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ABSTRACT. Pierce's Disease (PD) of grapevines costs more than \$100 million per year, even with public control programs in place that cost \$50 million per year (Tumber et al., 2012). If the PD Control Program ended, and the GWSS was distributed freely throughout California, the annual cost to the winegrape industry would increase by more than \$185 million (Alston et al., 2012). Using a simulation model of the market for California winegrapes, we estimate the benefits from research, development and adoption of PD-resistant vines as ranging from \$4 million to \$125 million annually over a 50 year horizon, depending on the length of the R&D lag and the rate of adoption. In addition to these quantitative results the paper offers insight into the broader question of economic evaluation of damage-mitigation technology for perennial crops.

Key Words: Pierce's Disease research, exotic pest, simulation model, perennial crop model, California wine and winegrapes

JEL codes: Q11, Q16, Q18, C61

1. Introduction

Pierce's Disease (PD) of grape vines, is endemic to California, and represents a significant threat to the California winegrape industry, which contributed \$2.1 billion, 6% of the value of California's farm production in 2010 (California Department of Food and Agriculture, 2011). PD is caused by a strain of the bacterium *Xylella fastidiosa* (*Xf*), spread by a group of insects called sharpshooters. It can kill grapevines quickly and, as yet, most vineyard managers do not have access to an effective cure or preventive measure.

The disease has been present since the beginning of winegrape production in California, spread mainly by a native vector, the Blue-Green Sharpshooter (BGSS). The BGSS inflicts chronic but usually manageable PD damage in the Napa Valley and North Coast areas. Concerns about PD escalated after a devastating outbreak in the Temecula Valley (in Southern California) in the late 1990s, spread by the newly arrived, non-native Glassy-Winged Sharpshooter (GWSS). Compared with native sharpshooters, the GWSS can fly farther and feed on a greater variety of plants and plant parts, and consequently has a much greater capacity to spread PD. In response to the increased threat from the new vector, the California Department of Food and Agriculture (CDFA) developed extensive PD/GWSS control and research programs.

Alston et al. (2012) developed a simulation model of the winegrape industry to evaluate the costs and benefits of PD and related policies. Using their most-likely estimates of key parameters in that model, they estimated that PD currently costs the producers and consumers of winegrapes approximately \$92 million per year, and would cost an additional \$185 million per year if the PD Control Program (PDCP) were halted. These estimates do not include the average annual costs of approximately \$49 million per year spent on preventive measures, comprising

about \$37 million (effectively borne by taxpayers) under the PD/GWSS program and \$8 million incurred by the nursery industry in costs of compliance with it (Tumber et al., 2012).

This paper builds on the work of Alston et al. (2012) by examining potential returns to Pierce's Disease research. Specifically, using the same simulation model, we evaluate the likely payoffs from a range of types of research-induced innovations that could flow from the types of projects that have been funded by the PD/GWSS Board. Since the PD research is still in process, we evaluate results for a range of alternative assumptions about the R&D lag (the length of time before results from research are made commercially available) and rates of adoption by growers once the technology has become available.

We evaluate the payoffs from these innovations over a 50-year horizon for two alternative scenarios regarding the status of the PDCP and corresponding PD prevalence. In one scenario, we assume the PDCP stays in place and prevents a large-scale "PD outbreak" (i.e., a scenario in which the GWSS would become endemic throughout California). In this scenario, with PD/GWSS prevalence continuing as at present, annual average undiscounted benefits over 50 years range from under \$5 million (for a technology that becomes available in 40 years and is adopted by 40 percent of PD-affected growers) to \$56 million (for a technology that is available in 10 years and is adopted by 100 percent of affected growers). In 2010 present value terms, this translates to an average annual benefit between less than \$1 million and \$15 million over the 50-year horizon. In an alternative scenario, in which the PD control program is ended, and a large-scale outbreak ensues, our estimates of the average annual benefits from the same technologies range from \$7 million to \$126 million, with an average annual discounted benefit of \$1 million to \$32 million over the 50-year horizon.

These results, presented in detail in Section 5, are derived from an analysis using a regionally disaggregated dynamic simulation model of the California winegrape market, with specific representation of the impacts of PD/GWSS on the vineyard capital stock and of alternative technologies anticipated to be developed from the past and ongoing research program, as reviewed in Section 2. A model of the economic impacts of the results from this research is developed in Section 4. As a preface to the development of this specific model, Section 3 provides some context from the broader literature on the economics of agricultural R&D. This section points to the importance of an explicitly dynamic treatment for perennial crops, especially when dealing with damage-mitigation technology in a case where the disease destroys durable capital, not just current yields. Section 6 summarizes the main findings and concludes the paper.

2. Pierce's Disease Research

The Pierce's Disease research program that was established in 2001 has been supported by funding provided by the federal and state governments, with some support from an industry assessment. The program has pursued a range of types of focused research, mainly conducted in the University of California and like institutions, complemented by other research programs in entomology, bacteriology, plant molecular biology and the general sciences. At the same time the disease serves as a model for more general research questions.

The Pierce's Disease Research Program

In 2001, the CDFA PDCP collaborated with the grape industry and developed the Pierce's Disease/Glassy-Winged Sharpshooter Board (PD/GWSS Board), which sought to expedite research and find solutions to PD and the GWSS. The grape industry lobbied and created an assessment, which directly funds PD and GWSS research. Since 2002, the PD/GWSS

Board has provided funding of between roughly \$1 million and \$4 million dollars annually for research projects. Also in 2001, the University of California (UC) Pierce's Disease Research Grants Program was established with funding from the USDA. The UC Program has the same objective as the PD/GWSS Board and works in collaboration with the PDCP in reviewing and selecting research projects to fund. Since 2002 the UC PD Research Grants Program has spent between roughly \$1.3 million and \$2 million dollars annually for research projects, but as of fiscal year 2011/12, it is no longer being funded. Several other funding agencies have contributed to total PD research funds since 2000, including USDA APHIS (Animal and Plant Health Inspection Service), the USDA Texas Fund, and the American Vineyard Foundation. Figure 1 shows funding by year and major funding agency.

