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ALSO IN THIS ISSUE

Behavioral Responses to Disease Forecasts: From Precision to Automation in Powdery Mildew Management, Olena Sambucci and Travis J. Lybbert 5

Reducing Non-native Species Introductions with Risk-based Inspection of International Trade, Amanda R. Lindsay, Michael R. Springborn and Rebecca S. Epanchin-Niell 9

Labor Cost Challenges Facing California Agriculture

Philip Martin

California will become the first state to require both a $15 an hour minimum wage and overtime pay for farm workers after eight hours of work a day or 40 hours a week in 2022.

Most seasonal harvest workers work less than eight hours a day, but some work six days a week.

AB 2757, the Phase-In Overtime for Agricultural Workers Act of 2016, would remove an exemption by January 1, 2022 that requires overtime pay for farm workers after 10 hours a day or 60 a week. Most nonfarm workers get overtime pay after eight hours a day and 40 hours a week.

California is one of four states that require overtime pay for farm workers; the 10/60 standard was established by the state Industrial Welfare Commission in 1976. AB 2757 failed in the Assembly June 2, 2016 on a 38-35 vote; 41 votes were needed for passage. However, farm worker overtime re-emerged as AB 1066 and became law in September 2016. A similar 8/40 overtime bill was vetoed in 2010 and failed in a final vote in the Assembly in 2012.

Under AB 1066, farm employers must begin to pay overtime to farm workers after 9.5 hours a day or 55 hours a week, with regular 8/40 overtime required after January 1, 2022. Employers with 25 or fewer workers will have until 2025 to pay 8/40 overtime.

There is very limited data on hours worked by California farm workers. Employers told the USDA's Farm Labor Report that U.S.-hired farm workers were employed an average 39 hours a week in January 2016, versus 41 in California and almost 47 in Arizona and New Mexico. Hours per week were higher in October 2015, almost 42 across the U.S. and 44 in California.

In July 2015, average hours per week were 41 across the U.S. and almost 44 in California, and in April 2015, 40 in the U.S. and 42 in California. Arizona and New Mexico consistently have the longest average farm worker workweeks, often 46–47 hours, while Hawaii has the shortest workweek, with an average 37 hours.

The USDA data are averages for all types of workers: crop and livestock, and year-round and seasonal. They require two caveats for California. First, over three-fourths of the workers reported to USDA are employed on the reporting farm 150 days or more; that is, they are disproportionately long-season and livestock workers. Second, the USDA data do not include workers brought to farms by crop support services such as labor contractors, who bring the majority of workers to farms in California.

Most seasonal harvest workers work less than eight hours a day, but some work six days a week. A seven-hour, six-day worker would work 42 hours, although many farmers schedule only half a day's work on Saturday.

Three types of workers are most likely to be affected by 8/40 overtime: livestock (dairy) workers, irrigators, and equipment operators. If 8/40 overtime were enacted, employers of dairy workers and irrigators would likely weigh the additional costs of hiring and training more workers versus paying current employees overtime. Calculations for equipment operators may be different, with overtime pay likely cheaper than buying additional equipment and hiring more operators.

The slowdown in Mexico-U.S. migration since the 2008–09 recession means that there are few newcomers arriving from Mexico, and many of the new workers entering the state's farm workforce are H-2A guest workers. In current tight labor markets, many employers are likely to improve the efficiency of scheduling workers or pay overtime because of the difficulties involved in recruiting additional workers.

The UFW argued that farm workers deserve the same overtime protections as nonfarm workers. Farmers predicted 8/40 overtime would backfire and reduce worker earnings, as farmers hired more workers rather than pay overtime.

USDA data are from a sample of employers who hire workers directly. A survey of workers, the National Agricultural Workers Survey (NAWS), asks California crop workers how many hours they worked last week in the current job and the number of days worked per week in the current job. NAWS reports a significant share of workers are employed more than eight hours a day and 40 hours a week.

