01	2,990.89	2,718.49	2,269.11
Total (ΔTS)	3,176.76	3,176.76	3,176.76	3,176.76
Initial Infection 40%				
Consumer surplus (ΔCS)	47.14	195.82	482.80	956.25
Producer surplus (ΔPS)	3,299.75	3,151.07	2,864.09	2,390.64
Total (ΔTS)	3,346.89	3,346.89	3,346.89	3,346.89

Economic Surplus Calculations (adopted from Fuller et al. (2015))

We apply a version of the framework of Alston, et al. (1998) to illustrate changes in economic welfare for grapevine nurseries, consumers, and producers, assuming approximately linear supply and demand curves and a vertically parallel supply shift induced by the policy. The base case is the current one for which we have data or project data for the future, with the certification program and virus-tested material available, and the counterfactual alternative case is one without certified material. **Figures 7-11** show the shift in supply as well as areas representing the corresponding changes in consumer surplus (ΔCS) and producer surplus (ΔPS) that we estimate.

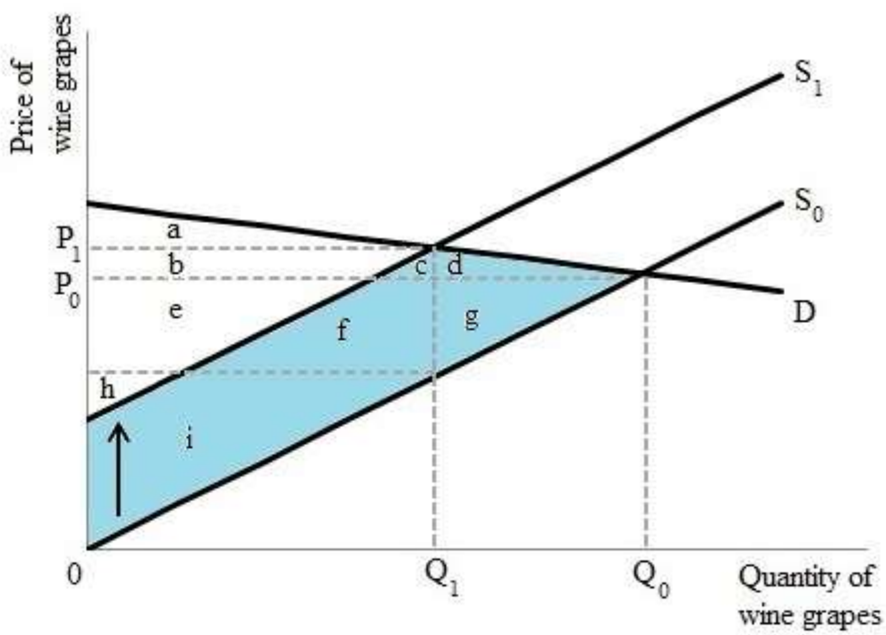


Figure 7. Change in Total Surplus with loss of certified material *(shaded)*

Figure 7 has $S_{0,}$ projected supply at with certified material, and S_1 is the case with no certified material represented by a parallel shift up of supply. Change in total surplus, ΔTS, is represented by the shaded area (c + d + f + g + i).