[Figure 1: *Total PD Research Funding by Year and Funding Agency*]

Types of Research

For the purposes of this paper, we have defined four categories of PD research: (a) general understanding, (b) vector management, (c) transgenic plants, and (d) conventional breeding. In our simulations we were able to model only the introduction of resistant varieties of grapevines, forms of innovation that could be derived from either genetic engineering approaches or conventional breeding, as discussed later in the paper. The other two categories of research have been significant and might yield substantial benefits as part of or in addition to those we estimate associated with varietal innovations. In what follows, we briefly describe each research category.

General Understanding. Research projects in this category focus on creating better understanding of the disease and its epidemiology. These projects do not have a particular focus on any end-product that can be used in the field, although in many cases they may form an

important basis for other research that does lead to practical technologies. It is not clear how to represent the impacts of research of this general nature in practical models and measures of research benefits.

Vector Management. Vector-management research focuses on finding better methods of sharpshooter control, especially methods for the control of the GWSS. Thus far, the most effective methods of vector management have proven to be heterogeneous across regions of the state as well as across operations; the best control strategy for an organic vineyard in the Napa Valley will be different from that for a nursery in Southern California.

Following the PD epidemic caused by the GWSS in Southern California around 2000, much PD research focused on finding an effective pesticide. As a result, imidacloprid, a very effective neonicotinoid was identified and is now utilized on a large scale in that area.¹ Research has shown that if imidacloprid is used consistently, and nearby grape and citrus growers also treat their vineyards and orchards, PD prevention is very near 100 percent (Daugherty and Pinckard, 2011).² Citrus growers in areas with very strong PD pressure (who are not directly affected by PD) are now urged to have their orchards treated with imidacloprid, which is offered without cost to private growers by UC Extension personnel (Toscano and Gispert, 2011). However, this pesticide cannot be used in organic, urban, or riparian areas, and it does not work well in some important vineyard areas outside of Southern California, including Napa-Sonoma where it is not taken up by the plants before the insects enter vineyards and begin feeding in the Spring. Recently, a study has suggested that imidacloprid may be tied to honey bee colony collapse disorder, which could lead restrictions on its use (Chensheng et al., 2012).

¹ Neonicotinoids are a class of insecticides chemically similar to nicotine.

² The GWSSs tend to spend their winters in citrus groves.

Release of parasitic wasps has also been investigated since 2000 and utilized since 2001 in various parts of the State where pesticides are not feasible. GWSS parasitoids seek out and lay eggs within the eggs of the GWSS. Several native wasps began parasitizing GWSS eggs after the GWSS arrived in California, and researchers have bred and released these. In addition, parasitoids of GWSS were found in the southeastern United States and Mexico—the native range of the GWSS—and some of these wasps are now bred and released as well. Rates of parasitism in areas where releases take place range between 20 and 90 percent, but little is known about the corresponding effect on disease prevalence (Morgan, 2012).

Transgenic varieties. Much work has been conducted in an effort to create grapevines that are resistant to PD but are otherwise identical to the grape varieties they replace. The goal of many such projects is to create a transgenic rootstock that can confer resistance to the rest of the plant without altering other characteristics of the plant or the grapes it produces.³ Several projects are underway. Some of the resulting rootstocks have shown promise in a greenhouse setting and are currently undergoing field testing, but they are not expected to be available in a commercial setting for at least 20 years (Dandekar, 2012; Gilchrist, 2012; Lindow, 2012).

Transgenic disease resistance can be accomplished by making adjustments to the genetic makeup of the plant such that either infection cannot occur or the disease symptoms are blocked, or to inhibit disease or disease response by way of biological control. Biological control involves the introduction of a pathogen into the plant, either through a topical application or an inoculation to the plant, or through transgenic breeding to create a rootstock or scion that itself produces the pathogen. Thus far, researchers have focused on using transgenics as a means of

³ Like many perennial crops, winegrapes in California are grafted: *Vinifera* scions are grafted onto rootstocks of native grape varieties to confer resistance to endemic diseases and pests such as phylloxera.

creating the biocontrol agent within the plant, as it has proved to be prohibitively expensive to produce the amounts necessary for topical or soil application (Dandekar, 2012).

Other transgenic strategies involve stopping the spread of disease once it enters the plant, or slowing its spread. Transgenic modification can also be used to prevent the expression of disease symptoms—cell death—without preventing the disease infection itself. This modification has the advantage that it does not involve sharpshooter deterrence or disease prevention; hence, neither the vector (the sharpshooter) nor the disease can become resistant (Gilchrist, 2012).

In general, genetic modification for pest and disease resistance entails large costs not only in the development of the technology but also in complying with the extensive regulatory review process that the technology must pass through before it is approved for commercial use (e.g., see Kalaitzandonakes et al., 2007). After they have been deregulated, these types of plants and any foods derived from them often face political and other market resistance, and this, along with the costs of the regulatory process, has limited the use of genetically engineered varieties for food crops and specialty crops (e.g., see Alston, 2004). The possibility to create vines that are resistant to PD (as well as, eventually, potentially other diseases or problems), and can produce wine or table grapes with exactly the same characteristics as vines that are susceptible to disease, has a great deal of potential. However, the breeding and approval process together can take well over 30 years—most of the researchers we interviewed were conducting research with time horizons of this length.

Conventional Breeding. Conventional breeding can produce usable results more rapidly than transgenics, both because the research itself can progress more quickly and also because it does not entail the extensive testing and regulatory review process to which genetically modified

plants must be subjected. In winegrapes, the process of creating conventionally bred resistant vines involves crossing winegrape varieties (*Vitis vinifera*), all of which are at least somewhat susceptible to PD, with other grape varieties that have resistance, in this case wild grape plants such as Canyon grape and Mustang grape (*Vitis arizonica/candicans*).

The challenge in conventional breeding approaches is to produce resistant vines that yield fruit from which wines with desired characteristics can be produced—wines with sensory attributes of those produced with winegrapes rather than wild grapes. By crossing *vinifera* with the wild grape species, and then repeatedly back-crossing the resulting hybrid varieties with *vinifera*, researchers have created vines with over 98 percent *vinifera* genetic material, and similar work has been done for table grapes. Through marker-assisted selection, both processes have been accomplished much faster than would have been possible otherwise, and the resulting varieties could be available commercially in approximately 10 years (Ramming and Walker, 2011).⁴

Wines are currently being produced with these grapes in a laboratory setting, but the vines are not yet available for commercial use. Once they become available, they are likely to be planted in areas where 100 percent *vinifera* cannot grow because of high PD pressure, such as in riparian areas of the Napa Valley. Grown here, these grapes can be blended with 100 percent *vinifera* varieties for better taste and *vinifera* labeling, since current regulations allow up to 25 percent of non-varietal grapes to be included in varietally labeled bottles (United States Department of the Treasury Alcohol and Tobacco Tax and Trade Bureau, 2008).

