Behavioral Responses to Disease Forecasts: From Precision to Automation in Powdery Mildew Management

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Disease forecasts aim to optimize disease management and reduce environmental impacts. We find that grape growers value improved disease control from such forecasts, but respond in complex ways that may undermine any positive environmental effects. Increased precision and automation may reduce the scope of these behavioral responses.

Better information can improve decisions. Since the late 1990s, real-time, high-resolution disease forecasts have enabled grape growers to manage powdery mildew with greater precision. Current advances in sensors and drones herald further gains in precision and, ultimately, a progression to fully automated disease control. In this study, we explore how California grape growers respond to powdery mildew forecasts and what these responses may mean for continued progression from precision to automation in disease control.

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Powdery Mildew Management and the PMI

Powdery mildew affects grape crops all over the world and is one of the major diseases in California agriculture. According to Sambucci, Alston, and Fuller (2015) powdery mildew management accounts for 17% of total pesticide use in the state (by weight of active ingredient) and 74% of total pesticide use on grapes. In recent decades, management of powdery mildew has relied less on grower instinct and more on increasingly precise disease prediction and even spore detection. The main innovation in this transition was the development of the Gubler-Thomas Powdery Mildew Index (PMI), which became available to growers in 1996.

The PMI is a weather-based forecasting index that predicts the rate of reproduction of powdery mildew spores and recommends corresponding fungicide spray intervals. The PMI quickly became a popular method of guiding the management of powdery mildew and is the primary tool recommended by the UC IPM program for managing powdery mildew on grapes. An online continuing education class on managing powdery mildew using the PMI was approved by the California Department of Pesticide Regulation (CA DPR) and introduced in 2004, and over 2,000 growers have completed the course since its introduction.

The PMI was developed as a tool to optimize application of fungicides to prevent outbreaks of powdery mildew. The original intent of the PMI was to guide growers to adjust intervals between fungicides sprays. When used in field trials in this way, the PMI eliminated two-three sprays per year, which implied significant savings for growers and a direct benefit to the environment.

Recent analyses of how growers actually respond to these disease forecasts call these field trial results into question—and offer insights into the promise of precision and automation in disease management.

PMI Responses Based on Pesticide Use Reports

California's pesticide use reporting system provides a unique opportunity for understanding how growers respond to the PMI. In a recent study that links a survey of winegrape growers to their pesticide use reports, the researchers found that growers respond to the PMI information by changing not only the timing of treatment as assumed in the PMI field trials but also their choice of pesticide and dosage rates. This multidimensional response in part reflects the fact that for many growers it is more costly to adjust the timing of treatment (i.e., reschedule workers and equipment) than to adjust product and dosage rates.

In further contrast to field trials, growers also "dialed up" their regimen more when the PMI ticked up than they "backed off" when the PMI ticked down. This asymmetric behavioral response seems to amplify a behavioral response on the part of the PMI model builders, who intentionally made the prediction model conservative in order to avoid false negatives that leave model users exposed to serious losses. This double asymmetry in risk response on the

Table 1. Changes in the Management of Powdery Mildew After the Completion of the Online Course

Region	Number of Growers	Average Crop Value	Average Daily PMI	Changes in the Number of PM Treatments	Change in the Cost of PM Management
		$ Per Ton			$ Per Acre
North Coast	31	2,322	63	-1.5	-28.13
Central Coast	57	1,135	48	1.6	48.18
N. Central Valley	68	553	53	2.1	85.03
S. Central Valley	133	547	52	0.4	14.49
Total	294				

part of the modelers and the growers induces more aggressive powdery mildew management tactics than what might be objectively optimal.

In a follow-up study, we examined the use of the PMI in the context of online continuing education courses. We used course completion records for the popular online PMI course to examine the management of powdery mildew before and after growers completed the course. The course provided guidelines on the use of the PMI to control powdery mildew, including the adjustments of intervals and the proper rotation of synthetic products to manage resistance.

The growers in the sample completed the online course as a partial fulfillment of the continuing education requirement for renewing their pesticide applicator license in 2004–2011, an overlapping but more recent period than the one examined in in the previous study of the use of the PMI. This time, the focus of the research was on online learning rather than the initial adoption of the PMI, but the observed changes in pesticide application behavior were quite similar to those from the earlier study.

We found that the adjustments to pesticide applications made by the growers followed the major guidelines of the online course, but, as previously observed, the heterogeneity was region-specific. Most growers experienced an increase rather than a decrease in the number of annual pesticide applications, and additional adjustments were made to the choice of product and dosage rates. As a result, the annual costs per acre of managing powdery mildew increased for growers in three out of the four regions. Table 1 provides a summary of key regional characteristics and results.