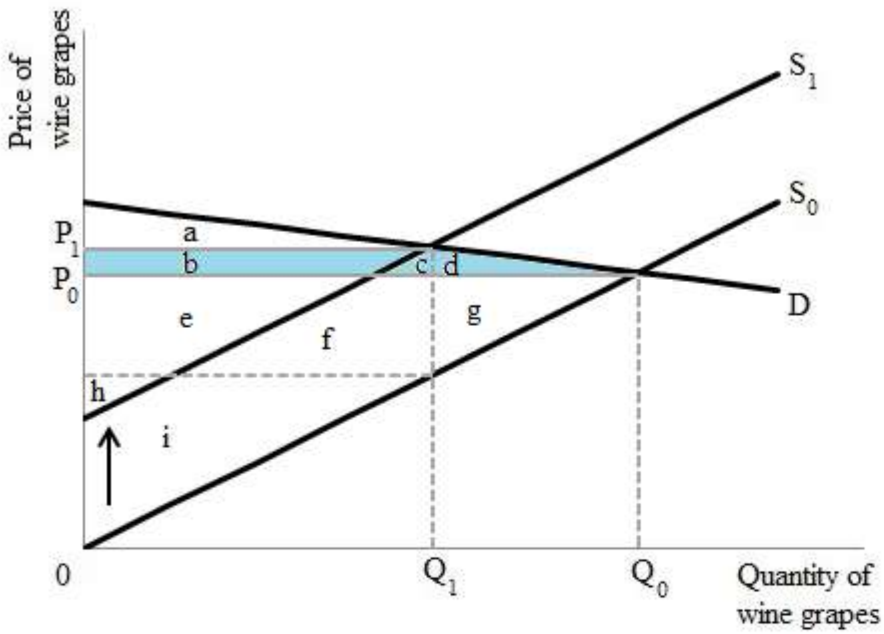


Figure 8. Change in consumer surplus

Figure 8 represents the change in consumer surplus, ΔCS, (-b -c -d) with loss of the program.

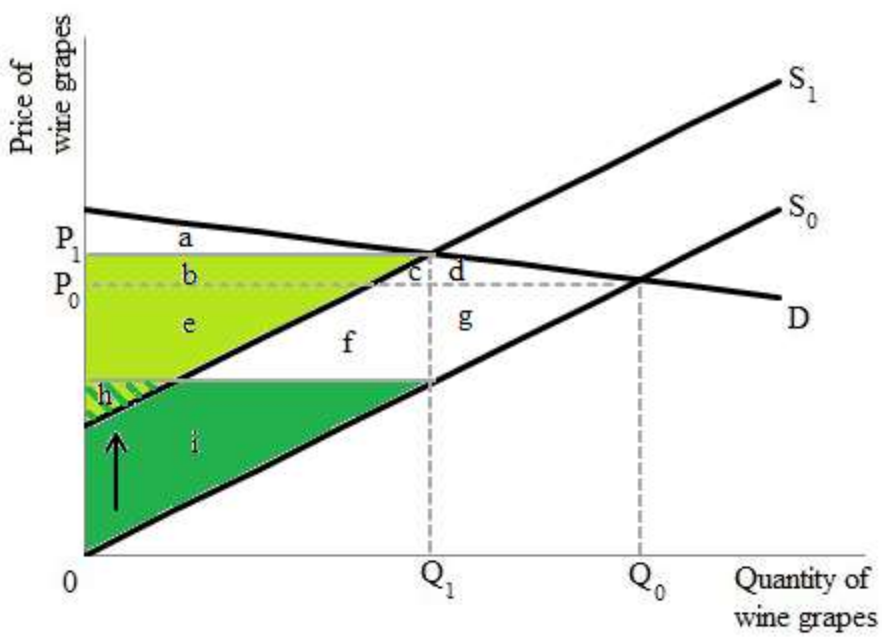


Figure 9. Equivalent areas of producer surplus

Figure 9 shows that by construction (i) = (b+e) therefore since change in producer surplus, ΔPS, is (+b-f-g-i) let us replace (i) so ΔPS = (+b-f-g-b-e) resulting in Figure 10 showing ΔPS = (-e-f-g) represented by the shaded area.

