Who pays for Sudden Oak Death? An econometric investigation of the impact of an emerging pathogen on California nurseries*

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This paper uses new nursery-level survey data to quantify pest management costs for California firms impacted by *Phytophthora ramorum* (Sudden Oak Death). Analysis of survey data shows that nurseries have not shifted production away from hosts of *P. ramorum*, but rather are investing in preventative and responsive pest management actions (fungicide application and inventory management, respectively) to limit their exposure to the pathogen. Econometric estimation of reduced form equations derived from a model in which profit-maximizing firms make investments to reduce the probability of infestation and associated losses suggest that pest management costs stemming from SOD are not borne equally across California nurseries. Pest management costs are higher for nurseries located in a zone of infestation, which suggests that the largest industry players are not bearing proportional cost increases since they are located outside the currently quarantined area. Despite the attention given to SOD in the media, aggregate management costs have actually been low and are estimated to be less than three percent of annual production expenses. Thus, while the effects of P. ramorum on California's environment may be profound, private costs to the nursery industry so far have been limited. This finding is largely a result of policy decisions as state regulators have chosen to fund a portion of pest management expenses themselves and have designed a so far credible certification mechanism to reduce the probability of market closure.

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1 Introduction

Since 1995, an emergent fungus-like pathogen called *Phytophthora ramorum* or "Sudden Oak Death" (SOD)[1] has caused the death of tens of thousands of oak trees, and twig and foliar diseases in numerous other plant species including Douglas fir, and coast redwood, in California and Oregon (California Oak Mortality Task Force 2005). The costs of *P. ramorum* in the wild are borne by the public sector and private homeowners and have been largely limited to tree removal, waste disposal, and fire risk management (Frankel 2003).[2]

While control of SOD in forests still remains elusive, recent publicity and regulatory policy have increasingly focused not on the disease in the wild, but on the management challenge that the pathogen represents for the California nursery industry. The natural spread of *P. ramorum* most likely occurs over relatively short distances via rain splash or wind-driven rain (Davidson et al. 2002), however, humans probably have a considerable influence on the long-distance spread with the most likely source being the movement of ornamental host plants such as rhododendron, camellia, and viburnum (Meentemeyer et al. 2004). Thus, nursery shipping channels are perhaps the most likely means by which SOD could spread to areas outside of the Western United States.

Efforts to prevent the spread of SOD via the nursery channel are imposing new expenses on a high-value industry in a state where agricultural costs of production are already considered to be high. In response to the detection of *P. ramorum* at wholesale horticultural nurseries in Los Angeles and San Diego Counties in 2004, over one million nursery plants were destroyed and nursery imports from California were halted by several

[1] The terms *Phytophthora ramorum* and Sudden Oak Death are often used interchangeably in the media; however, the scientific relationship is that the *P. Ramorum* pathogen is the causal agent of the Sudden Oak Death disease.
[2] The environmental impacts of SOD are likely profound because of the critical role that oaks play in many coastal ecosystems.

states (California Oak Mortality Task Force 2005). At the time of this detection, losses due to extended import restrictions for California growers were estimated in the popular press to be as high $100 million (Raine 2004). Losses due to ongoing management and regulatory compliance efforts after import restrictions were quickly lifted, as distinct from this initial shock, have not been quantified.

In this paper, we use original survey data to identify actual steps that nurseries are taking in response to SOD and provide the first quantitative estimates of the costs that SOD-control regulation imposes on the California nursery sector. Despite the attention given to SOD in the media, aggregate management costs have actually been low and are estimated to be less than three percent of annual production expenses. Thus, while the effects of P. ramorum on California's environment may be profound, private costs to the nursery industry so far have been limited. Costs incurred in the event of infestation and market closure, like that experienced in 2004, are additional to these costs, not inclusive.

The relatively modest cost of SOD to the nursery industry in practice is likely a result of the nature of the regulatory regime chosen by the California Department of Food and Agriculture (CDFA), which has been effective in preventing import restrictions, a cause of large revenue losses, and has passed a key cost of SOD monitoring on to taxpayers, rather than imposing these costs on firms. Import restrictions have been avoided through the use of a certification process in which firms are awarded SOD compliance agreements. A compliance agreement compels firms to maintain detailed tracking records of all host stock and allow frequent onsite inspection of hosts for evidence of infestation by CDFA regulators. In return, the agreement allows the sale of host product that: (i) is produced within a zone of infestation[3] and transported/sold outside of a zone of infestation, or (ii) is produced anywhere in California and transported/sold outside of the state. The costs of inspection, including both labor and laboratory testing, are borne by the CDFA.

While, in practice, inspection costs appear to have been a large component of SOD management costs in the nursery sector, firms has incurred new costs in the effort to prevent infestation. If a single host plant is found to be infected, the nursery is restricted from selling any host product until it is determined to be free of SOD. To avoid an infestation and subsequent loss of revenues associated with impacted sales and/or damaged product, a nursery can invest in pest management actions that reduce its exposure to SOD. To this effect, the California Oak Mortality Task Force has drafted a Best Management Practices (BMPs) guide, which distinguishes between preventative and responsive BMPs. A key preventative BMP is an effective fungicide program which would reduce a nursery's probability of infection, and a central responsive BMP is intensified inventory management efforts (monitoring host plants and surrounding areas for symptoms of SOD, as well as maintaining accurate shipping documentation for the purpose of effective tracebacks and traceforwards) that help minimize realized damages should infection occur. Of course, a nursery may forgo additional pest management expenditures and shift production away from host product as another means of avoiding infestation. In analyzing new survey data, we find that nurseries have not shifted production away from host product, but rather are actively investing in fungicide treatment and inventory management to limit their exposure

[3] The zone of infestation refers to California counties that are under quarantine for SOD. As of April 2005, these counties were: Humboldt, Mendocino, Lake, Sonoma, Napa, Solano, Marin, Contra Costa, Alameda, San Francisco, San Mateo, Santa Clara, Santa Cruz, and Monterey.

to a *P. ramorum* infestation; these additional expenditures translate into modestly increased production expenses at the nursery level on average.[4]

Our econometric analysis indicates that pest management costs stemming from SOD, while relatively small compared to total production expenses, are not borne equally across California nurseries. For instance, a one standard deviation change in percentage of host product is associated with inventory management cost increases equivalent to three times the mean reported value, and a one standard deviation change in the acreage of onsite host product essentially doubles the fungicide. In addition, we find that nurseries located in a zone of infestation incur larger increases to both pest management activities as they face a higher probability of infestation. Thus, large nurseries with a high percentage of host product that are located in an infested area are the biggest losers in terms additional pest management investments.

The remainder of this paper is organized as follows: In section 2 we develop a simple model of the nursery's investment decision problem in the face of SOD that supplies a reduced form equation to be estimated econometrically and testable hypotheses. Section 3 discusses the data we use for econometric estimation. Section 4 discusses our estimation strategy and the econometric results, and provides estimates of the impact of SOD on the California nursery sector. We conclude in section 5.

2 Modeling the nursery's decision

2.1 *Theoretical model*

In this section we develop a theoretical model of nursery behavior that is consistent with the pest management literature. The model draws from both Hillebrandt's (1960)

[4] These increased production expenses imply that firms may be experiencing reduced profits or increased debt burdens as a result of SOD. Firms may also have responded to these challenges by increasing productivity (output per worker), laying off workers, or reducing wages of existing workers. Our analysis does not attempt to identify which of these has occurred.

marginal analysis model which applied the concept of marginality to pest control, and Carlson's (1969) decision theory model which utilized Bayesian decision theory. It incorporates Lichtenberg and Zilberman's (1986) contemporary damage control specification approach, however we do not make an explicit functional form assumption. Thus, the model is consistent with the empirical findings of Carrasco-Tauber and Moffitt (1992) who find that the explanation of the magnitude of pesticide productivity estimates may lie somewhere other than with functional specification. Finally, we develop our model within an endogenous risk framework similar to Archer and Shogren's (1996) model in order to reflect a nurseryman's ability to expend resources that influence a nursery's probability of a *P. ramorum* infestation.