Both transgenic varieties and conventionally bred non-*vinifera* varieties would face significant market resistance in today's environment, and a slow path to development and

⁴ Marker-assisted selection uses easily identifiable traits linked to disease resistance to identify whether the resistance is present, without having to check for disease resistance itself, which would require more time.

adoption, but the key determinants may change rapidly. Both the R&D lag and the adoption rate are likely to depend on the extent of the prevailing disease pressure, and current popular sentiment regarding these technologies, both of which may change significantly between now and the time when the technologies could begin to become available for commercial use.

Funding for Research

Figure 2 shows research funding by year and type of research. Annual Pierce's Disease research funding has declined since it reached a peak of over \$9 million in 2006. Funding for "general understanding" types of research has been dominant over the course of the programs. Transgenic plant research has been the second-most funded type of research, and continues to receive funding. Vector management research received more funding in earlier years, but once imidacloprid was established as effective against sharpshooters in areas that had been hit particularly hard by PD, funding for vector-management research projects tailed off. Conventional plant-breeding research first received funding in 2001, and funding for that research has been renewed regularly since. Table 1 shows totals for the different research categories and funding agencies. The CDFA PD/GWSS Board has funded the most research, followed by the UC Pierce's Disease Fund. Together, these two organizations have provided nearly 70 percent of all PD research funding since 2000.

[Figure 2: *Funding by Year and Research Type*]

[Table 1: *Total Funding by Agency and Research Category*]

3. Conceptual Issues in Measuring Research Benefits

Much has been written by economists about approaches to be applied, and conceptual and empirical issues to be addressed, in measuring the returns to agricultural research investments. This work has been reviewed and summarized in various places including Alston et al. (1998)

and, more recently, Alston et al. (2010). The conventional analysis typically uses a comparative static supply and demand framework to represent the market equilibrium, with and without a research-induced supply shift, and the implied changes in Marshallian producer and consumer surplus are used to represent total gross annual research benefits (GARB) and the distribution of those benefits between consumers and producers. The pattern of GARB over time then is dictated by the path of adoption of the innovation and the implied path of the research-induced supply shifts. Much of the literature in this vein has emphasized the roles of assumptions about the functional forms of supply and demand, the nature of the research-induced supply (or demand) shift, and the effects of market structure and market distortions as influences over the measures of total benefits and the distribution of benefits.

The most natural application of this approach is to varietal improvements for annual crops, though some of the applications have included livestock production systems or perennials, including forestry, and many studies have applied the same model to agriculture in aggregate (e.g., see the meta-analysis by Alston et al., 2000). Some of these applications may be questionable because the dynamics of production and adoption of technology are not well captured by the comparative-static analysis, and this is a particularly pertinent consideration for livestock and perennial crop production systems, where dynamics are longer and more important. In the present application we are dealing explicitly with a perennial crop for which research is being undertaken aiming to generate new technologies that can be introduced to mitigate losses from a vector-transmitted disease that destroys productive capital in the form of grapevines.

The important departures from the conventional model arise in two main ways. First, the technology is of the “damage mitigation” sort, rather than the simple “yield-enhancing” or “cost-reducing” sort that is typical of the literature. Lichtenburg and Zilberman (1986) demonstrated

that explicit specification of the damage-mitigation aspect of such technologies could have significant implications for findings—though subsequent work indicates that the use of a relatively flexible specification of the functional form of the model could reduce the distortions from mis-specification of the mechanics of the technology (Babcock et al., 1992; Chambers and Lichtenberg, 1994; Saha et al., 1997). In this case, the damage is of a capital destruction nature, which was not anticipated by the analysis of Lichtenberg and Zilberman (1986) and this has implications for the nature of the costs of the pest and disease, to be mitigated by technology, that suggest that an explicitly dynamic approach may be required.

Second, the fact that we are dealing with a perennial crop has direct implications for the model specification. In particular, a static model of supply response to price is always an abstraction from reality in models of agricultural markets, but the abstraction is especially large in the case of long-lived perennial crops. The penalty for making such a large abstraction may be compounded in the context of models of agricultural innovation directed to damage mitigation where the damage is of the capital destruction (vine-killing) rather than yield-reducing sort.⁵ These features of the problem have implications for the time path of the research-induced changes in production and prices that might be difficult to capture accurately in a conventional comparative static representation, and previous studies have shown that the time path of innovation is a crucial determinant of the net benefits (e.g., see Alston et al., 2010).

In addition to the considerations already mentioned, we have an interest in comparing the returns between alternative research investments. The range includes investments directed toward vector control that would have relatively immediate effects on production and could be employed with discretion depending on pest prevalence, and investments into genetic

⁵ Certainly, it is always possible to apply the comparative static analysis as an approximation but until an explicitly dynamic analysis has been undertaken as a benchmark, we cannot say how close the comparative static approximation might be.

technologies that would work by embodying resistance to the disease in the rootstock or the scion.⁶ These genetic technologies take time to be introduced (they require replacing the existing vines) and then they are employed year-in, year-out. In this sense the technologies are very different, especially with respect to their dynamic implications, and it might be challenging to represent those differences meaningfully in a comparative static analysis.

Other features of the problem that are pertinent for the specification of the model of research benefits include (a) the fact that winegrapes are highly differentiated products, with a regional pattern to quality variation that is correlated with the prevalence of the pest and disease, such that a disaggregated model—in both the space and product quality dimensions—is appropriate, and (b) California is a “large” producer in the sense that California’s production of winegrapes affects prices, and most of California’s production is exported to other states or countries, such that a partitioning of benefits between producers and consumers is necessary to gain insight into the benefits to California versus the larger economy from California’s PD research program. The model that is described and applied below was designed with this application in mind, and explicitly addresses the spatial and dynamic dimensions of the pest and disease problem as it influences the California wine industry, and the research-induced innovations designed to mitigate the resulting costs.