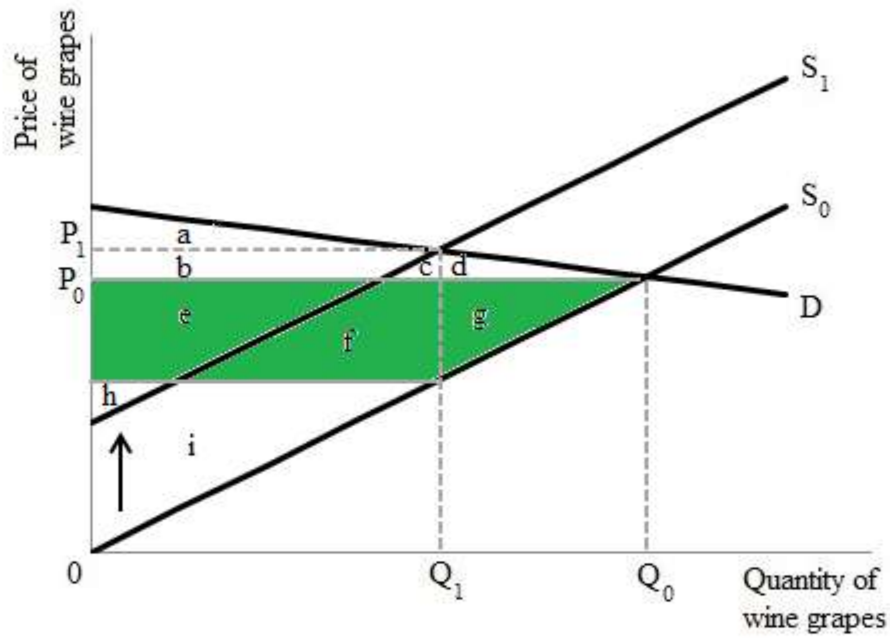


Figure 10. Change in producer surplus

Combining the ΔCS and ΔPS, results in ΔTS = -(b + c + d + e + f +g) which is represented below in Figure 11.

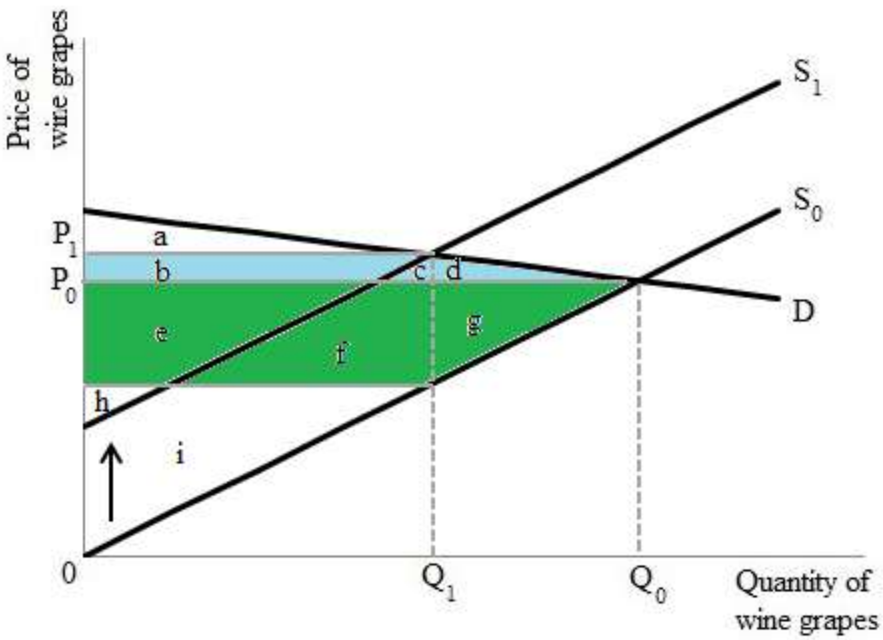


Figure 11. Change in consumer and producer surplus

The shaded area in Figure 11 is the area we are estimating using the following formulas.

Mathematically we begin with the equation for quantity supplied, where *P* is the crush price of grapes per ton and *k* is the vertical shift down in supply ($/ton) resulting from the availability of certified stock:

$$\boldsymbol{Q_s = \alpha + \beta(P + k).} \tag{A-1}$$

By definition elasticity of supply, ε, is $\varepsilon = \left(\frac{\delta Q_S}{\delta P}\right)\left(\frac{P}{Q_S}\right)$, and by definition, $\beta = \delta Q_s/\delta P$ from (A-1). If $k = 0$, then $\beta = \varepsilon Q_S/P$ from (A-1). Quantity demanded is

$$\boldsymbol{Q_D = \gamma - \delta P.} \tag{A-2}$$

We let η be the absolute value of the price elasticity of demand $\eta = \left|\left(\frac{\delta Q_D}{\delta P}\right)\left(\frac{P}{Q_D}\right)\right|$. Since $\delta = \delta Q_D/\delta P$ from (A-2), then $\delta = \eta Q_D/P$. Setting supply equal to demand and solving for the equilibrium price, P*, we obtain:

$$\boldsymbol{P^* = \frac{-(\alpha + \beta k - \gamma)}{\delta + \beta}.} \tag{A-3}$$