Our endogenous risk modeling strategy captures relevant uncertainties (*i.e.* the probability of infection and the expected damage should an infection occur) associated with a potential *P. ramorum* infestation. In order to understand how nurseries chose to invest in alternative activities to maximize expected profits in the presence of uncertainty, we identify the optimal pest management choices for a representative profit-maximizing nursery that can make ex-ante investments that limit exposure to damage in the event of a probabilistic detrimental event. We consider a one period planning horizon and two separate types of pest management activities, one that is preventative in nature and the other responsive. We do not consider the shifting of production away from host product to be a relevant pest management alternative as our survey data indicates that, of the forty-five nurseries sampled, not one reported a significant reduction in host product acreage as a result of SOD (see Table 1).

In the absence of a production shift away from host product, a nursery can limit exposure by investing in preventative and responsive pest management activities.[5] The preventative activity is represented by a continuous variable *F* which measures fungicide intensity, *i.e.* the amount of fungicide applied per acre. The responsive activity is represented by a continuous variable *I* which measures inventory management intensity, *i.e.* the level of inventory management allocated per acre.

The probability of a nursery becoming infected with SOD is a function of fungicide intensity *F*, total acres of host product *q*, and the location of the nursery *L*. We represent this probability as $\theta(\cdot)$ where

$$\theta = \theta(F, q, L).\ 0 \le \theta \le 1 \qquad (1)$$

The parameters *q* and *F* are restricted to be non-negative and finite, and *L* is a continuous index that measures the presence of SOD in the surrounding environment such that as *L* increases, the environmental presence increases. For simplicity, L s bounded between zero and one. We assume that an increase in fungicide intensity lowers the probability of infection at a decreasing rate, $\theta_F < 0$ and $\theta_{FF} > 0$,[6] the marginal effect of increasing intensity is higher for nurseries in infested areas, $\theta_{FL} < 0$, and the marginal effect of increasing intensity is constant across host product acreage, $\theta_{Fq} = 0$. This latter assumption implies that the marginal benefit of per acre fungicide application is not higher (lower) for nurseries with more (less) total acreage devoted to host product.[7] Lastly, we assume that the

[5] Our survey data indicates that the primary preventative activity is fungicide-use and the primary responsive activity is inventory management (see Table 1). Recall from the previous section that "inventory management" refers to consistent monitoring of host plants and surrounding areas for symptoms of *P. ramorum*, as well as maintaining accurate shipping documentation for effective tracebacks and traceforwards.

[6] Here, and in the remainder of this paper, subscripts denote derivatives. In general, the first derivative of a function $G(\cdot)$ with respect to the variable *i* is denoted by G_i, and the second derivative with respect to the variables *i* and *j* is denoted G_{ij}.

[7] This perhaps unrealistic assumption is made to keep the model empirically tractable. It incorporates into the model the absence of pest management "halo" effects across acreage.

probability of infection increases with host product acreage and the environmental presence of SOD; that is $\theta_q > 0$ and $\theta_L > 0$.

The consequence of a SOD outbreak is measured as revenue losses stemming from impacted sales (due to regulatory restrictions/closed markets) and/or damaged product (due to the disease itself). The expected dollar value of this loss, referred to as "damage", is represented by D(·), and is a function of inventory management intensity *I*, total acres of host product *q*, and the percentage of host product sold out-of-state *T*:

$$D = D(I, q, T),\ 0 \leq D < \infty \qquad (2)$$

where *I*, *q*, and *T* are restricted to be non-negative and finite. We assume that an increase in inventory management intensity reduces expected damage at a decreasing rate, $D_I < 0$ and $D_{II} > 0$, the marginal effect of increasing intensity is higher for nurseries that sell more host product out-of-state, $D_{IT} < 0$, and the marginal effect of increasing intensity is constant across host product acreage, $D_{Iq} = 0$ (see footnote 9). We also assume that expected damage increases with host product acreage and the percentage of host product sold out-of-state, $D_q > 0$ and $D_T > 0$. This latter assumption is included to capture the reluctance of out-of-state buyers to contribute to the spread of SOD. That is, conditional on sustaining a SOD infestation, out-of-state purchasers of host product are more reluctant to resume business with the infected nursery, even after it has been determined to be SOD-free.

To model the costs associated with investments in inventory management and fungicide-use, we assume that costs specific to pest management activities are separable from other production expenses:

$$TC = C + C^F + C^I, \qquad (3)$$

where *TC* represents total production costs, *C* represents costs not associated with pest management, C^F represents fungicide costs, and C^I represents inventory management costs.

We model fungicide costs as a function of fungicide intensity F and acres of host product q. We assume that the marginal cost of these variables is strictly positive and increasing (C^F_F, C^F_q, C^F_{FF}, and $C^F_{qq} > 0$), and that the marginal cost of increasing intensity is constant across acreage of host product, $C^F_{Fq} = 0$. Similarly, we model inventory management costs as a function of inventory management intensity I and acres of host product q. We assume that the marginal cost of these variables is strictly positive and increasing (C^I_I, C^I_q, C^I_{II}, and $C^I_{qq} > 0$), and that the marginal cost of increasing intensity is constant across acreage of host product, $C^I_{Iq} = 0$.

Having defined the probability of infection, expected damage, and relevant pest management costs, we incorporate these functions into a representative nursery behavioral model to identify implied pest management costs under different probabilistic scenarios. In the event that $\theta = 0$, the scenario prior to 2002 when SOD was found in nursery plants, the representative nursery's profits are:

$$\Pi^{\theta = 0} = R(q, \cdot) - C(q, \cdot) - C^F(F, \cdot) - C^I(I, \cdot) \quad (4)$$

where R is the revenue generated from the production of all nursery product. Note that q does not enter into either of the pest management cost functions since the number of acres devoted to host product is not an appropriate decision variable in the absence of SOD. The nursery maximizes equation (4) over the relevant decision variables, the solution to which we denote by q^o, F^o, and I^o. Thus, total profits when $\theta = 0$ are:

$$\Pi^{\theta = 0} = R(q^o, \cdot) - C(q^o, \cdot) - C^F(F^o, \cdot) - C^I(I^o, \cdot). \quad (5)$$

In the event that $\theta > 0$, the scenario following 2002, the nursery revisits its pest management allocations and decides whether or not to increase pest management intensities. We represent these increases as ΔF and ΔI, and assume that investment decisions are made prior to the realization of infestation status. Given that probability of infection and expected damage are represented by θ and D respectively, expected profits are:

$E(\Pi^{\theta > 0}) =$

$R(q, \cdot) - \theta(F^o + \Delta F, q, L) * D(I^o + \Delta I, q, T) - C(q, \cdot) - C^F(F^o + \Delta F, q) - C^I(I^o + \Delta I, q)$. (6)

Note that *q* now enters the pest management cost functions since host product acreage is an appropriate pest management decision variable when $\theta > 0$.

Based on the results of our survey data, discussed in Section 3.2, we assume that host product acreage does not change in response to SOD. The implications for equation (6) are that *R*, *C*, and *q*, (revenues, costs not associated with pest management, and host product acreage), take on the same values as in equation (5). Thus, expected profits are now:

$$E(\Pi) = R(q^o, \cdot) - C(q^o, \cdot) - \theta(F^o + \Delta F, q^o, L) * D(I^o + \Delta I, q^o, T) - C^F(F^o + \Delta F, q^o) - C^I(I^o + \Delta I, q^o), \quad (7)$$

and the objective of the nursery is to maximize E(Π) over ΔF and ΔI given the exogenous variables q^o, F^o, I^o, L, and T. This maximization problem leads to the following necessary conditions:

FOC wrt ΔF: $-\theta_{Fo + \Delta F} * D = C^F_{Fo + \Delta F}$; (8)

FOC wrt ΔI: $-\theta * D_{Io + \Delta I} = C^I_{Io + \Delta I}$. (9)

Both first order conditions imply that additional pest management investments are made until the marginal benefit of increasing the intensity of application exactly equals marginal cost. The optimal changes in fungicide and inventory management intensity, ΔF^* and ΔI^*, are defined implicitly by equations (8) and (9). To derive our theoretical hypotheses, we assume that ΔF^* and ΔI^* are determined independently of one another[8], which implies that $\Delta I = 0$ in (8) and $\Delta F = 0$ in (9).