However, as with the USDA survey, most of the workers interviewed in the NAWS were hired directly by farmers rather than brought to farms by crop support services. The crop workers interviewed in California had an average of 16 years experience doing farm work and did an average 205 days of farm work in the past year. One quarter had harvesting jobs.

Minimum Wages

California in April 2016 approved SB 3 to raise the state's $10 an hour minimum wage to $15 by 2022 for large employers, and by 2023 for employers with 25 or fewer workers. The minimum wage will rise by $1 an hour in January each year beginning in 2017, and increase with inflation from 2024. The governor can suspend minimum wage increases for a year in recessions or if there are serious budget crises.

SB 3 was enacted to head off a $15 an hour union-sponsored initiative on the November 2016 ballot that was expected to be approved by voters. The minimum wage increase is expected to affect 5.4 million of California's 15.1 million workers, raising their wages by an average $2.20 an hour or $3,700 a year.

Table 1. California Farm Workers and Earnings, 2014

	Primary Workers	Earnings ($mil)	Average Earnings ($)	Only Job	Share
Agriculture	691,615	11,430	$16,527	499,440	72%
Oilseed and grain farming	4,587	116	$25,363	3,144	69%
Vegetable and melon farming	44,878	1,068	$23,789	30,760	69%
Fruit and tree nut farming	153,999	2,710	$17,600	102,805	67%
Greenhouse and nursery production	34,715	884	$25,452	26,530	76%
Other crop farming	19,052	446	$23,414	14,244	75%
Cattle ranching and farming	25,224	737	$29,223	19,817	79%
Hog and pig farming	132	4	$26,804	109	83%
Poultry and egg production	2,851	83	$29,143	2,123	74%
Sheep and goat farming	543	12	$21,759	465	86%
Animal aquaculture	441	13	$30,104	324	73%
Other animal production	3,069	77	$25,144	2,308	75%
Support activities for crop production	391,711	4,982	$12,719	288,435	74%
Support activities for animal production	3,156	81	$25,765	2,585	82%
Support activities for forestry	2,589	76	$29,217	2,012	78%
Nonfarm	137,711	4,548	$33,025	--	--
All Workers with at least one ag job	829,326	15,978	$19,266	--	--

Source: Quarterly Census of Employment and Wage, Bureau of Labor Statistics, http://www.bls.gov/cew/

The UCB Labor Center estimated that almost 40% of those affected by the $15 minimum wage are 20 to 29 years old, and that over half have a high school education or less. Over 55% of those expected to benefit from the rising minimum wage are Latino. A third of California workers affected are in retail trade and food services; less than 5% are in agriculture.

There is much speculation about the impacts of the $15 minimum wage in the San Joaquin Valley. In Fresno and other San Joaquin Valley cities, the $15 minimum wage would be three-fourths of the projected $20 median wage in 2022, while $15 will be less than half of the projected median wage in San Francisco in 2022.

California farmers opposed the 50% increase in the minimum wage. They complained that labor costs have risen rapidly because of the Affordable Care Act and paid sick leave, as well as the slowdown in Mexico-U.S. migration. Almost 200,000 workers in Fresno County are expected to be affected directly by the minimum wage increase. Many employers predict that they will have to lay off workers and raise prices.

4-S Responses to Higher Wages

California farmers specialize in the production of high-value fruits and nuts, vegetables and melons, and other horticultural crops, including nursery crops, mushrooms, and other minor crops. California produced $34 billion worth of FVH crops in 2014, including $21 billion worth of fruits and nuts, $8 billion worth of vegetables and melons, and $5 billion worth of other horticultural crops. That is, California accounted for 70% of the $30 billion value of U.S. fruits and nuts, 42% of $19 billion value of vegetables and melons, and 19% of the $27 billion worth other horticultural crops (Figure 1).