High-value winegrapes are grown mostly in the North Coast region, where yields are the lowest, and milder weather can bring increased pressure of powdery mildew outbreaks. In the Central Valley, yields per acre are highest and winegrapes are sold at much lower prices. In addition, other types of grapes such as raisin grapes and table grapes are also grown in the Central Valley. Average daily temperatures are quite a bit higher in the Valley regions, and growers use a different mix of chemicals to control powdery mildew: mostly sulfur, rotated with some synthetic chemicals.

As with the earlier study, growers respond along multiple dimensions, with the most significant changes happening to the choice of product and dosage rather than the timing of sprays. The main changes to the spraying programs after completing the online course are the decrease in the use of sulfur and the increase in dosage rates for all other products, especially when the disease pressure is high.

Growers in three of the four major grape growing regions in our sample experience an increase in powdery mildew management costs after the completion of the course ranging between $14–84 per acre annually. Growers in the North Coast region experience a decrease in costs of about $24 per acre annually due to a decrease in the number of annual sulfur sprays and the resulting savings.

The increases in costs for the other regions come from the increase in the number of applications, as well as the use of products that are more costly, such as synthetic fungicides and stylet oil. The growers are expected to apply more sprays in years where the powdery mildew pressure is high, and fewer sprays in years where it is low. Our results take variation in annual powdery mildew pressure into account and hold for all years.

The observed increase in the costs of managing powdery mildew can be viewed as a proxy for a corresponding increase in private benefits to the growers from the new powdery mildew strategy. Since we do not observe the efficacy of powdery mildew treatments, before or after the completion of an