2.2 *Testable hypotheses*

To investigate the potential impact of economies of scale on optimal fungicide and inventory management intensities, we define $q^o \equiv s * m$, where s is nursery product acreage and m is percent of total acreage devoted to host product. Thus, nursery-level percent increases in fungicide and inventory management costs are represented by:

$$\%\Delta C^F = C^F(F^o + \Delta F^*, s * m) / C^F(F^o) \quad \text{and} \quad \%\Delta C^I = C^I(I^o + \Delta I^*, s * m) / C^I(I^o). \tag{10}$$

We assume that initial pest management intensities, F^o and I^o, do not significantly affect percent increases in inventory management and fungicide costs. This is a valid theoretical assumption as pre-SOD pest management strategies do not specifically target host product; that is, a nursery's pest management program prior to SOD does not account for profit stream uncertainties related to a potential *P. ramorum* infestation. Formally, this assumption is represented by $F^o = I^o = 0$ and $C^F(F^o) = C^I(I^o) = 1$ in equations (10)[9]. Thus, nursery-level percent increases in fungicide and inventory management costs are now

$$\%\Delta C^F = C^F(\Delta F^*, s * m) \quad \text{and} \quad \%\Delta C^I = C^I(\Delta I^*, s * m), \tag{11}$$

which imply that pest management cost increases are identified through optimal changes in intensity and the interaction of nursery product acreage with percent of acreage devoted to host product.

By differentiating equations (11) with respect to *s*, *m*, *L*, and *T* using the implicit function theorem, we find that all partial effects are positive under our preferred theoretical assumptions; that is, percent increases in fungicide and inventory management costs

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[8] This assumption drives the comparative statics analysis, as allowing the optimal intensities to be solved jointly leads to ambiguous results We test the validity of this theoretical assumption using regression analysis and report the results in section 4.3; our empirical analysis suggests that this is a valid theoretical assumption .

[9] We test the validity of this theoretical assumption using regression analysis and report the results in section 4.3; our empirical analysis suggests that this is a valid theoretical assumption.

increase with nursery product acreage, percent of acreage devoted to host product, environmental presence of SOD, and percent host product sold out-of-state. Nurseries with a large inventory of nursery product and nurseries with a high concentration of host product have a relatively large amount of acreage devoted to host product, *ceteris paribus*; thus, both the probability of infection and expected damage will be relatively high, implying an incentive to invest more intensively in pest management activities. Similarly, nurseries located in an area with a relatively high concentration of SOD in the surrounding environment face a relatively high probability of infection; thus, they too have an incentive to invest more intensively in pest management activities. Lastly, nurseries that sell a relatively large percentage of host product out-of-state face relatively high expected damages should infection occur. The additional damage is a result of the out-of-state buyers' reluctance to import a potentially disastrous epidemic; thus, these nurseries also have an incentive to invest more intensively in pest management activities.

2.3 *Reduced-form equations*

To empirically test our theoretical behavioral model's predictive capability, we econometrically estimate the following reduced-form equations:

$$\%\Delta C^F = \beta_o + \beta_1 \textit{total acreage} + \beta_2 \textit{percent host} + \beta_3 \textit{total acreage} * \textit{percent host} + \beta_4 \textit{zoneI} + \beta_5 \textit{percent out-of-state} + W_F{}'\beta_{WF} + \varepsilon, \text{ and} \quad (12)$$

$$\%\Delta C^I = \delta_o + \delta_1 \textit{total acreage} + \delta_2 \textit{percent host} + \delta_3 \textit{total acreage} * \textit{percent host} + \delta_4 \textit{zoneI} + \delta_5 \textit{percent out-of-state} + W_I{}'\beta_{WI} + \mu \quad (13)$$

where $\%\Delta C^F$ and $\%\Delta C^I$ represent percent increases in fungicide and inventory management costs, respectively, and W_F and W_I are vectors of control variables. The *percent host* variable measures the percent of total acreage devoted to host product and *total acreage* measures nursery product acreage. The interaction variable *total acreage * percent host*, which when factored by 100 measures host product acreage, is included in the reduced-form equations as the relevant revenue uncertainties are functions of host product acreage. The *zoneI* variable is equal to one if the nursery is located within a zone of infestation and zero otherwise. This variable captures the environmental presence of SOD as nurseries that are located in quarantined areas are more likely to become infected. The *percent out-of-state* variable measures the percent of nursery product that is (i) host product and (ii) sold out-of-state[10].

3 Data

In this section we describe our data, and discuss potential data problems for econometric estimation. Specifically, we discuss potential biases stemming from non-random sampling and our inability to exactly identify the number of California nurseries producing host product and our strategy for addressing these issues.

3.1 *Sample of firms surveyed*

To collect nursery-level data for our investigation, we developed a survey instrument using insights gained from several meetings with nursery industry professionals[11]. The survey data covers topical nursery characteristics (e.g. "how many acres are devoted to growing nursery products/host products?") and cost structure (e.g. "has there been an increase in the cost of your fungicide program due specifically to SOD?), but not actual costs or profit levels, due to concerns about non-response.[12]

A complete list of California producers of host product is not available, so we identified potential survey participants as licensed nursery wholesalers that produce

[10] Specifically, if *A* represents nursery product acreage, *B* represents host product acreage, and *C* represents nursery product sold out-of-state, then this variable measures $[(B \cap C) / A] * 100$.

[11] These professionals included scientists from the CDFA, nursery sector lobbyists, University of California Cooperative Extension Specialists, and California nurserymen from many different types (*i.e.* size, location, product mix) of nurseries.

[12] The survey instrument is available from the authors upon request.

coniferous evergreens, broad-leaved evergreens, deciduous shade trees, deciduous shrubs, or rose plants[13]. We further restricted this sample to nurseries that are strictly wholesalers and operate on at least five acres of land. The CDFA's Plant Health and Pest Prevention Services online directory of California licensed nurserymen provided detailed location information for 255 nurseries that fit our search criteria, but not telephone numbers.[14]

To contact nurseries, we compiled an initial list of telephone numbers using the Google search engine, which produced phone numbers for 142 nurseries. An additional 44 telephone numbers were obtained through various other channels including conversations with nurserymen and nursery sector lobbyists. In total, we gathered numbers for 186 (of the 255) potential survey participants, and then began contacting them to determine if they produce host product. Ultimately, we spoke with managers at 112 firms, of which 68 produced host product at some time since 2002, the year SOD regulation began. Among these host producers, 45 managers participated in our survey and 30 managers completed a more detailed survey that we used to identify the feasible set of pest management activities relating to SOD. These included fungicide, inventory management, irrigation/water treatment, treatment of cut greens, soil management, green waste disposal, purchasing insurance, and shifting production away from host product[15].

3.2 *Data Summary*

Table 1, based on responses received to the extended survey administered to 30 firms, indicates that the most popular pest management activities being taken in response to SOD in California nurseries are inventory management and fungicide use. Few nurseries

[13] All host plants fall into one of these categories.
[14] This online search was conducted in July, 2004.
[15] This detailed list of possible pest management actions was constructed on the basis of extended interviews with several nurserymen. These interviews took place at the nursery and usually lasted between one and three hours. In one instance, the interview included a guided tour of the production process, during which we discussed possible pest management responses at each stage of production.

are actively investing in improved irrigation/water treatment, treatment of cut greens, soil management, or green waste disposal, all of which are SOD best management practices. Firms do not report expanding their insurance coverage either. A few firms do report high green waste disposal costs, but these are likely a consequence of infestation and associated stock destruction, rather than preventative investments.