4. Model and Model Parameterization

To evaluate the potential benefits from PD research investments, we created and utilized a regionally disaggregated dynamic simulation model of supply and demand for California winegrapes. Since that model is described in detail in Alston et al. (2012) only a brief overview

⁶ In the present application, however, as discussed above we do not evaluate vector control technologies.

is presented here, followed by some detail on the specification of the parameterization to represent the consequences of different types of research-induced innovations.

In this model of California winegrape production, each of six regions (defined on the basis of characteristics of winegrape production and the prevalence of PD) produces one of three quality classes of winegrapes (“High,” “Medium,” or “Low,” defined using average prices of winegrapes produced).⁷ In the Napa and Sonoma area, vineyards yield a few tons per acre of winegrapes that fetch very high prices, while in the Central Valley, yields are much higher but prices are much lower (see Appendix Table A-1). The remainder of the state’s winegrapes fall between these two yield and price extremes. Prices and yields can also vary a great deal across varieties, even within regions (among varieties of the same color as well as between red and white winegrape varieties). However, for the purposes of this analysis all varieties are aggregated within each of the six production regions. We defined the production regions by aggregating over California’s 17 crush districts on the basis of the volume-weighted average price per ton of grapes produced, as well as the incidence and epidemiology of PD.⁸

Patterns of PD also vary greatly over the state. In the Napa and Sonoma Valleys where the GWSS is not present, the BGSS has a strong preference for lush, new growth. In this area, there are few, if any, effective pesticides for controlling the vector. While some growers have revegetated riparian areas with plants that do not attract the insect, this method has not proved cost effective for most growers; in some cases, where prevalence is high, vineyard land is left idle (Fuller et al., 2011). In Southern California, the GWSS poses major threats because it is a long-distance flyer that can feed on many different parts of the grapevine (among hundreds of

⁷ See Appendix Table A-1 for definitions of regions and summary statistics; see Alston et al. (2012) for greater detail.

⁸ California’s crush districts are the level of aggregation at which the California Department of Food and Agriculture reports grape volume, price, acreage, and sugar content, among other things.

other plant species and subspecies). In southern California, soil types and temperatures, as well as insect behavior, are such that systemic insecticides are very effective in keeping sharpshooter populations low. Other regions in California face much lower, if any, PD pressure, although in some cases large-scale prevention measures may be keeping sharpshooter populations at the current (very low) levels.

The parameters used in the demand side of the model are based on estimates by Fuller and Alston (2012). On the supply side, the model is dynamic, as is necessary to capture the essential character of supply response for a perennial crop, like winegrapes. Once planted, several years pass before grapevines become mature and bear fruit. Grapevines can then remain economically productive for many years—often several decades—and, as a result, planting decisions and subsequent maintenance and care can have effects that linger. Multi-period effects are particularly relevant when considering the impact of PD, which destroys productive capital by killing vines, such that it takes time for lost vines to be replaced and for production to recover.

The structure of the model reflects these biological characteristics of the production system, combined with economic responses that reflect the nature of factor supply to the industry, and other aspects of costs and production that vary over space and time, as well as the demand for grapes differentiated by quality. The model is parameterized to represent economic behavior and the role of alternative PD-mitigation technologies based on a combination of econometric estimates and calibration approaches, as is typical of both *ex ante* and *ex post* evaluations of research impacts. Such an approach is particularly appropriate in the present context; we are proposing to evaluate effects of investments in R&D that imply effects in markets outside the range of historical experience, projected many years into the future.

Parameterization of Impacts of R&D—Efficacy, Adoption Rates, and R&D Lags

To better understand research being conducted and its potential future outcomes, we interviewed the scientists conducting the research. Because we could not feasibly interview each individual conducting research relating to PD, we attempted to speak with researchers who were prominent within the four research categories we had designated. We chose these individuals either by examining records of PD research funding to determine who had received large portions, or through referral from PD program staff members or other researchers we had already interviewed.

In interviews, we asked questions about the expected duration of the research process, and any potential lags in commercialization and adoption associated with the regulatory process or for other reasons, eventual adoption rates, and the potential effectiveness of the new technology in preventing PD, as well as additional costs to vineyard owners associated with the use of the technology compared with conventional alternatives. The parameters corresponding to each of these questions can be specified differently for each of the six different regions represented in the model. In total we interviewed seven individuals. From these individuals we elicited that the total remaining R&D lag (the time from the present until the new technology resulting from a particular category of research will be available for commercial adoption) is between 10 and 40 years, and that most PD researchers are working towards technologies that will have 100 percent efficacy against the disease, if the research is successful. Researchers indicated that adoption rates can be expected to vary among types of technology, depending on perceptions of that technology at the time of its release (for instance, in the event of low PD pressure growers may be reluctant to adopt transgenic varieties or even conventionally bred non-*vinifera* varieties, but if PD pressure is very severe we might expect to see much faster and more

widespread adoption of these technologies). Based on these conversations, we considered a range of adoption rates between 40 and 100 percent in PD-affected areas. Table 2 shows useful parameters gleaned from interviews.

[Table 2: *Research and Development Model Parameters*]

Simulations

We conducted simulations of the impacts of alternative varietal PD-mitigation technologies, characterized by alternative combinations of assumptions about R&D lags and adoption rates, under two alternative policy scenarios. In each instance we assumed 100 percent efficacy, as indicated by our elicitation processes. In the first scenario (the “Status Quo”), current PD pressure continues as it currently stands, with the PD Control Program in place. Currently PD pressure is highest in Southern California, where the GWSS is the primary vector, and in the high-value Napa-Sonoma region, where the disease is spread by the BGSS, and effective pesticides are lacking. However, detailed information on current PD incidence is available only for some regions, so in order to get a better idea of the pressure across the state, we sent a questionnaire to a group of Pierce’s Disease experts, and subsequently discussed the responses with a smaller group of economists, plant pathologists, and viticulturalists. We also included questions about future grape production characteristics addressed to a subset of respondents to help parameterize yield growth and grape acreage in the model. Both production and disease characteristics are regionally defined.⁹

The other scenario for comparison is the “Outbreak” scenario, in which the PD Control Program ends, and an outbreak results. The outbreak takes time (10 years) to develop as pest pressure grows in the absence of a control program. Outbreak rates of PD losses differ by

⁹ Alston et al. (2012) provide further information about regional definitions, the questionnaire, model parameters for PD and winegrape production, and results from sensitivity analysis for a range of baselines and outbreak scenarios.

region, based on survey responses. In general, southern parts of the state have higher PD losses than areas farther north. This scenario was also parameterized based on survey responses and discussion with PD experts.