Many of these commodities are labor intensive, meaning that labor costs are 20–40% of production costs. The 1986 Immigration Reform and Control Act ushered in an era of plentiful labor and falling real wages for farm workers, as unauthorized Mexicans moved to the United States and spread throughout U.S. agriculture and the U.S. economy. The number of unauthorized foreigners peaked at 12 million in 2007, including seven million Mexicans. At least a million of the eight million unauthorized foreigners in the U.S. labor force were employed in agriculture.

Since the 2008–09 recession, Mexico-U.S. migration has slowed, so that there are almost no newly arrived unauthorized Mexicans in the farm workforce, while in 2000 a quarter of farm workers had arrived within the past year from Mexico. Farm employers noticed the slowdown in Mexican newcomers, complained of labor shortages, and pursued four broad strategies to cope with the aging and settled farm workforce: satisfy, stretch, substitute, and supplement.

The first strategy is to satisfy current workers to retain them longer by offering bonuses, training supervisors, and taking other steps to make current employees feel wanted. Most farmers believe that the supply of labor inside U.S. borders is fixed or inelastic, so that higher wages will not attract or retain more farm workers. Instead, benefits and bonuses, such as low-cost health care to employees and their families or adding a 10% bonus to earnings for staying until the end of the season, are being implemented. Some employers are improving the training of first-level supervisors to reduce favoritism and harassment.

There may be physical limits to how long farm workers can continue to lift and carry heavy bags of fruits and vegetables in 100 degree heat as their average age approaches 40. A familiar aphorism says that it is hard to find a farmer under 40 because of the capital required to farm and hard to find a farm worker over 40 because of the physical demands of farm work.

The second strategy is to stretch the current work force with mechanical aids that increase productivity and make farm work easier. Most fruits and vegetables are over 90% water, and hand harvesters spend much of

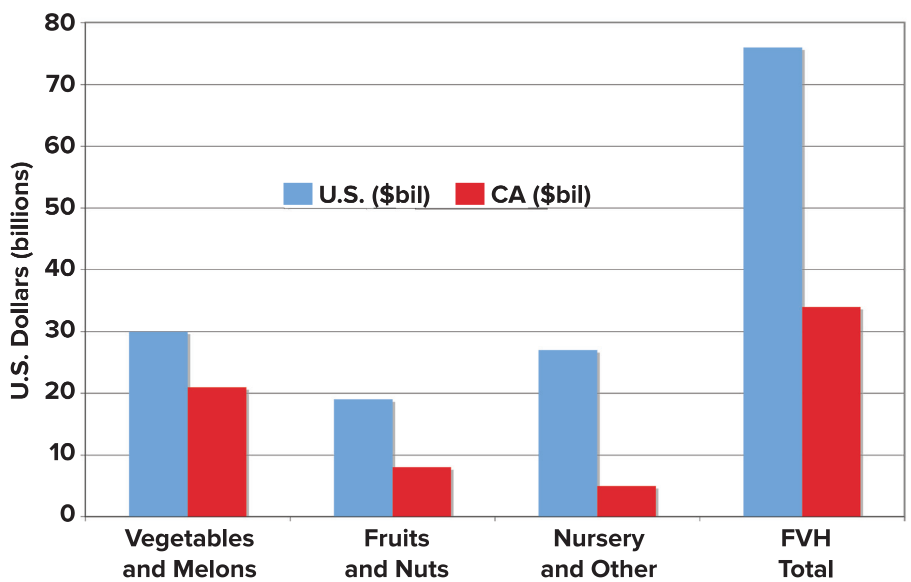

Figure 1. U.S. and California Fruit, Vegetable and Horticultural Sales, 2014

Source: USDA, Economic Research Service, http://www.ers.usda.gov/

their time carrying harvested produce down ladders to bins or to the end of rows to receive credit for their work.

Smaller trees mean fewer ladders and faster picking, and hydraulic platforms reduce the need to fill 50 to 60 pound bags of apples and oranges from ladders. Slow-moving conveyor belts that travel ahead of workers harvesting berries, broccoli, and other vegetables reduce the need to carry harvested produce, making workers more productive and harvesting jobs more appealing to older workers and women.