Consistent with the model developed in section 2, nurseries in our sample have not significantly shifted production away from host plants, which implies that these nurseries view the investment in pest management actions as the primary means of managing SOD exposure. This finding is not an artifact of our sampling methodology; in fact, we over-sampled large nurseries and nurseries that have entered into a SOD compliance agreement (see discussion following Table 3 below), which are exactly the types of nurseries that are most likely aware of the impact of continued host production on expected profits. The implications of this over-sampling for our econometric analysis are discussed below.

The data we use to estimate which firms are making the greatest additional investments in inventory management and fungicide and the total cost of SOD prevention to California nurseries can be subdivided into two categories: sample data that describe nurseries that participated in the survey and population data that describe all nurseries that were potential participants in the survey. Summary statistics for data from the 45 survey participants is summarized in Table 2. On average, firms report small increases, in percentage terms, in ongoing inventory management costs and fungicide costs as a result of SOD. While the data reported in Table 1 shows that almost 40 percent of firms report no changes in inventory management costs and 60 percent of firms report no changes in fungicide use, the standard deviation for both variables is about double the mean value, so investment levels are relatively high for some nurseries.

Firms in our sample sold very little host product out of state in 2003, on average, despite their relatively large size. As discussed below, this is not an artifact of our sampling methodology; that is, it is unlikely that we have undersampled nurseries that sell host product out of state, relative to the state average. Also, the low sales rate is not a result of the quarantines and market closures that began in 2004 as this data reflects 2003 sales patterns. We also expect that these sales patterns are exogenous to 2005 pest management activities and exploit this exogeneity in our regression analysis.

The mean value of the *zone-of-infestation*, *signed a SOD compliance agreement*, and *Google search engine* variables reports the percentage of nurseries in our sample that take on a value of one. Thus, 22 percent of the sample nurseries are located in a zone-of-infestation, 58 percent have signed a SOD compliance agreement, and 76 percent have a phone number that is reported by the Google search engine. The county wage variable was constructed using data from the 2002 Census of Agriculture. As a $/hr measure is not available at the county level, we report the ratio of hired farm labor ($ payroll) to hired farm labor (workers). Both the onsite workers and percent year round variables were collected via our survey instrument and only 28 of the 45 sampled nurseries provided responses. The intensity of pre-SOD fungal application variable was constructed using the online California Pesticide Information Portal, which can be found on the California Department of Pesticide Regulation web page. Nursery-level pesticide permit numbers were obtained through the county Agricultural Commissioners Office, and the search for fungal chemicals was restricted to those chemicals that are relevant to *P. ramorum* (special thanks to Steve Tjosvold).

The distribution of the variables in our sample can be compared to the distribution of these variables in a larger sample of nurseries in California in order to allow us to identify selection biases in our data. Available data for all 211 host-product producing nurseries in California is summarized in Table 3. Comparing the population mean values with the sample mean values reported in Table 2, we see that there is a marked difference between the population and the sample. In the population, the average nursery has 63 acres of nursery product, 35 acres less than the sample average of 98 acres. Only 13 percent of nurseries in the population are located in a zone of infestation, nine percent less than the sample average of 22 percent. This trend continues for the percent of nurseries that have signed a SOD compliance agreement (28 percent population versus 58 percent sample), as well as the percent of nurseries that have a phone number reported by the Google search engine (46 percent population versus 76 percent sample).

The data suggests that we have over-sampled large nurseries, nurseries that are located in a zone of infestation, nurseries that have signed a compliance agreement, and nurseries whose telephone number is reported by the Google search engine. In addition, we have probably not undersampled nurseries that sell product out of state as the within sample pairwise correlations with total acreage and compliance are both positive; thus suggesting that oversampling large nurseries and nurseries that have signed a compliance agreement is akin to not undersampling nurseries that sell host product out of state. It is not surprising that we over-sampled nurseries with a telephone number reported by Google since this was the primary means by which we constructed our contact list. Over-sampling for the other variables is likely due to self-selection of nurseries into our sample. For instance, large nurseries, nurseries that are located in a zone of infestation, and nurseries that have signed a compliance agreement are likely more aware of the potentially costly effects of SOD infestation and thus more likely to report the impact that it has had on their business.

Therefore, our econometric estimation strategy must take into account the potential self-selection bias of our sample data.

Sample selection bias can be treated econometrically using Heckman's (1979) two step procedure. The decision to participate in the survey and changes in pest management costs are modeled separately, and participation-decision parameters are used to estimate the probability of participation, which is included as an additional regressor for changes in pest management costs. This procedure, which we discuss in greater detail in section 4, produces consistent estimates for the parameters of interest in the presence of selection bias.

Another data concern for our analysis is the estimation of the number of nurseries that sell host product. This is important for accurate estimation of total cost of SOD prevention to the California nursery sector. We survey only wholesalers, but nurseries that do both wholesale and retail business are likely incurring costs similar to those reported by our sample of firms. The CDFA's database of licensed nurserymen indicates that there are 177 nurseries that operate on at least five acres of land, have both wholesale and retail functions, and produce coniferous evergreens, broad-leaved evergreens, deciduous shrubs, deciduous shade trees, or rose plants. Adding these nurseries to the list of strictly wholesale nurseries yields a potential population of 432 nurseries. We know whether 112 of these nurseries produce host product, 61 percent of them (68 firms) do, but do not know whether the remaining 320 grow SOD hosts or not. Thus, when we calculate estimated total costs of SOD control, we present three scenarios: The low estimate assumes that none of the 320 grow hosts, in which case the population of nurseries is 68, the medium estimate assumes that 61 percent of them do, in which case the population is 263 (68 + 0.61*320), and the high estimate assumes that all of them do, in which case the population is 388 (= 68 + 320). Our preferred estimates will be those in which the population is assumed to be 263.

4 Regression analysis

In this section we present our estimation strategy and report our econometric results. Our goal is to identify which nursery firms are incurring SOD control costs and to estimate the total cost of SOD prevention to the California nursery sector.

4.1 *Estimation strategy*

To control for selection bias in the parameter estimates, we use Heckman's two-step procedure. The econometric estimation of an equation using non-random samples subject to selection bias can be characterized as a special case of estimation in the presence of omitted variable bias (Heckman 1979, 1980). Heckman two-step estimation produces consistent parameter estimates provided that certain identifying assumptions are met. In particular, to consistently identify our parameters of interest, the estimated inverse Mills' ratio should not be a linear combination of the right hand side variables that are specified in equations (12) and (13). Since the parameter estimates of the participation decision are used to estimate the inverse Mills' ratio, we can insure a nonlinear relationship between the estimated inverse Mills' ratio and the right hand side variables by including at least one variable in the participation-decision specification that does not appear in the specification of changes in pest management costs. We include two such variables, *compliance* and *google*, in the participation-decision specification, which is given below by equation (14). The decision to participate in the survey is denoted by the latent variable p^*_i, which follows:

$$p^*_i = \alpha_o + \alpha_1 \textit{total acreage}_i + \alpha_2 \textit{zoneI}_i + \alpha_3 \textit{compliance}_i + \alpha_4 \textit{google}_i + e_i,$$

$$e_i \sim N(0, 1). \qquad (14)$$

Recall from section 3.2 that *compliance* takes on a value of one if the nursery has signed a SOD compliance agreement and *google* takes on a value of one if the nursery's phone number is provided by the Google search engine. Both variables are good candidates for inclusion as they are available for all California nurseries, and they are directly correlated with a nursery's decision to participate in our survey but are not directly correlated with the decision to invest in pest management actions. While *compliance* might be indirectly correlated with the decision to invest in pest management actions, its effect is through the *zoneI* and *percent out-of-state* variables, which represent the types of nurseries that are required by law to sign a compliance agreement.[16] The *compliance* variable is directly correlated with participation as nurseries that enter into this agreement are aware of potential impacts of SOD, and are thus considered more likely to participate in the survey. The *google* variable is uncorrelated with a nursery's decision to invest in pest management actions since it does not influence a nursery's marginal benefit or marginal cost of such an investment. Instead, it is correlated with a nursery's decision to participate since the Google search engine was the primary source for collecting contact information.