In each case, we model the adoption of varietal technologies—technologies that involve the creation of a new, resistant plant or rootstock. We assumed that growers would not grub out healthy vines but adopting growers in areas affected by PD would use the PD-resistant varieties as soon as they become available for new plantings and replacement plantings. PD mitigation costs are approximately \$150 per acre in areas with PD prevalence. We assumed that, for the proportion of land in which the new vines are adopted, these costs will become zero once the new, resistant vines are planted.

5. Results and Discussion

In each policy scenario—“Status Quo” and “Outbreak” defined in terms of a particular set of assumptions about the prevalence of PD in each region—we simulated region-specific plantings, bearing acreage, production, and prices of winegrapes over a 75 year horizon, using the modeling approach described in Alston et al. (2012). The baseline scenario in each case reflects currently available technology. Then we repeated these simulations allowing for the adoption of alternative PD-mitigation technologies, defined in terms of (a) the remaining R&D lag, (b) the percentage adoption rate after the technology becomes available, and (c) alternative annual expenditures by growers in pest and disease management, since resistant vines, for example, would not require the use of pesticides or other PD-mitigation efforts as embodied in the baseline. Comparing the outcomes between the simulation for a particular PD-mitigation technology, versus the baseline with current technology, yields a measure of the effect of the introduction of the new technology. We calculated changes in producer and consumer surplus as

a result of a range of technologies under both the “Status Quo” policy scenario and the “Outbreak” policy scenario.

The combinations of assumptions about R&D lags and adoption rates in Table 4, corresponding to alternative possible varietal innovations, represent both new varieties developed by conventional (marker-assisted) breeding and new transgenic varieties. The appropriate specific combination of assumptions to represent a particular type of technology is a matter for speculation, since even the researchers themselves do not know exactly (or sometimes, even roughly) when their technology will become available, or how widely it will be adopted. However, in general, conventionally bred vines are likely to be available sooner than transgenic varieties, and, given the current attitudes to genetically engineered crops, to have higher adoption rates than their transgenic counterparts. Net benefits from technologies for PD resistance also will depend on any increased cost borne by growers, such as a technology fee for resistant vines, but for this analysis we assumed that any such fees would have minimal net impact on the cost of vineyard replacement.

Benefits from PD-Mitigation Technologies in the “Status Quo” Policy Scenario

Panel a of Table 3 presents regional average annual changes in consumer surplus, producer surplus, and net economic surplus changes for a particular PD-mitigation technology (a PD-resistant variety with a 20-year R&D lag and 80 percent adoption), compared to the baseline technology, given the “Status Quo” policy, as an illustrative example. The measures of changes in economic surplus are expressed as annual averages of undiscounted changes over a 50-year horizon, beginning in 2012. The counterpart discounted present value measures are reported in Panel b of Table 3, computed in 2010 values, using a real discount rate of 4 percent per annum. In what follows, unless stated otherwise, we refer to the measures expressed in average annual values, because they are comparable to other familiar measures such as the annual value of

production and annual expenditures on PD research, but acknowledging that they do not take into account the timing of the flows of benefits and costs.

[Table 3: *Regional Benefits for Technology Available in Year 20, with 80 Percent Adoption*]

Across the state, the annual average change in producer surplus is generally positive, representing a net gain. However, in one region, Northern California, the new technology makes producers worse off (the average annual losses from the new technology are relatively small, estimated as \$129,000). This area does not have PD in the baseline, so producers do not benefit from yield gains from the new PD-resistant technology, but the increase in total quantity brought about by the adoption of the new technology in other regions brings the equilibrium price down. The regionally reported consumer surplus gains can be misleading—these are gains attributed to consumers of winegrapes (and wine) from the individual regions and not to consumers located in the specified region. Consumers of winegrapes from all regions experience net gains when supply increases and price decreases. The net benefit is the sum of producer and consumer surplus and is positive for each region—producer surplus losses are outweighed by consumer surplus gains in those regions where producers experience a loss. The regional net benefits range from approximately \$11,000 per year (Northern California) to \$15 million per year (Napa-Sonoma). The range is large because of regional differences in baseline PD prevalence, the quantity of winegrapes produced, and the price of those grapes. The total statewide benefit (the sum of consumer and producer surplus) is nearly \$36 million per year.

Table 4 presents the corresponding measures of statewide average annual benefits from PD-mitigation technologies for a range of combinations of adoption rates and R&D lags. Panel a represents the undiscounted annual average benefits; Panel b, the annual average benefits in 2010 present value terms. In Panel a, statewide benefits range from \$3.5 million per year (40 percent

adoption and a 40-year R&D lag) to \$55.8 million (100 percent adoption and a 10-year R&D lag). The total benefit is roughly proportional to the adoption rate, but it is also sensitive to the R&D lag. From our interviews with PD researchers, we estimated that none of the new technologies would be available for adoption in less than 10 years—i.e., by 2022. For a given adoption rate, a technology that is available sooner will clearly yield greater benefits, even using our undiscounted measures. When the future benefits are discounted to 2010 values, as in Panel b of Table 4, the effects of the longer R&D lags in reducing benefits are even greater.

[Table 4: *Statewide Benefits for Alternative Technology Scenarios, Relative to Baseline*]

Benefits from PD-Mitigation Technologies in the “Outbreak” Policy Scenario

We also calculated the statewide welfare changes for alternative technology scenarios in an “Outbreak” scenario. The bottom half of each panel of Table 4 presents these results. The benefits from PD-mitigation technologies are much larger in the “Outbreak” scenario because the baseline PD costs are now much greater than under the “Status Quo” scenario. The average annual benefit from the PD-mitigation technology ranges from \$6.6 million, given a 40-year R&D lag and 40 percent adoption, to \$125.8 million, given a 10-year R&D lag and 100 percent adoption (which is perhaps more likely in this scenario with its very heavy PD losses).