The change in the equilibrium price implied by removal of certified material is given as

$$\Delta \boldsymbol{P}^{*} = \boldsymbol{P}_{1}^{*} - \boldsymbol{P}_{0}^{*} = \left(\frac{-(\alpha + \beta k - \gamma)}{\delta + \beta}\right) - \left(\frac{-(\alpha + \beta k_{0} - \gamma)}{\delta + \beta}\right) = -\frac{\beta k}{\delta + \beta}, \tag{A-4}$$

since $k_0 = 0$ results in k which is the vertical shift. Next expressing this change as a proportion of the initial price,

$$\boldsymbol{Z} = \frac{\boldsymbol{P}_{1}^{*} - \boldsymbol{P}_{0}^{*}}{\boldsymbol{P}_{0}^{*}} = \frac{-k}{\boldsymbol{P}_{0}}\left(\frac{\beta}{\delta + \beta}\right) = -\boldsymbol{K}\left(\frac{\varepsilon}{\eta + \varepsilon}\right), \tag{A-4'}$$

assuming $Q_{s*} = Q_{d*}$, where $K = k/P_0$. In our analysis, withdrawing the program, K<0 implies Z>0. The total change in total surplus (b + c + d + e + f + g) can be written as shown in A-5

$$\Delta \boldsymbol{TS} = \boldsymbol{P}_{0}\boldsymbol{Q}_{0}\boldsymbol{K}(\mathbf{1} + \mathbf{0.5}\boldsymbol{Z}\boldsymbol{\eta}). \tag{A-5}$$

The total surplus change can be approximated by estimating the change in regional profits from the loss of virus-tested material, as shown in Eq. A-5′.

$$\Delta \boldsymbol{TS} = \boldsymbol{\pi}_{NC} - \boldsymbol{\pi}_{c} = \boldsymbol{P}_{0}\boldsymbol{Q}_{0}\boldsymbol{K}. \tag{A-5'}$$

This estimate of the change in total surplus does not take into account the shaded triangle to the right of Q_1 in Figure A-1, but can be used as an approximation because ratios are maintained relative to areas to the left of Q_1.

Because the derived demand for wine grapes at the farm level is modeled as an input into the production of wine, "consumer" surplus in the present context represents benefits accruing to the buyers of wine grapes and other intermediaries, including final consumers of the wine those wine grapes are used to produce. Producer surplus includes the quasi-rents accruing to suppliers of inputs used in farming and in nurseries; consumer surplus includes the quasi-rents accruing to off-farm processing, and marketing inputs as well as final consumer surplus. Economic rents typically refer to the difference between the costs of supplying a good and its market price. If some factors of production are fixed only in the short or intermediate term, the rents that accrue to them are called quasi-rents. See (Just, Hueth, & Schmitz, 2008) for further detail.

The change in consumer surplus, ΔCS (area a + b + c) is:

$$\Delta \boldsymbol{CS} = -\boldsymbol{P_0 Q_0 Z}(\mathbf{1} - \mathbf{0.5}\boldsymbol{Z\eta}), \qquad \textbf{(A-6)}$$

which can be approximated using a measure of the change in total surplus and the elasticities of supply and demand:

$$\Delta \boldsymbol{CS} \approx -\boldsymbol{P_0 Q_0 Z} = \Delta \boldsymbol{TS}\frac{\boldsymbol{Z}}{\boldsymbol{K}} = \Delta \boldsymbol{TS}\frac{\boldsymbol{\varepsilon}}{\boldsymbol{\varepsilon}+\boldsymbol{\eta}}. \qquad \textbf{(A-6')}$$

The change in producer surplus, ΔPS (area d + e + f) is

$$\Delta \boldsymbol{PS} = -\boldsymbol{P_0 Q_0}(\boldsymbol{K} - \boldsymbol{Z})(\mathbf{1} - \mathbf{0.5}\boldsymbol{Z\eta}), \qquad \textbf{(A-8)}$$

which can be approximated similarly using:

$$\Delta \boldsymbol{PS} \approx \Delta \boldsymbol{TS}\frac{(\boldsymbol{K}-\boldsymbol{Z})}{\boldsymbol{K}} = \Delta \boldsymbol{TS}\frac{\boldsymbol{\eta}}{\boldsymbol{\eta}+\boldsymbol{\varepsilon}}. \qquad \textbf{(A-8')}$$