More can be done to raise the productivity of hand harvesters. Trees and plants have been designed for maximum yields, not maximum worker productivity. Dwarf trees, talk-stalk broccoli that requires less bending to cut, and table top production of strawberries (as in some European countries) could stretch a smaller farm workforce by increasing worker productivity. However, the time between development of new plants and labor-saving machines and their widespread diffusion is often measured in decades.

The third strategy is substitution or replacing workers with machines. Labor-saving mechanization is the story of agriculture, as the U.S. went from 95% of U.S. residents in agriculture in 1790 to less than 2% today. The production of the big-five crops, corn, soybeans, wheat, cotton and rice, has been mechanized, and there have been enormous labor-saving changes in livestock production as well, including robotic milking systems. Most nuts are harvested mechanically, with machines shaking them from trees and sweeping them into rows for pick up.

Fresh fruits and vegetables have defied mechanization for several reasons. Many are fragile, and human hands are far gentler than mechanical fingers to harvest grapes or peaches. Machines that shake apples or pears from trees damage a higher share of the fruit than hand harvesters, meaning a smaller share goes to market. Finally, machines are fixed costs and workers are variable costs, meaning that farmers must pay for a $200,000 harvesting machine whether there are apples to pick or not, while they do not pay wages to workers if storms or disease destroy the apple crop.

The fourth adjustment is to supplement current workers with H-2A guest workers. The H-2A program was created in 1952 and was used primarily by sugar cane growers in Florida and apple growers along the east coast until the mid-1990s. North Carolina tobacco farmers became the largest users after ex-government officials created an association that, for a fee, recruits workers in Mexico, brings them to North Carolina, and deploys them to farmers. This turn-key and loyal H-2A labor force proved very attractive to farmers, especially as the workers gained experience by returning year after year.

Receiving government certification to employ H-2A guest workers requires employers to satisfy three major criteria. First, farmers must try to recruit U.S. workers and provide reasons why U.S. workers who applied for jobs were not hired.

Second, farmers must provide free housing to H-2A guest workers and out-of-area U.S. workers. Housing is a special concern in California, where most labor-intensive agriculture is in metro countries that often have shortages of affordable housing and restrictions on building more.

Third, the law requires that the presence of H-2A guest workers should not "adversely affect" U.S. workers. The government enforces this no-adverse-effect requirement by setting a super-minimum wage called the Adverse Effect Wage Rate, which is $11.89 an hour in CA in 2016, when the state's minimum wage is $10 an hour.

The H-2A program is expanding, doubling over the past decade to over 140,000 farm jobs certified by the U.S, Department of Labor (DOL) to be filled by guest workers in FY15 on about 7,500 U.S. farms. California has experienced some of the fastest growth in H-2A jobs, doubling from 4,100 in FY13 to 8,600 in FY15 and likely to exceed 10,000 in FY16. One-half of the California H-2A certifications were with farm labor contractors (FLCs) who provide workers to farmers, moving them from one farm to another if necessary. Some 243 U.S. workers were referred to fill H-2A jobs in FY15, and 23 (or less than 10%) were hired.

What's Next?

After two decades of plentiful farm workers and stable wages, California farmers face the prospect of higher labor costs due to market reasons linked to the slowdown in unauthorized Mexico-U.S. migration and state legislation that increases the minimum wage from $10 to $15 and requires 1.5 times regular pay for hours worked after eight a day and 40 a week. Higher wages and rising labor costs have prompted farmers to pursue satisfy, stretch, substitute, and supplement strategies. Stretch and supplement are the most likely short-term responses, and stretching and substitution are most likely over time.

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

Olena Sambucci and Travis J. Lybbert

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.

Powdery mildew affects grape crops all over the world and is one of the major diseases in California agriculture.