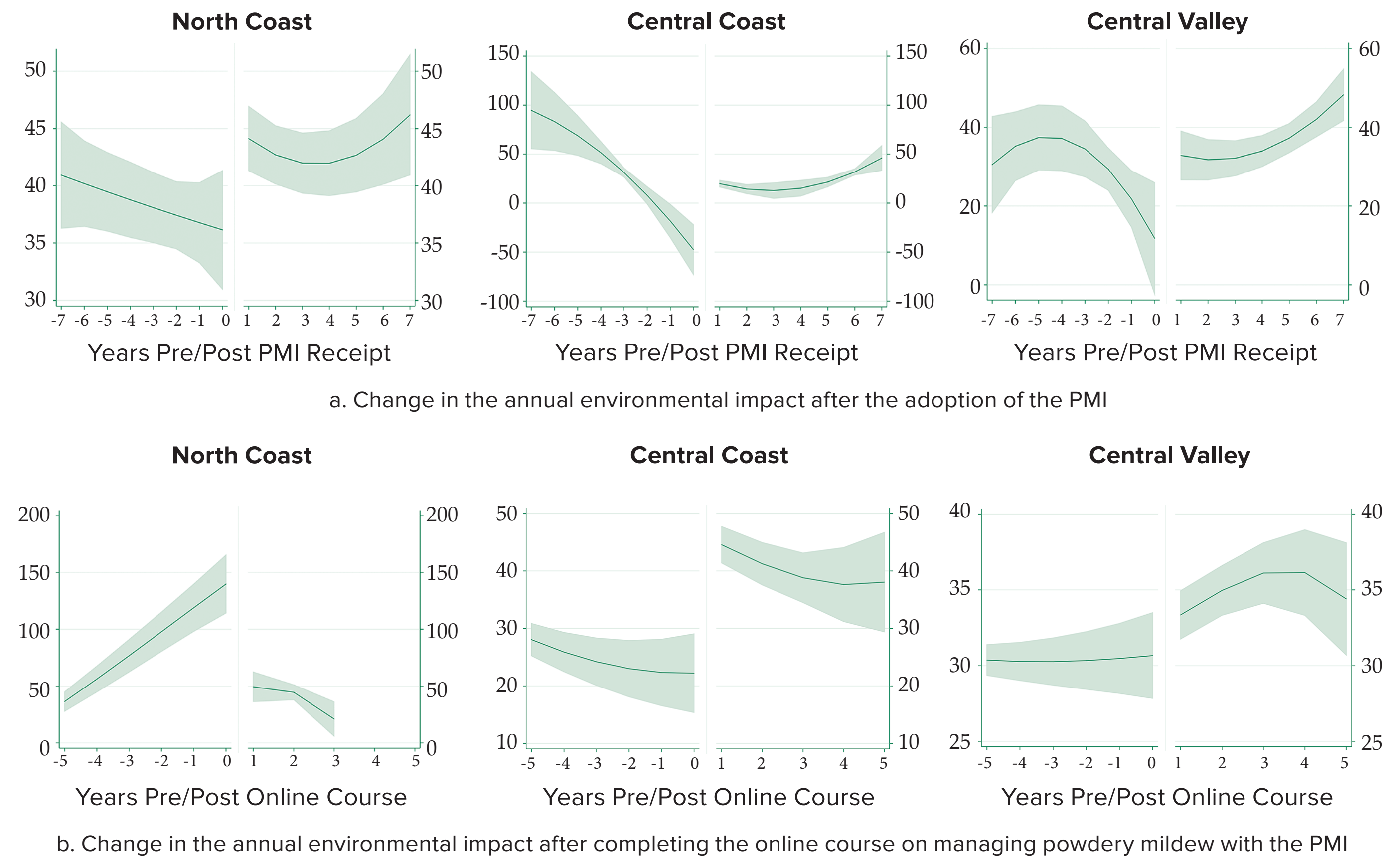

Figure 1. Event study of impact of the PMI receipt and completion of an online course on the integrated PURE risk index by growing region

Notes: All regressions include year fixed effects and plot random effects. Shaded areas represent 95 percent confidence intervals.

Source: Panel a is from Figure 6 in Lybbert et al. 2016, panel b is from Figure 15 in Sambucci and Lybbert 2016.

online course, we can view the increase in costs as a revealed preference for the new management program, and, therefore, conclude that from the perspective of the growers there is an added value to the production process at least equal to the additional costs.

Changes in Environmental Risk

Early field trials that adjusted only treatment timing in response to the PMI suggest strong positive environmental effects. The multiple margins of adjustment found in both analyses described above—combined with growers' asymmetric risk response—complicate the evaluation of the net environmental effects of the PMI. We use the Pesticide Use Risk Environmental (PURE) scores, developed at the UC Davis Department of Land, Water, and Air Resources, as a measure of the overall environmental risks associated with a given pesticide regime on given plot in a given year.

PURE scores are computed using pesticide applications recorded in the Pesticide Use Reports (PUR) database maintained by the California Department of Pesticide Regulation and reflect the toxicity of products, the dosage rates, local soil and other factors, and the prevailing weather at the time of application. We track how PURE scores of growers change after they begin receiving or are exposed to PMI forecasts. We find that in most cases the PMI increases rather than decreases environmental risks.

Figure 1 shows the combined results, from the two studies on the use of the PMI discussed above, for changes in the environmental impact following either the adoption of the PMI (panel a) or the completion of an online course on the use of the PMI (panel b). These results suggest that net environmental effects of the PMI—given the complex ways growers use the information—may actually be negative.

While findings from the two studies are largely consistent in this regard, the more recent study suggests that North Coast region growers are beginning to use the PMI in a way that reduces environmental risk. The fungicides used to manage powdery mildew are considered to be low toxicity to both workers and the environment. The finding that growers adopt more aggressive strategies with access to forecast information may, however, apply to other crops and settings where the toxicity of products is more worrisome.

From Precision to Automation in Agricultural Risk Management

These results offer insights into the progression from increased precision to full automation in agricultural risk management. The advent of the PMI enabled much greater temporal precision in risk management. While this greater precision seems to have improved disease control, it did not have the desired positive effect on the environment because most growers responded to this information in an asymmetric and risk averse manner: *PMI low? Business as usual. PMI high? Attack!* This response is very sensible considering that an outbreak of powdery mildew spreads extremely fast and can wipe out an entire crop; thus, backing off by stretching intervals when the PMI is low entails considerable potential risk exposure for growers. Even with a reliable forecast, most growers seem reluctant to increase their risk exposure for the sake of saving the costs of a few fungicide applications.

We conclude with a few reflections on how to understand our results in the continued march to automation. Improvements in the spatial resolution of disease detection are the likely next step in increased precision. In recent years, methods that detect the number of powdery mildew spores throughout the vineyard have been gaining in popularity (e.g., spore traps). As spore detection becomes cheaper and faster, greater precision in disease management will potentially benefit both growers and the environment.

Since 1990, predicting and detecting powdery mildew has seen significant advances, new fungicide products have been released, and spraying equipment has gained some efficiency. The progression from precision to automation in disease management will only be complete when detection is fully integrated with automated applications of fungicides. Imagine, for example, an automated variable-rate pesticide sprayer—a land- or air-based drone—equipped with the capacity to detect powdery mildew spores in real time or to receive such alerts from a dedicated detection drone. Such a system, which is not too many years away, would suppress powdery mildew outbreaks "just-in-time" and with vine-level precision.

A fully automated drone-based system for managing powdery mildew could save labor costs and improve disease management. Our research suggests that it might have especially potent environmental benefits by eliminating the double asymmetry in risk responses on the part of disease model builders and grape growers—responses that are born of the residual uncertainty and imprecision of the current system. The ultimate progression to full precision and full automation will reduce interference from these human behavioral responses and provide a degree of powdery mildew control that is far more likely to be both privately and environmentally optimal.

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