4.2 *Participation results*

The participation regression results are reported in Table 4. Nursery product acreage, in the absence of other variables, does not significantly explain nursery participation; however, nurseries located in a zone-of-infestation are more likely to participate in the survey. Controlling for nurseries that signed a SOD compliance agreement, neither total acreage nor location significantly explain participation; however, we find that nurseries that signed a compliance agreement are more likely to participate.

[16] Of the 45 nurseries sampled, only one had entered into a SOD compliance agreement that was not required to by law. However, this nursery was located in a zone-of-infestation; thus, it is likely that the decision to enter into the agreement was based on the environmental presence of SOD.

This result is robust to inclusion of a control variable for nurseries whose phone number is reported by the Google search engine. This result is not surprising as nurseries that subject themselves to frequent onsite testing are more aware of the repercussions of SOD; thus, they are more likely to participate in the survey.

The estimated partial effects reported in regression 4b suggest that nurseries that have entered into a compliance agreement are 32.8 percent more likely to participate in our survey, and that nurseries whose phone number is reported by the Google search engine are 19.8 percent more likely. For the full specification of the participation equation, regression 4a, 79 percent of the predictions are correct and the likelihood ratio statistic is 37.6, which implies that the hypothesis that all parameter estimates are zero is rejected at a 99 percent level of confidence.

4.3 *Pest management results*

The estimation results for percent increases in ongoing inventory management and fungicide costs are reported in Table 5. Regression 1 represents the main empirical findings of this paper with respect to pest management costs while regressions 2, 3, 4, and 5 serve as robustness checks. In the following paragraphs we first present the results under our preferred reduced-form specification (regression 1) and then discuss the robustness of these results in the presence of relevant control variables (regressions 2 and 3) and under alternative estimators (regressions 4 and 5).

For inventory management costs, total acreage of nursery product, percent of acres devoted to host product, the interaction between them, and whether the nursery is located in a zone of infestation all have statistically significant partial correlations. The statistically significant point estimates are all positive, which is consistent with the testable hypotheses derived from our behavioral model. The estimated marginal effect of increasing the percent of acres devoted to host product by one percent is: $\partial \% \Delta C^{I} / \partial \textit{percent host}$ = -0.086 + 0.485/100 * *total acres*. For the average nursery with 97.64 total acres of nursery product the estimated marginal effect is 0.386 (se 0.0514), which implies that a one unit increase in the percentage of host product is correlated with an additional 0.4 percent increase in inventory management costs for the average nursery, holding all other variables constant. Under a one standard deviation (29 percent) change in percentage of host product, the additional increase in inventory management costs jumps to 10.8 percent, which is triple the mean reported value. Thus, our analysis suggests that nurseries with a high percentage of host product incur relatively large inventory management cost increases. .

The estimated marginal effect of increasing total acreage by one acre on inventory management costs is: $\partial \% \Delta C^{I} / \partial \textit{total acres}$ = -0.039 + 0.485/100 * *percent host*. For the average nursery with 19.04 percent of total acreage devoted to host product the estimated marginal effect is 0.053 (se 0.0085), which implies that a one unit increase in total acreage is correlated with an additional 0.05 percent increase in inventory management costs for the average nursery, holding all other variables constant. Under a one standard deviation (119 acres) change in total acreage, the additional increase in inventory management costs jumps to 6.0 percent, which is equivalent to essentially doubling the mean reported value. Although the effect isn't as dramatic as the impact for changes in host percentage, our analysis suggests that larger nurseries incur relatively higher inventory management cost increases.

Our finding that the effect of a one standard deviation change in the percentage of host product dominates the effect for a one standard deviation change in total acreage is consistent with risk management in general. The former effect is analyzed while holding total acreage constant (which implies that the revenue *share* of host product production is changing), and the latter effect is analyzed while holding host percentage constant (which implies that the revenue *level* of product production is changing); thus, our analysis is consistent with risk management theory in the sense that averting behavior [17] is motivated more by the percentage of welfare at stake rather than just the level of welfare at stake.

Regression 1 also indicates that nurseries located in a zone of infestation incur larger increases to their cost of inventory management; these nurseries face a higher probability of infestation leading them to invest more. The average increase in inventory management costs is 5.96 percent higher for nurseries that are located in a zone-of-infestation; this estimate is significant at a 99 percent level of confidence. In contrast, out-of-state sales of nursery products are not associated with increases to inventory management costs, suggesting that the expected damage sustained from a SOD infestation is not significantly correlated with the percent of host product sold out-of-state, for the average nursery. This finding is not consistent with the theoretical prediction of our behavioral model, however, it is important to note that 22 of the nurseries in our sample do not sell any host product out of state and only 5 (out of 45) reported a measure greater than 2.5 percent. Thus, for the average nursery in our sample, out of state sales is not a significant enough portion of overall revenue to justify additional pest management investments[18].

For fungicide costs, only the interaction between the percent of acres devoted to host product and total acreage of nursery product is statistically significant. This interaction

[17] In this case, averting behavior is captured by investments in pest management activities.
[18] Recall from section 3.2 that the within sample pairwise correlations between out of state sales and size and compliance suggests that we have not undersampled out of state sellers of host product; thus, this empirical finding is not likely an artifact of our sampling methodology.

variable, when factored by 100[19] measures the level of onsite host product and the positive point estimate indicates that nurseries that have more host product incur greater increases in fungicide costs. For our sample of nurseries, the average level of host product is 15.22 acres, which implies that increasing the level of host product by one acre increases fungicide costs by an additional 4.8 percent (se 2.2511) for the average nursery, assuming all other variables take sample average values. For nurseries that have onsite host product equivalent to one standard deviation (27 acres) above the mean, additional fungicide costs essentially double to 8.7 percent (se 4.0791). Both estimates are statistically significant at a 95 percent level of confidence and the implication is that the tradeoff for expanding production of host product from the sample average of 16 acres to 45 acres is a doubling of the additional investment in fungicide.

Regression 1 also (weakly) indicates that nurseries located in a zone of infestation incur larger increases to their cost of fungicide, which is consistent with the theoretical prediction of the behavioral model. The average increase in fungicide costs is 6.08 percent higher for nurseries that are located in a zone-of-infestation, however this estimate is only statistically significant at an 80 percent level of confidence. In contrast, out-of-state sales of nursery products are not associated with increases to fungicide costs, suggesting that the probability of a SOD infestation is not significantly correlated with the percent of host product sold out-of-state (see footnote 22).

To investigate the robustness of the reduced-form specification under regression 1, we report estimation results in the presence of control variables specific to investments in inventory management and fungicide. As an additional robustness check, we estimate the

[19] This essentially converts *percent acres SOD product* to *fraction of acres SOD product*; thus, when multiplied by *total acres nursery product*, the result is interpreted as the total number of acres devoted to host product.

reduced-form specification, including control variables, using two different estimators, seemingly unrelated regression (SUR) and ordinary least squares (OLS).