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

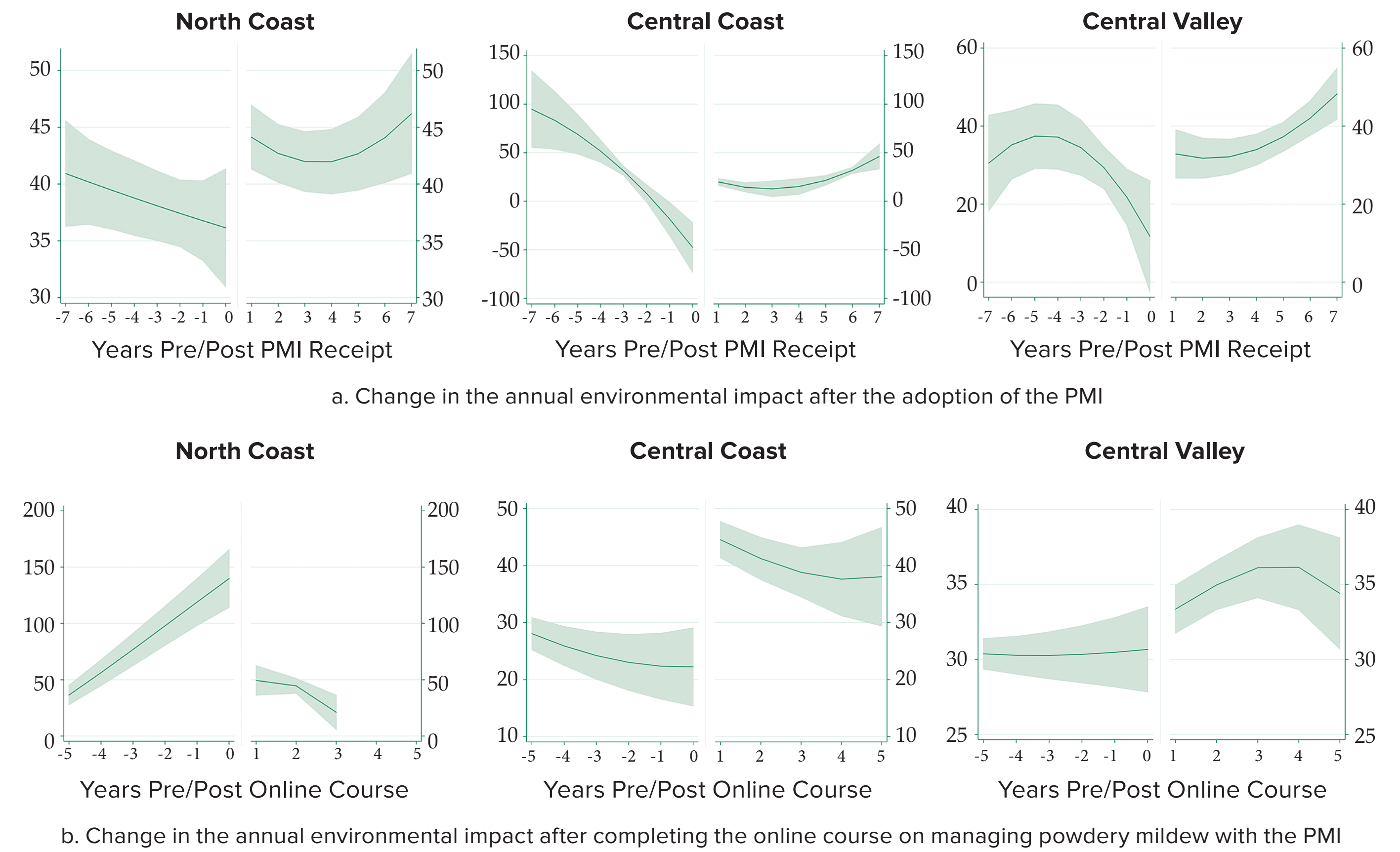

Figure 1. Event study of impact of the PMI receipt and completion of an online course on the integrated PURE risk index by growing region

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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Reducing Non-native Species Introductions with Risk-based Inspection of International Trade

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Pests and pathogens can hitchhike on imported goods and cause substantial damage in new environments. Here we describe research that informs the design and evaluates the gains of a new U.S. program for inspecting imported goods to reduce pest introductions.