6. Conclusion

Pierce’s Disease research funding has declined substantially in recent years. However, the results of these simulations suggest that the net benefits from this research could be substantial. Several alternative research types have a high probability of providing 100% PD resistance, and for these technologies the differences in their potential payoffs depend on when they become available and their adoption rates among grape growers who are affected. In general, technologies with earlier release dates and greater likely adoption rates, such as

conventionally bred PD-resistant vines, are therefore likely to have greater associated economic net benefits. Technologies that cannot be released for many years and that face market resistance, such as genetically modified vines, will have smaller economic benefits.

The counterfactual comparison is also important. When comparing to the “Outbreak” scenario associated with ending the PD Control Program, the benefit from PD-resistant varieties is more than twice as large as in the “Status Quo” scenario. The future of PD and the related policies are quite uncertain, but the expected benefits from R&D leading to PD-resistant varieties will probably fall somewhere between those estimated for the Status Quo and Outbreak scenarios. In the current climate of budget shortfalls and cutbacks, it seems unlikely that the PD control program will be kept in place in its current form, increasing the likelihood of an “Outbreak” scenario.

Like studies of the benefits from agricultural R&D generally (e.g., see Alston et al., 2010) in the case of PD research our results indicate that the payoffs are large, even though the innovation process entails very long lags both in research and in the adoption process before benefits begin to be realized in the field. These lags are especially long for perennial crops, such as wine grapes, and where the innovation is inherent in the biological capital stock that must be replaced with new investment before benefits can begin. This paper highlights how benefits change over different time horizons for the R&D lag. All else equal, technologies that are available sooner will have greater benefits, and greater benefit-cost ratios. But even under pessimistic assumptions about R&D lags, and optimistic assumptions about PD control policy, PD research appears likely to yield large net benefits.

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Table 1: Total PD Funding by Agency and Research Category, 2000–2012

	General Understanding	Vector Management	Conventional Breeding	Transgenic Plants	Total
	\$ (Nominal)				
CDFA PD/GWSS Board	7,826,982	2,341,466	3,171,843	7,172,505	20,512,796
UC PD Fund	7,779,279	3,228,199	630,000	3,238,172	14,875,650
USDA APHIS Fund	2,691,218	2,814,841	631,601	3,717,884	9,855,544
USDA Texas Fund	3,062,228	960,848	0	0	4,023,076
Assembly Bill 1232 and American Vineyard Foundation Fund	1,319,984	409,523	0	154,629	1,884,136
CDFA PDCP	2,500	169,472	0	0	231,972
Consolidated Central Valley Table Grape Pest and Disease Control District	0	0	90,000	0	90,000
Total	22,742,191	9,924,349	4,433,444	14,283,190	51,383,174

Source: Compiled by the authors based on Tumber et al. (2012) and Esser (2011).

Notes: CDFA stands for California Department of Food and Agriculture. PD/GWSS stands for Pierce’s Disease/Glassy-Winged Sharpshooter. USDA stands for the United States Department of Agriculture. APHIS stands for the Animal and Plant Health Inspection Service. PDCP stands for the Pierce’s Disease Control Program. Values are computed as the simple sum of nominal values over the period 2000–2012.

Table 2: Elicited Parameters for PD-Resistant Varietal R&D and Adoption

Category	Conventional Breeding			Transgenic Plants		
	High	Best Guess	Low	High	Best Guess	Low
Total R&D (Years)	20	10	10	30	20	15
Adoption Rate (%)	100	80	40	60	60	40
Efficacy (%)	100	100	80	100	100	80

Notes: Adoption rate refers to areas in which PD is prevalent. Adopting growers are assumed to adopt at the time of planting new or replacement vines but without changing the timing of normal replacement of existing vineyards, at age 25 years. We have assumed the implementation cost to be 0 for all technologies because we did not have cost information on any technology, and we have reason to believe that vine costs will not change for either technology type.

Table 3: Benefits from New Technology with a 20-Year R&D Lag and 80 Percent Adoption, Relative to Baseline Technology, Status Quo Scenario

a. Annual Average Benefits, 2011–2060

	Changes in Producer Surplus	Changes in Consumer Surplus	Total Benefit
		\$ (<i>Thousands</i>)	
Napa-Sonoma	9,498	5,820	15,318
Coastal	187	281	468
Northern SJV	213	1,170	1,383
N. California	-129	139	11
S. California	4,531	222	4,753
Southern SJV	11,471	2,877	14,348
State Total	25,772	10,509	36,281

b. Annual Average Discounted Benefits, 2011–2060

	Changes in Producer Surplus	Changes in Consumer Surplus	Total Benefit
		\$ (<i>Thousands</i>)	
Napa-Sonoma	2,288	1,147	3,435
Coastal	45	56	100
Northern SJV	88	232	320
N. California	-14	27	14
S. California	1,035	44	1,079
Southern SJV	2,950	582	3,533
State Total	6,393	2,088	8,481

Notes: The Total Benefit is the sum of changes in consumer and producer surplus. “SJV” refers to San Joaquin Valley. All monetary values in Panel a and Panel b are expressed in real 2010 dollars. Values in Panel b are discounted to 2010 present values using a real discount rate of 4 percent per annum.

Table 4: Statewide Total Benefits from Alternative Technologies

a. Annual Average Benefits, 2011–2060

% Adoption	R&D Lag (Years)			
	10	20	30	40
<i>\$ Millions</i>				
Relative to the Baseline, Status Quo Policy Scenario				
100	55.8	45.4	24.5	8.8
80	44.5	36.3	19.5	7.0
60	33.2	27.2	14.6	5.3
40	22.1	18.1	9.8	3.5
Relative to the Baseline, Outbreak Policy Scenario				
100	125.8	103.4	44.7	10.6
80	101.8	84.5	37.4	9.9
60	77.3	64.7	29.5	8.6
40	52.2	44.2	20.6	6.6

b. Annual Average Discounted Benefits, 2011–2060

% Adoption	R&D Lag (Years)			
	10	20	30	40
<i>\$ Millions</i>				
Relative to the Baseline, Status Quo Policy Scenario				
100	15.5	10.6	5.0	1.6
80	12.3	8.5	4.0	1.2
60	9.2	6.4	3.0	0.9
40	6.1	4.2	2.0	0.6
Relative to the Baseline, Outbreak Policy Scenario				
100	31.5	22.4	8.8	2.0
80	25.9	18.5	7.4	1.9
60	20.0	14.3	5.9	1.6
40	13.8	9.9	4.1	1.2

Notes: All dollar values are expressed in constant, 2010 dollar values. Present values are computed in year 2010 values using a real discount rate of 4 percent per annum.