The specification for inventory management in regression 2 includes a county-level control variable that measures annual wage paid to agricultural laborers. We include this variable because of the labor intensiveness of inventory management[20]; however it is not included in the specification for fungicide because of the capital intensiveness of additional fungicide application. Comparing the results under regressions 1 and 2, we see that the point estimates of our reduced-form specification are robust to the inclusion of the county-level wage variable. Additionally, the control variable is (weakly) significant at an 89 percent level of confidence and the positive point estimate suggests that a $100 increase in annual agricultural wage is correlated with an additional 0.05 percent inventory management cost increase for the average nursery, holding all other variables constant. Under a one standard deviation ($2,081) change in annual wage, the additional increase in inventory management costs increases to 1.0 percent, which is only about one third of the mean reported value. This suggests that there is a relatively small, positive wage effect on inventory management investments, which is unsurprising given that inventory management is a labor intensive pest management activity.

The specifications for inventory management and fungicide costs in regression 3 include nursery-level control variables that measure pre-SOD levels of labor and fungicide investment. We include these variables in order to control for nurseries that were actively investing in relevant pest management activities prior to our survey. Since inventory management is labor intensive, we include control variables that measure the annual

[20] Since inventory management captures monitoring and documentation activities performed by onsite workers, the decision to increase intensity will depend on the costs associated with higher labor costs. Increased labor costs will in turn depend on the agricultural wage, so this wage variable is likely to influence decisions regarding the intensity of inventory management.

number of onsite laborers employed by the nursery and the percent of these laborers that are employed year round. Neither variable enters significantly, which suggests that pre-SOD labor levels are not correlated with inventory management investments, and our reduced-form point estimates from regression 1 are fairly robust to this alternative specification.

The fungicide estimation results under regression 3 are similar to those mentioned above. Since additional investments in fungicide are largely capital intensive, we include a nursery-level control variable that measures pre-SOD average intensity of fungicide application. This variable is defined as total pounds of fungal chemical applied divided by total acres treated, and does not enter the reduced-form specification significantly. This result suggests that pre-SOD intensity levels are not correlated with fungicide investments, and we also note that our reduced-form point estimates from regression 1 are fairly robust to this alternative specification.

The insignificance of the nursery-level control variables in regression 3 supports the theoretical assumption that pre-SOD pest management intensities do not affect investments specific to Sudden Oak Death. Recall that this assumption was incorporated into the behavioral model in section 2.2. This empirical finding is consistent with our theoretical assumption as pre-SOD pest management strategies do not specifically target host product; that is, a nursery's pest management program prior to SOD does not take into account the relevant profit stream uncertainties particular to a potential *P. ramorum* infestation. Thus, the finding that initial pest management intensities are not significantly correlated with percent increases in inventory management and fungicide costs is intuitively consistent.

The specifications for inventory management and fungicide costs in regression 4 include relevant control variables[21] and the parameters are estimated using the SUR estimator. This estimation procedure allows for non-zero correlation between the unobservable determinants of inventory management and fungicide costs, which are represented in the last row of Table 5 by μ and ε respectively. We find that the estimated correlation between the unobservable determinants is 0.149, and that the corresponding Breusch-Pagan test of independence[22] supports the hypothesis that this estimate is not statistically significantly different from zero. Thus, the theoretical assumption that optimal pest management intensity changes are made independent of one another does not conflict with our empirical findings, if we believe that zero-correlation between unobservable determinants is consistent with independent decision-making behavior. Additionally, regression 4 also indicates that our reduced-form point estimates from regression 1 are fairly robust to this alternative estimator.

The final robustness check that we include is reported under regression 5. The specifications for inventory management and fungicide costs include the same control variables from regression 4 and the parameters are estimated using the OLS estimator. The purpose of this exercise is to investigate the necessity of controlling for the self-selection biases that were discussed in section 4.1. We find that, in absence of the estimated inverse Mills' ratio, the point estimates reported under regression 5 are fairly consistent with the reduced-form estimates under regression 1; however, there does appear to be some slight differences in magnitude, thus indicating self-selection biases (albeit small) introduced by

[21] The nursery-level control variables for inventory management, number of annual workers and percent employed year round, are omitted as only 28 of the 45 sample nurseries provided this information. As reported in regression 3, both of these variables enter insignificantly and are thus unlikely to impact the results reported in regression 4.

[22] The Breusch-Pagan null hypothesis is a diagonal disturbance matrix. Under the specification posited in regression 4, the chi-squared test statistic with one degree of freedom is 1.004, which implies failure to reject the null at any appreciable level of confidence.

our non-random sampling methodology. This evidence is further supported by the statistically significant correlation between the estimated inverse Mills' ratio and ongoing cost of inventory management increases across regressions 1 through 4.

4.4 *Impact of SOD on California nurseries*

Given that SOD has not affected the quantity of host plants being put on the market and the price received from sales, total additional inventory management and fungicide costs represent the welfare effects of SOD on the California nursery sector in the absence of infestation and associated product destruction and market closure. To estimate these additional costs, we use data from the 2002 Census of Agriculture and assume that (i) changes in the cost of inventory management coincide with changes in the cost of hired farm labor, and (ii) changes in the cost of a nursery's fungicide program coincide with changes in the cost of chemicals other than fertilizer, lime, and soil conditioner. We also assume that the cost of hired labor and the cost of chemicals reported in the 2002 Census of Agriculture represent the initial, pre-SOD, cost levels. We multiply the robust percent increase point estimates from regression 1 by the initial cost data, which results in the average change in the level of both inventory management and fungicide costs. These estimates are then summed to get the average level of impact per nursery (measured in current dollars). Lastly, the average level of impact is multiplied by the number of nurseries that produce host plants, which yields the welfare effects of SOD on the California nursery sector. As discussed previously, because of uncertainty about the total number of host producers, we present three scenarios for the total cost estimates that correspond to our low, medium, and high estimates for the number of host growers Recall that our preferred measure is the medium estimate because it is constructed using our survey data which indicates that 61 percent of the population nurseries produce host product.

4.5 *Estimated annual level of costs incurred as a result of SOD*

The estimated annual pest management cost increases expected by the average nursery as a result of SOD are reported in Table 6. Under the current regulatory environment, the average nursery spends an additional $12,000 annually on hired farm labor and $1,500 annually on chemicals; thus, total impact for the average nursery is about $13,500 per year. In the event that all California counties are designated zones-of-infestation, (we refer to this as the full-quarantine scenario), the average nursery would spends an additional $27,000 on hired farm labor and $2,500 on chemicals. Thus, total impact under the full-quarantine scenario is $29,500 per year, which is more than double the impact under the current regulatory environment. The reason for the large increase in average costs is that nurseries in the current zones of infestation are, on average, smaller and have a lower percentage of onsite host product; thus, by moving to the full-quarantine scenario, the average nursery located in an infested area is both larger and produces a higher percentage of host product, both of which have a positive effect on average cost increases.

The additional labor expenditures represent almost 90 percent of the total change in pest management expenditures. This finding, not apparent from the survey summary statistics, is consistent with information we received in our extended interviews with nurserymen. During these interviews, we determined that the major production expense associated with the production of nursery products is labor, and that any significant impact due to SOD would likely be driven by a change in the relative labor intensity of producing host product.

Total impact for the average nursery under the current regulatory framework or in a situation of “full quarantine” is quite small when compared to annual levels of production expenses. In 2002, the average nursery spent $528,000 in total production expenses (2002

California Census of Agriculture), which implies that the total impact under scenarios 1 and 2 is only a 2.6 percent and a 5.6 percent increase in production expenses. This finding is consistent with rational nursery behavior since, in the absence of pest management activities that specifically target host stock, the change in expected profits depends largely on the probability of infection and the damage should an infection occur. Since nurseries are not shifting production away from host product, the change in relative profitability of host production is small, which implies that the probability of an infection and/or expected damage should an infection occur are/is small. However, it is important to point out that the cost changes reported in Table 6 are ongoing at the nursery level, meaning that the new level of cost for each nursery will be sustained indefinitely. Moreover, additional costs would be incurred in the event of an infestation as a result of product destruction and market closure.