The importation of live plants, such as those planted in our yards or in pots in our homes, has long been a pathway for the unintentional introduction of non-native insect pests and pathogens to the United States. Notable examples of such introductions include the Citrus longhorned beetle (Anoplophora chinensis) and White pine blister rust (Cronartium ribicola), both of which have caused substantial damage by killing trees and have prompted costly control campaigns. The international trade vector has also been expanding at a substantial rate: over the past four decades, the dollar value of plants for planting imports to the U.S. has grown at 68% per decade.

The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is tasked with minimizing the entry and spread of pests, diseases, and weeds to protect agriculture and natural resources. As part of this mission, APHIS inspects shipments containing imported plant material at ports of entry across the country. However, resources for these inspections have not grown at the same rate as imports, prompting APHIS to reexamine the efficiency of shipment inspection policies.

Recently, APHIS has explored moving from a relatively uniform approach for inspecting shipments to a risk-based inspection approach that concentrates effort on sources of imports that have more problematic inspection histories. While the basic idea of risk-based inspections is simple, designing the actual system is complicated by the involvement of thousands of offshore producers, each likely to adapt their behavior to any change in the border inspection strategy. In a forthcoming study (Springborn et al., in press), we evaluate how to effectively design such a system: how should producers be categorized into high- versus lower-risk groups and how differently should these groups be treated (e.g., in intensity of inspections)?

Using a numerical model calibrated to the actual system, we find that adopting risk-based inspection can provide a greater incentive for producers to clean up their shipments, even for producers inspected with less intensity than under a uniform inspection approach. We estimate that shifting to a risk-based inspection approach can cut the expected rate of infested shipments entering the United States by one-fifth, simply by reallocating existing resources.

Overview of the Inspection Procedures

Inspection of live plant imports involves an inspector examining individual plants within a shipment for signs of pests or pest damage. Inspected shipments that are found to be infested—we refer to these as "intercepted" shipments—may be either treated, destroyed or returned, imposing a cost on the producer and preventing entry of the associated pests. Infested shipments may enter the United States if pests are not detected by inspection or a shipment is not inspected. When shipments are not intercepted, they continue on to their intended destination. Because the inspection process takes time, inspected shipments that are not intercepted still generate costs for producers due to delay and use valuable inspection resources.

Following the approach of APHIS, we differentiate shipments by their origin-commodity combination, where the origin is the country of export and commodity is the genus of plant.

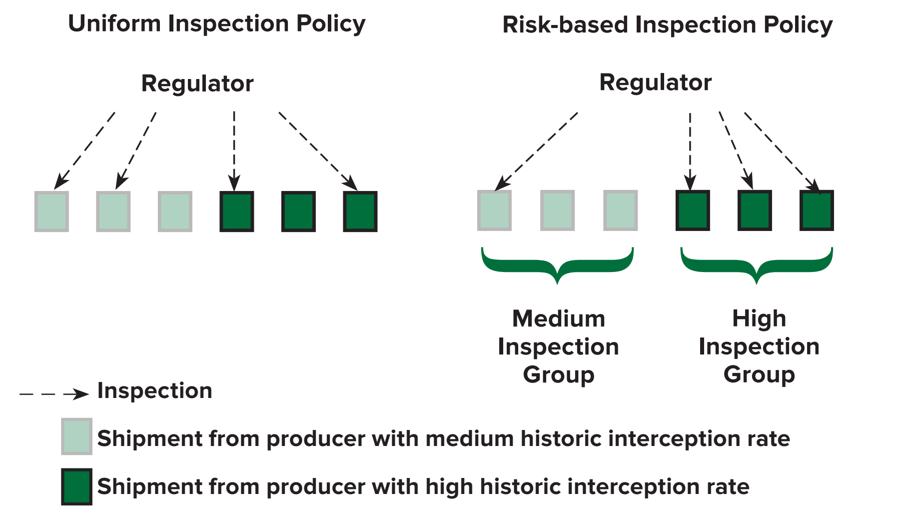

Figure 1. Under uniform inspection, all shipments face the same probability of inspection. Under risk-based inspection, higher risk shipments are inspected more frequently than lower risk shipments.