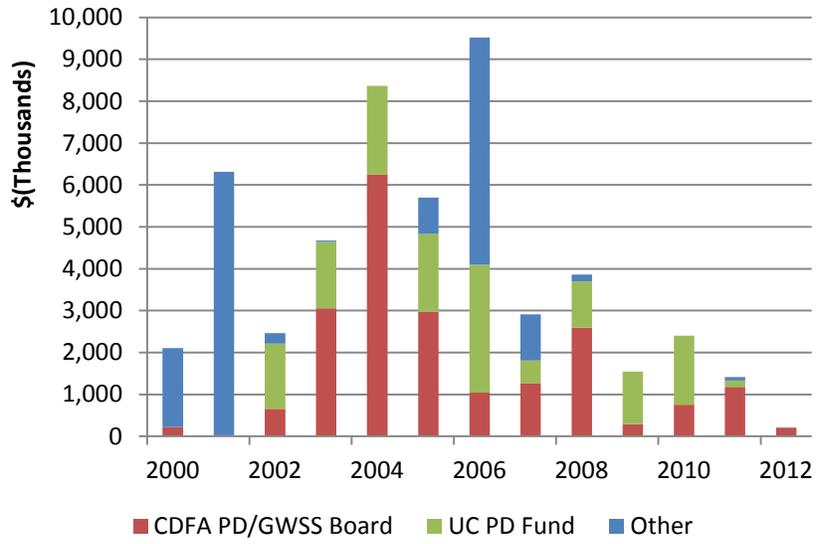


Figure 1: Total PD Research Funding by Year and Funding Agency

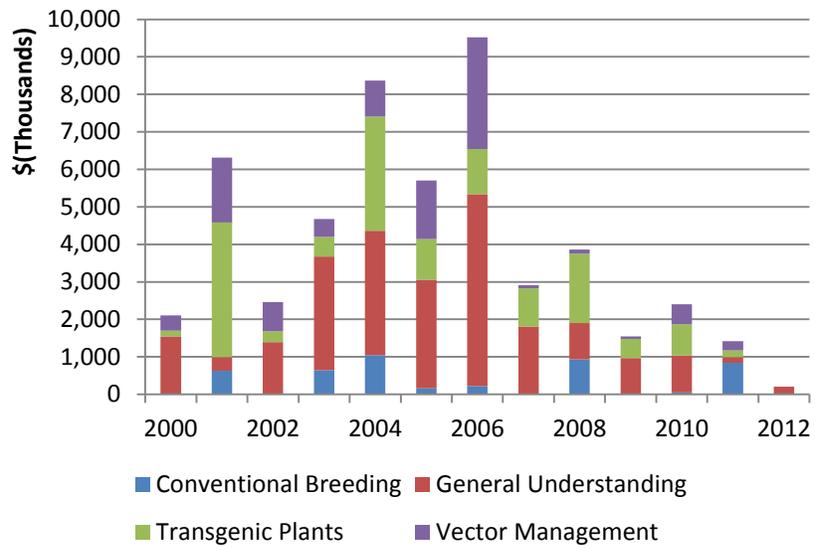


Figure 2: *PD Research Funding by Year and Research Type*

Appendix Table A-1: Production Regions – Definitions and Basic Statistics

Production Region	Districts	Bearing Acreage, 2010	Tons Crushed, 2010	Yield per Acre, 2010	Average Price, 2010
		<i>Acres</i>	<i>Thousands of Tons</i>	<i>Tons per Acre</i>	<i>2010\$/ton</i>
Napa-Sonoma		100,424	331	3.30	2,526
	3	55,647	192	3.45	2,011
	4	44,777	139	3.10	3,238
Coastal		55,266	313	5.66	971
	5	3,164	15	4.67	680
	6	6,563	28	4.23	992
	7	45,539	270	5.94	984
Northern SJV		84,530	705	8.34	477
	11	66,802	607	9.09	470
	17	17,728	98	5.52	525
Southern SJV		132,215	1,831	13.85	289
	12	28,220	270	9.56	360
	13	78,643	1,151	14.64	273
	14	25,352	410	16.19	290
S. California		46,994	244	5.20	1,075
	8	45,336	239	5.27	1,074
	15	646	1	1.66	798
	16	1,012	4	4.01	1,192
N. California		37,489	165	4.38	904
	1	16,276	66	4.05	1,122
	2	7,939	32	4.05	1,109
	9	7,064	49	6.89	414
	10	6,210	18	2.82	1,071
Total		456,918	3,589	7.85	673

Notes: "SJV" refers to San Joaquin Valley.

Appendix: Model Details

Alston et al. (2012) provide more-complete model details, including our rationale for the choice of functional form, parameterization and sensitivity analysis. What follows is a brief outline of the mathematical structure of the model and its components.

Investment in New Plantings

Investment in an acre of plantings in a given region in year t yields a stream of annual net income, or variable profits, over the lifetime of the investment (π dollars per acre) that depends on yield (Y tons per acre), price (P dollars per ton), and variable costs (VC dollars per acre):

$$(1) \quad \pi_{t+n} = P_{t+n} Y_{t+n} - VC_{t+n},$$

such that the present value of the returns to that investment is given as:

$$(2) \quad PV_t = \sum_{n=0}^T \pi_{t+n} (1+r)^{-n},$$

where PV_t is the present value in time t of the net revenue stream created by the investment in an acre of vines planted in time t ; π_{t+n} is the net income that will accrue to the newly planted vineyard in the year $t+n$; r is the real discount rate; and T is the lifespan of the investment.