The estimated annual pest management cost increases expected by the California nursery community are given in Table 7. These estimates are calculated by multiplying estimated increases for the average nursery by the number of nurseries affected by the presence of SOD. This estimation strategy is sensitive to the number of nurseries that produce host product, so we provide a low, medium, and high estimate of the total impact of SOD on the nursery community. Under the current regulation, the low estimate of total annual costs aggregated across nurseries is just under $1 million, the medium estimate is $3.6 million, and the high estimate is $5.2 million. Under a full quarantine scenario, these estimates essentially double to $2.0 million, $7.8 million, and $11.5 million respectively.

The estimated annual impact of SOD on the California nursery sector is relatively small when compared to annual sales of nursery products. In 2003, the total value of sales[23]

[23] For nurseries with $100,000+ in total sales.

by California nurseries of coniferous evergreens, broad-leaved evergreens, deciduous shade trees, deciduous shrubs, and rose plants was $559 million. If all nursery crops[24] are included, total sales were just over $1 billion (U.S. Department of Agriculture, 2004). Thus, under the current regulatory environment, the high estimate of the annual impact of SOD is less than 1 percent of total sales of coniferous evergreens, broad-leaved evergreens, deciduous shade trees, deciduous shrubs, and rose plants, and about 0.5 percent of total sales of all nursery crops. Under the full-quarantine scenario, the high estimate is two percent and one percent, respectively.

4.6 *Total impact of SOD since regulation began*

The results for the estimated pest management costs incurred by the California nursery community for the years 2002 though 2004 are reported in Table 8. For each year, we first calculate the impact of SOD for the average California nursery under the current regulatory environment, and then multiply this estimate according to each of the population estimates. Total costs are aggregated across years assuming a 5 percent discount rate and reported in 2004 dollars.[25] Under the current regulation scenario, the low estimate of total costs since regulation began is $2.6 million, the medium estimate is $10.1 million, and the high estimate is $14.9 million. For the total infestation scenario, these estimates approximately double to $5.7 million, $22.1 million, and $32.6 million respectively.

By not extending the boundaries of the quarantined areas to include all California counties, the regulatory agencies saved the nursery community at least $3.1 million from 2002 though 2004. This result is the difference between scenarios 1 and 2 under the low

[24] Here, 'all nursery crops' refers to broadleaf and coniferous evergreens, deciduous shade and flowering trees, deciduous shrubs, fruit and nut plants, palms, ornamental grasses, woody ornamentals and vines, Christmas trees, transplants for vegetable and strawberry production, and propagation material.

[25] These results do not take into account inflation between the years 2002 and 2005. Given that the estimates are reported in millions of dollars and that the time period in consideration is only three years, our reported results should be very close to any inflation adjusted measure.

nursery population estimate in Table 8. Under the medium estimate this value is $12.0 million, and under the high estimate it is $17.7 million. If we assume that the 2003 value of sales for all nursery crops is an accurate three year average for the years 2002 through 2004, then California sales of all nursery crops for this time frame is about $3 billion. Using this valuation of total sales, the nursery sector saved at most 0.6 percent of total nursery crop sales by not having the boundaries of the quarantined areas extend to include all California counties.

5 Conclusion

Nurseries are actively investing in inventory management and fungicide in order to limit their exposure to SOD. Our analysis shows that few nurseries are actively investing in other pest management actions such as irrigation/water treatment, treatment of cut greens, soil management, green waste disposal, or insurance. We find that nurseries in our sample have not significantly shifted production away from host plants, which implies that these nurseries view the investment in pest management actions as the primary means of combating a *P. ramorum* infestation at this time.

We use original survey data to identify actual steps that nurseries are taking in response to SOD and provide the first quantitative estimates of the costs that SOD-control regulation imposes on the California nursery sector. Our analysis suggests that additional pest management costs are not borne equally across California nurseries; rather, SOD specific costs are higher for nurseries located in a zone of infestation. This suggests that the largest industry players are not bearing proportional cost increases since they are located outside the currently quarantined area. Despite the attention given to SOD in the media, aggregate management costs have actually been low and are estimated to be less than three percent of annual production expenses.

In conclusion, while the effects of *P. ramorum* on California's environment may be profound, private costs to the nursery industry have so far been limited. This finding is largely a result of policy decisions as state regulators have chosen to fund a portion of pest management expenses themselves and have designed a so far credible certification mechanism to reduce the probability of market closure. It is important to note that our analysis does not suggest that the overall economic impact of SOD is small. The social impacts of SOD are likely to reach far beyond the nursery industry, as the native vegetation die-off caused by *P. ramorum* has created a habitat ripe for exotic weed invasion and soil erosion, has degraded wildlife habitat, has increased hazardous fire conditions, and has decreased property values (Frankel, 2003).

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Table 1: Reported changes for the feasible set of pest management actions: Results from a survey of California wholesale nurseries (July 2004 to January 2005)

Activity	*Percent of all nurseries that reported changes as a result of SOD*	*Average cost impact (% increase)*
Inventory management	63	10
Fungicide use	40	16
Irrigation or water treatment	7	3
Treatment of cut greens	3	3
Soil management	13	3
Green waste disposal	13	34
Insurance	0	--
Percent of acres devoted to host product	0	--

Notes: Sample size is 30 nurseries.
Source: Authors' survey.

Table 2: Descriptive statistics for sample data

Variable	Mean	Std. dev.	Obs.
Percent increase in ongoing inventory management cost	3.79	10.10	45
Percent increase in ongoing fungicide cost	6.92	13.96	45
Total acres devoted to nursery products	98.29	123.66	45
Percent of total acres devoted to host product	20.22	26.95	45
Zone-of-Infestation? (0/1)	0.22	0.42	45
Percent host product sold out-of-state	1.44	3.66	45
Signed a SOD compliance agreement? (0/1)	0.58	0.50	45
Google search engine provides phone number? (0/1)	0.76	0.43	45
County annual agricultural wage ($100/year)	98.77	20.81	45
Number of onsite laborers per year	108	133	28
Percent onsite laborers employed year round	87	22	28
Intensity of pre-SOD fungal application	1.18	1.20	45

Notes: The fungicide, inventory management, and percent host product variables required a transformation from a discrete to a continuous variable for the purpose of econometric estimation. In the survey, nurseries were asked to categorize the percent increase of their inventory management and fungicide costs into six categories: 0 percent, 1-5 percent, 6-25 percent, 26-50 percent, 51-75 percent, and over 75 percent. We assigned to each of these ranges the mean value of that category: 0 percent, 3 percent, 15.5 percent, 38 percent, 63 percent, and 87.5 percent respectively. Similarly, nurseries were asked to categorize the percent of acreage devoted to host product into five categories: 1-5 percent, 6-25 percent, 26-50 percent, 51-75 percent, and over 75 percent. We assigned to each of these ranges the mean value of that category: 3 percent, 15.5 percent, 38 percent, 63 percent, and 82.5 percent respectively.
Source: Authors' survey.

Table 3: Descriptive Statistics for pooled sample of survey respondents and non-respondents

Variable	Mean	Std. dev.	Obs.
Total acres devoted to nursery products	63.33	197.9	211
Zone-of-Infestation? (0/1)	0.13	0.335	211
Signed a SOD compliance agreement? (0/1)	0.28	0.450	211
Google search engine provides phone number? (0/1)	0.46	0.500	211

Notes: Data for non-respondents from California Department of Food and Agriculture.