We refer to these unique origin-commodity combinations as "producers."

As illustrated in Figure 2, under a uniform approach, the regulator inspects all producers with equal likelihood. In contrast, under a risk-based inspection policy, producers are divided into medium- and high-risk groups based on their historic interception rates—a record characterizing previous inspection performance. Producers with a high historical interception rate are assigned to the high-risk group and receive more frequent inspections.

Historic interception rates are continuously updated to incorporate outcomes from recent inspections, capturing either deterioration or improvement in the cleanliness of a producer. As such, producers can move from the medium to high group and vice versa, based on performance.

Modeling Risk-based Inspection

In our risk-based inspection model, the regulator announces a cutoff that determines how producers will be treated—those with interception rates above the cutoff are placed in the high-risk group, with the remainder falling in the medium-risk group. The regulator also announces how inspection frequencies will differ between groups.

Producers respond by choosing their level of phytosanitary effort to reduce infestations in their shipments, with the goal of minimizing their expected losses. These potential losses come from the costs of phytosanitary effort, border inspection delays, costs from intercepted shipments, and being banned from the market entirely if interception rates are extreme. Phytosanitary effort is costly but reduces the anticipated level of all other losses.

In reality, it is typically not feasible for producers to control infestations with certainty. Nor is it possible for border inspections to intercept all infested shipments. Thus, we model uncertainty in both of these components. We empirically ground the analysis by using data on live plant imports and shipment inspection outcomes to estimate parameters in the model. We also calibrate our model of producer behavior so that the model replicates overall inspection outcomes observed in the data.

The ultimate goal of the inspection policy is to minimize the number of shipments that enter past U.S. borders but are infested. We identify the policy that minimizes the expected rate of these accepted infested shipments. The policy's focus on inspection highlights the role of border interceptions in preventing pest introductions. However, in reality—and in our model—reductions of accepted infested shipments come mainly from incentivizing producers to clean up shipments at the source, and only secondarily from interceptions at the border.

Benefits and Design of a Risk-based Inspection Policy

We compare outcomes under a risk-based inspection policy to those under a uniform inspection policy to evaluate the potential gains. Under a risk-based inspection policy, shipments from high-risk offshore producers are inspected more frequently and those from medium-risk producers are inspected less frequently.

Figure 2 illuminates the phytosanitary benefits of a risk-based inspection policy by comparing the predicted phytosanitary effort response (vertical axis) of a producer as a function of the producer's historic interception rate (horizontal axis) for both the baseline uniform inspection policy (dashed line) and the optimal risk-based inspection policy (solid line). Producers in both the medium and high-risk groups exert higher phytosanitary effort under a risk-based policy than under a uniform inspection approach

While producers falling into the medium-risk group—below the interception rate cutoff (thick vertical line)—are inspected less frequently under the risk-based policy relative to the uniform approach, they nonetheless exert higher phytosanitary effort than under the uniform policy. The reason for this is that they have a stronger incentive to provide cleaner shipments to avoid being transferred into the high-risk inspection group in which they would be inspected more frequently.

In addition, producers in the high-risk group, with interception rates close to the cutoff, exert substantially more phytosanitary effort than under the uniform inspection policy. These producers are motivated to increase phytosanitary effort to increase the chance of transitioning to the medium inspection group, where they would be inspected less frequently.

These two features of producer response under risk-based inspection, in which producers exert enhanced effort on either side of the interception rate cutoff, illustrate an idea known as "enforcement leverage." This enforcement leverage—combined with the direct effect of higher inspection frequency in the high group (relative to the uniform approach)—lead to reductions in the expected rate of infested shipment entering the United States.