The investment decision entails comparing the expected present value of the stream of net income with the cost of the new plantings, $C_t = C(PL_t)$. New plantings in time t are chosen to maximize the expected net present value of the vineyard investment; the expected present value of net returns per acre will be equal to the marginal cost of the new plantings per acre:

$$(3) \quad PV_t = C'(PL_t).$$

Bearing Acreage, Yield, and Production

Vineyard acreage in a given region evolves according to:

$$(4) \quad A_{a,t} = \begin{cases} PL_t & \text{for } a = 0 \\ A_{a-1,t-1} & \text{for } 1 \leq a \leq 25 \\ 0 & \text{for } a > 25, \end{cases}$$

where $A_{a,t}$ is the acreage of vineyards currently a years old, and vines are lost annually to non-PD causes at a proportional rate δ_0 , and to PD at a proportional rate δ_1 . We assume these vines are replanted automatically every year unless they are aged 23 years or older. Therefore the age structure of the vines within a particular vineyard, originally planted a years in the past, changes over time depending on the rate of loss to PD, and in turn, so does the average yield per acre.

The yield of mature vines in a given region is written as a trend model of the form:

$$(5) \quad YM_{t+n} = YM_t + gn,$$

where YM_{t+n} is the projected yield per mature bearing acre in year $t+n$, which is equal to the value in the base year, YM_t , plus a linear growth rate g . The average yield per acre in year t , $Y_{a,t+n}$, is also affected by the age structure of the vines, and the past replacement of vines lost to PD and other causes. Thus

$$(6) \quad Y_{a,t+n} = \left(\sum_{b=0}^{25} AA_{b,a} AY_b \right) YM_{t+n},$$

where $AA_{b,a}$ is the proportion of vines that are b years old in an acre that is a years old, and AY_b is the yield per acre of vines b years old as a fraction of the yield of a mature vine.

$$(7) \quad AA_{b,a} = \begin{cases} 1 & a, b = 0 \\ \delta_0 + \delta_1 & 1 \leq a \leq 22, b = 0 \\ 0 & 23 \leq a \leq 25, b = 0 \\ 0 & a = 0, 1 \leq b \leq 25 \\ (1 - \delta_0 - \delta_1) AA_{a-1,b-1} & 1 \leq a, b \leq 25 \end{cases}$$

Production is given by the product of the age-specific yield per acre from Equation (6) and the number of acres from Equation (4), summed over age categories:

$$(8) \quad Q_{t+n} = \sum_{a=0}^{25} Y_{a,t+n} A_{a,t+n}$$

Investment Cost for New Plantings and Replacement Plantings

Investment cost (C_t), is a cubic function of the amount of new plantings (PL_t):

$$(9a) \quad C_t = c_1 PL_t + c_2 PL_t^3.$$

Hence, the equations for average and marginal cost of the new plantings are quadratic functions:

$$(9b) \quad AC_t = c_1 + c_2 PL_t^2; \text{ and}$$

$$(9c) \quad C'(PL_t) = MC_t = c_1 + 3c_2 PL_t^2.$$

Substituting (9c) into (3) yields an explicit equation for the optimal quantity of plantings in each period, t conditional on the present value of the anticipated stream of net revenues that will flow from new investment in that period:¹⁰

$$(10) \quad PL_t^* = \sqrt{[(\widehat{PV}_t - c_1)/3c_2]}.$$

Variable Cost

In the Napa-Sonoma and Southern San Joaquin regions—but not in the other regions—variable costs are also an increasing function of the total region-wide vineyard acreage, reflecting the effects of upwards sloping supply of specialized inputs (in particular, high-quality land), captured in land rent, R_{t+n}^i . In addition, variable costs depend on the disease prevalence in the

¹⁰ The same competitive market solutions can be derived, equivalently, by solving numerically for the profit-maximizing quantity of new plantings in each year, conditional on the stream of future prices for winegrapes, which are predetermined for each iteration of the model.

region, and resources expended on preventive measures; d_r is a dummy variable that equals one if r is one of these three regions, and zero if not.

$$(11) \quad VC_{b,t+n}^i = v_{0,b}^i + v_1^i d_r + RC_{t+n}^i + R_{t+n}^i .$$

The average per-acre cost for replacement vines is also assumed to be a quadratic function of the replacements, but with different parameters to reflect the higher costs per vine to replace a single isolated vine in comparison to planting an entire vineyard de novo:

$$(12) \quad RC_t = c_3 + c_4 RP_t^2 .$$

Demand for California Winegrapes

We classify each of the six regions as producing one of three price categories of wine grapes. The demand side of the model is represented by linear inverse demand equations expressing the prices for each of the price categories ($i = Low, Medium, \text{ or } High$) of wine grapes, as a function of the quantities of all three quality categories as follows:

$$(13) \quad \begin{aligned} P_{Low,t} &= (h_0^{Low} + m_{Low}^{Low} Q_{Low,t} + m_{Med}^{Low} Q_{Med,t} + m_{High}^{Low} Q_{High,t}) (1 + b^{Low})^t \\ P_{Low,t} &= (h_0^{Med} + m_{Low}^{Med} Q_{Low,t} + m_{Med}^{Med} Q_{Med,t} + m_{High}^{Med} Q_{High,t}) (1 + b^{Med})^t \\ P_{Low,t} &= (h_0^{High} + m_{Low}^{High} Q_{Low,t} + m_{Med}^{High} Q_{Med,t} + m_{High}^{High} Q_{High,t}) (1 + b^{High})^t \end{aligned}$$

Model Closure and Solution Procedure

The model is closed by equating annual demand with annual supply for each of the three qualities of winegrapes and solving for the implied prices. Current investment decisions depend on expectations of prices over at least the next 25 years—the life of the vineyard. The model solution procedure follows an iterative recursive process for a given policy scenario; in each iteration, we solve for the stream of investments that will maximize the present value of profits over a 50-year time horizon, given assumed values for the stream of future prices. We utilize

three-year (2009–2011) averages as a set of starting values for the stream of future prices and total acreage to derive the net present values per acre over a 75-year horizon. The set of starting values implies a stream of plantings over the 50-year planning horizon of 2011–2060, after which a steady state is imposed. Using that stream of plantings, given in Equation (10), along with the initial age-specific vineyard acreage in 2010 and Equation (4), the stream of age-specific vineyard acreage is projected over a total of 75 years. The product of projected acreage and implied yields is the stream of projected production, which is then substituted into the demand system to compute the corresponding market-clearing prices. Next, these solutions replace the initial values for prices, and the process is iterated until the equilibrium stream of prices does not change appreciably.