Table 4: Results from probit estimation of the nursery-level decision to participate in the survey

Dependent Variable: Participate in survey? (0/1)					
	(1)	(2)	(3)	(4a)	(4b)
	Probit	Probit	Probit	Probit	$\partial F/\partial x$
Total acres nursery product (100 acres)	0.055	0.058	0.023	0.003	0.001
	(0.041)	(0.041)	(0.051)	(0.053)	[0.013]
Zone of infestation? (0/1)		0.559	0.137	-0.076	-0.018
		(0.269)**	(0.298)	(0.314)	[0.072]
Signed compliance agreement?(0/1)			1.172	1.130	0.328
			(0.222)***	(0.230)***	[0.072]***
Google provides number? (0/1)				0.796	0.198
				(0.232)***	[0.056]***
Constant	-0.836	-0.922	-1.294	-1.695	
	(0.102)***	(0.112)***	(0.144)***	(0.204)***	
Observations	211	211	211	211	211
Percent correctly prediction	--	--	--	79.15	--
Log Likelihood	-108.5	-106.4	-91.96	-85.78	--
Pseudo R^2 (McFadden)	0.007	0.026	0.159	0.215	--
LR χ^2 (# of restrictions)	1.61(1)	5.83(2)	34.78(3)	47.14(4)	--
Prob > χ^2	0.204	0.054	0.000	0.000	--

Conventional standard errors in brackets. Significantly different from zero at 90%(*) 95%(**) 99%(***).

Table 5: Results from Heckman two step estimation of pest management costs

	(1) Heckman	(2) Heckman	(3) Heckman	(4) SUR	(5) OLS
Dependent variable: percent increase in the ongoing cost of inventory management					
Total acres nursery product	-0.039	-0.035	-0.047	-0.036	-0.038
	(0.008)***	(0.008)***	(0.030)	(0.008)***	[0.013]***
Percent acres host product	-0.086	-0.082	-0.152	-0.083	-0.065
	(0.029)***	(0.028)***	(0.053)***	(0.029)***	[0.021]***
Total acres nursery product * percent acres host product (1/100)	0.485	0.483	0.555	0.483	0.464
	(0.054)***	(0.053)***	(0.099)***	(0.052)***	[0.073]***
Zone of infestation? (0/1)	5.957	5.689	5.027	5.716	4.228
	(1.978)***	(1.943)***	(2.857)*	(1.647)***	[2.157]*
Percent of host product sold out-of-state (relative to total nursery product)	-0.291	-0.332	-0.653	-0.328	-0.352
	(0.319)	(0.311)	(0.580)	(0.316)	[0.309]
County annual agricultural wage ($100/year)		0.055	-0.006	0.049	0.054
		(0.033)	(0.053)	(0.032)	[0.041]
Number of onsite laborers per year			0.002		
			(0.024)		
Percent onsite laborers employed year round			-0.037		
			(0.063)		
Inverse Mills' ratio	4.762	4.789	6.558	4.786	
	(1.971)**	(1.921)**	(2.458)***	(1.780)***	
Constant	-4.187	-9.874	-1.303	-9.300	-4.188
	(2.699)	(4.367)**	(9.193)	(4.091)**	[4.185]
Uncensored Observations	45	45	28	45	45
Total Observations	211	211	194	45	45
Wald χ^2 (# of restrictions)	171.25 (5)	182.81 (6)	139.74 (8)	207.98 (6)	
Prob > χ^2	0.000	0.000	0.000	0.000	
R-squared					0.79
Dependent variable: percent increase in the ongoing cost of fungicide					
Total acres nursery products	-0.002		-0.012	-0.012	-0.010
	(0.022)		(0.023)	(0.023)	[0.017]
Percent acres host product	-0.040		-0.079	-0.076	-0.086
	(0.081)		(0.084)	(0.084)	[0.056]
Total acres host product	0.315		0.423	0.420	0.426
	(0.148)**		(0.160)***	(0.160)***	[0.128]***
Zone of infestation? (0/1)	6.077		3.738	3.884	4.533
	(4.666)		(4.851)	(4.817)	[6.820]
Percent of host product sold out-of-state (relative to total nursery product)	-0.603		-1.215	-1.202	-1.166
	(0.896)		(0.960)	(0.959)	[0.748]
Total pounds fungal chemical applied / total acres treated			2.482	2.504	2.280
			(1.729)	(1.715)	[1.782]
Inverse Mills' ratio	-0.994		-2.477	-2.571	
	(5.064)		(5.125)	(5.109)	
Constant	3.537		5.449	5.208	2.753
	(6.699)		(6.795)	(6.763)	[2.751]
Uncensored Observations	45		45	45	45
Total Observations	211		211	45	45
Wald χ^2 (# of restrictions)	12.08 (5)		14.00 (6)	14.25 (6)	
Prob > χ^2	0.0337		0.0297	0.0270	
R-squared					0.27
Correlation between μ and ε				0.1494	

Conventional standard errors in parentheses, robust in brackets. Significantly different from zero at 90%(*) 95%(**) 99%(***). The variables μ and ε represent the unobservable determinants of percent increases in ongoing costs of inventory management and fungicide, respectively.

Table 6: Estimated annual pest management cost increases expected by the average nursery as a result of SOD

Scenario	Hired Farm Labor ($1,000)	Chemicals ($1,000)	Total ($1,000)
(1) Current zone of infestation	12.01	1.50	13.51
	[7.41, 16.61]	[0.64, 2.36]	[8.98, 18.05]
(2) All California counties zone of infestation	26.96	2.54	29.50
	[16.55, 37.38]	[0.59, 4.48]	[19.24, 39.76]

Notes: 'Chemicals' refers to chemicals other than fertilizer, lime, and soil conditioner. Scenario (1) refers to the regulatory environment as of December, 2005. Scenario (2) considers the impact of all California counties becoming infested. A 95% confidence interval is reported below each estimate.
Source: Authors' estimate

Table 7: Estimated annual pest management cost increases expected by the California nursery community as a result of SOD

	Population Estimate		
Scenario	Low N = 68 (million $)	Medium N = 263 (million $)	High N = 388 (million $)
(1) Current zone of infestation	0.92	3.55	5.24
	[0.61, 1.23]	[2.36, 4.75]	[3.48, 7.00]
(2) All California counties zone of infestation	2.01	7.76	11.45
	[1.31, 2.70]	[5.06, 10.46]	[7.46 15.43]

Notes: Scenario (1) refers to the regulatory environment as of December, 2005. Scenario (2) considers the impact of all California counties becoming infested. We spoke with 112 of the 432 nurseries that fit our population criteria. Of the 112, 68 nurseries (or 61 percent) sell host product and 44 do not. We estimate aggregate annual costs for three possibilities concerning the 320 nurseries that we did not contact. The low result assumes none of the 320 produce host product, the medium result assumes that 61 percent of the 320 produce host product, and the high result assumes that all of the 320 produce host product. A 95 percent confidence interval is reported below each estimate.
Source: Authors' estimate.

Table 8: Estimated pest management costs incurred by the California nursery community as a result of SOD: 2002 though 2004

	Population Estimate		
Scenario	Low N = 68 (million $, 2004)	Medium N = 263 (million $, 2004)	High N = 388 (million $, 2004)
(1) Current zone of infestation	2.62 [1.73, 3.49]	10.12 [6.72, 13.51]	14.93 [9.92, 19.94]
(2) All California counties zone of infestation	5.71 [3.73, 7.70]	22.09 [14.41, 29.78]	32.59 [21.25, 43.93]

Scenario (1) refers to the regulatory environment as of December, 2005. Scenario (2) considers the impact of all California counties becoming infested. We spoke with 112 of the 432 nurseries that fit our population criteria. Of the 112, 68 nurseries (or 61 percent) sell host product and 44 do not. We estimate aggregate annual costs for three possibilities concerning the 320 nurseries that we did not contact. The low result assumes none of the 320 produce host product, the medium result assumes that 61 percent of the 320 produce host product, and the high result assumes that all of the 320 produce host product. A 95 percent confidence interval is reported below each estimate. All values expressed in 2004 dollars using a 5 percent rate of return.
Source: Authors' estimate.