Accounting for the behavioral response of producers (as above), the optimal risk-based inspection policy involves inspecting 100% of shipments from high-risk producers using approximately 82% of the available inspection budget.

Shipments in the medium-risk group are inspected with a probability equal to 0.28, almost one-quarter of the rate of high-risk shipments. The interception rate cutoff, determining group assignment, is set such that just over half (57%) of shipments entering the United States are assigned to the high inspection group.

We estimate that—relative to uniform inspection policy—the optimal risk-based inspection policy cuts the expected rate of infested shipments entering the U.S. by one-fifth. It does so by increasing inspection frequency in the high-risk group and decreasing inspection frequency in the medium-risk group—both by roughly 50%. This improvement is substantial, especially given that it results simply from reallocation of existing inspection effort.

To generate the results discussed above, we considered a model based on a single representative producer type. We considered a model that incorporated four different producer types as characterized by shipping frequency and phytosanitary effort costs. Incorporating this heterogeneity did not affect the results reported above, but did affect the level of the interception rate cutoff (vertical line in Figure 2), a policy parameter that must be announced by the regulator.

In reality, there is substantial heterogeneity, with thousands of producers that vary along a continuum. Fully capturing this heterogeneity is not computationally feasible. However, this is a design parameter that the regulator can settle on through trial and error, starting with high values—fewer producers in the high category translating to little risk that inspection resources will be overwhelmed—and iterating towards lower cutoff values until inspection resources are fully utilized.

Discussion

Given the substantial ecological and economic damages that can result from unintentional introduction of invasive pests via trade, measures to safeguard our natural resources are critically important. However, resources for implementing such measures are limited. Our research shows how shifting from a uniform policy to a risk-based policy for inspecting imported shipments of live plants can reduce the number of infested shipments accepted into the United States, and hence the likelihood of pest introduction, simply by reallocating existing inspection resources.

Our modeling results also help support effective design of a risk-based inspection program in the complex setting of international trade inspections, involving many more targets for inspection than considered by previous studies. We estimate that this approach would substantially enhance the performance of monitoring and enforcement efforts, even though the overall level of effort does not change, by targeting riskier shipments more intensively and incentivizing producers to clean up their shipments.

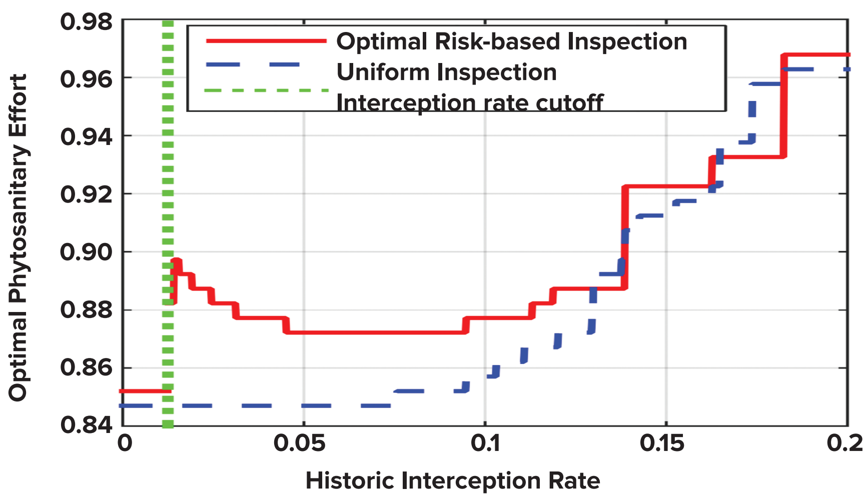

Figure 2. Optimal phytosanitary response for a representative producer (homogenous producer model). Phytosanitary effort is normalized to take a value between zero and one. When a producer's historic interception rate moves above 0.20, their shipments are banned from entry.

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For additional information, the authors recommend:

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