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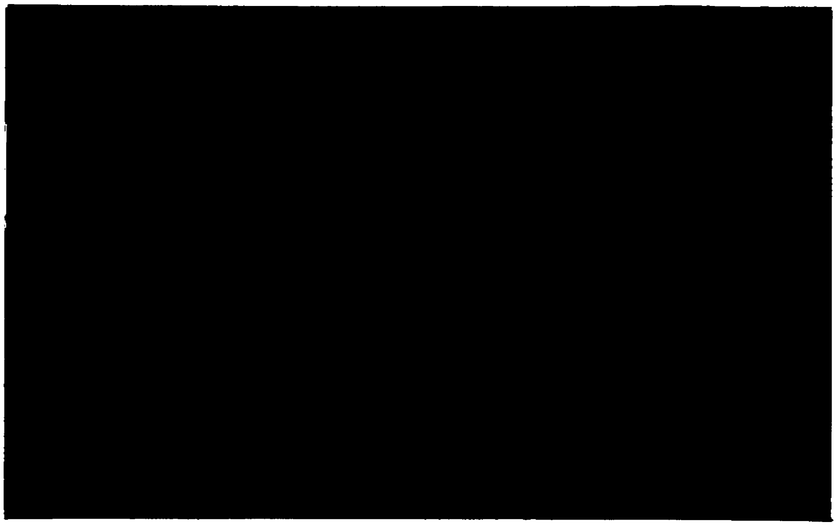

PESTICIDES, RE-ENTRY REGULATION AND FARMWORKER SAFETY

by

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Working Paper No. 90-20

January 1991

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Pesticides have become increasingly controversial in California and, indeed, throughout the nation. They have long been linked to ecological damage, including destruction of avian populations such as pelicans, bald eagles and many other species. Over the past few years, Environmental Protection Agency proposals for pesticide use restrictions to protect endangered species have been the subject of fierce debate. During the late 1980s, the focus of public attention shifted to the risks to human health and safety associated with pesticides. Concern over pesticides in groundwater has prompted intense scrutiny of groundwater quality. The Environmental Protection Agency and the U.S. Geological Survey have sampled a broad variety of wells at the national level, while the California State Department of Health Services continues to monitor drinking water wells at the state level. Concern over pesticide residues on foods erupted into public consciousness with the scare over Alar in apples and has remained intense. Recent surveys undertaken by the Food Marketing Institute indicate that food safety, especially pesticide residues, continues to be a major concern of consumers. Environmental groups in California have pushed for increasingly strict regulation of pesticides. The "Big Green" initiative currently on the ballot would phase out all food uses of pesticides classified as definite or probably human carcinogens or reproductive toxins, would set residue tolerances to ensure a cancer risk of no greater than one in a million and would specify a thousand-fold safety factor for all non-cancer health risks in setting residue tolerances on foods.

While foodborne residues appear to have the tightest hold on the public imagination at present, fieldworker and applicator safety issues are arguably the most pressing health and safety problems associated with pesticide use. This issue has also been the subject of intense discussion recently, as the Environmental Protection Agency worked to issue new regulations on farmworker safety. The United Farm Workers of America has made pesticide exposure the centerpiece of their organizing campaigns in recent years.

One of the most commonly used methods for protecting fieldworkers from exposure to toxic pesticides is to restrict entry into treated fields until enough of the residues degrade into nontoxic byproducts. During the growing season, workers may be forbidden to work in treated fields for a period of time known as a re-entry interval. Other regulations forbid harvest for a specific period of time after application of a pesticide; this time period, known as a pre-harvest interval, is set to protect harvest workers and also to allow foodborne residues to decay to an acceptably low level.

While the pesticides currently used are generally short-lived, the time required for residues to disappear completely is sufficiently long that re-entry intervals based on zero detectable residues would render farming impossible. Even relatively short re-entry intervals may create significant problems for scheduling farming operations. Since absolutely safety cannot reasonably be attained, policy makers confront a choice as to what level of safety to target. Answering this question requires evaluating tradeoffs between the risk of poisoning borne by workers and revenue losses suffered by growers caused by restrictions placed on harvesting. We analyzed these tradeoffs at the farm level, focusing on end-of-season use of an acutely toxic insecticide, i.e., setting an appropriate pre-harvest interval. We began with the pesticide use decisions faced by a grower. We then examined the effects of alternative pre-harvest intervals on the grower's profits and on the expected number of poisoning incidents. Finally, we consider the tradeoff between a grower's losses and the medical costs of poisoning cases and evaluate current policy in light of our findings.

Re-Entry Regulation and Pesticide Use

We analyzed the effects of setting a pre-harvest interval on patterns of pesticide use using a stylized model of crop growth for a fruit or vegetable crop, since these crops are affected the most heavily by re-entry regulation. There is typically an optimal time to harvest such crops. If the crop is harvested too early, yield or quality may be less than the maximum. If the harvest is delayed, revenue may be lower for a variety of reasons. There may be losses due to fruit drop. The crop may get overripe and thus suffer more spoilage or earn a lower price. The price of the crop may fall as the season progresses because of increases in supply as harvesting is initiated in more and more growing regions. Thus, whenever possible, the grower will harvest at the optimal time because profit will be at a maximum.

Suppose that a late-season insect infestation occurs. Assume that if the grower treats the infestation when it occurs, the crop will not be damaged. If the pesticide used has a pre-harvest interval that is sufficiently long, treating the pest infestation when it occurs, i.e., reactively, may force the grower to delay the harvest beyond the optimal time. On the other hand, if the farmer treats the crop in anticipation, the pesticide will have decayed somewhat by the time the pest arrives. It will be less effective, and the crop will suffer some damage. In other words, a pre-harvest interval will force the grower to deal with a tradeoff between losing money from delaying the harvest or from additional damage to the crop. If the value of the additional damage incurred by treating the crop a day earlier exceeds the revenue lost from delaying the harvest by a day, the grower should follow a reactive pesticide use strategy. If the revenue lost from delaying the harvest by a day exceeds the value of the additional damage incurred by treating the crop a day earlier, the grower should follow an anticipatory pesticide use strategy.

Anticipatory treatment with pesticides, sometimes termed prophylactic pesticide use, has been widely criticized, and many of the efforts involved in promoting integrated pest management have been devoted to fostering reactive pesticide use patterns. It has been hypothesized that prophylactic strategies are due to aversion to risk or inadequate training. Our analysis indicates that re-entry regulation or, for that matter, anything that interferes with scheduling operations, may also motivate prophylactic pesticide use.

Codling Moth Infestations in Apples

Empirically, we looked at the use of organophosphate insecticides to protect apple crops from infestations of codling moth larvae from moth flights shortly prior to harvest. The yield and quality of the apples were assumed to increase up until the maturity date, which is the earliest date at which the crops may be harvested. After the maturity date, yield and quality will remain constant for a considerable length of time, but the price the farmer receives will decline as time passes because the aggregate supply of apples will increase as producers in other regions harvest and market their crops. The price will continue to decline until it equals the price for processing uses. An analysis of the intraseasonal trends in farm-level apple prices in three major producing states (Washington, Michigan, California) indicated that the price of apples for fresh consumption declines exponentially at a rate of 0.24 percent per day as the season progresses.

A late-season flight of codling moths produces an infestation of larvae in the fruit, i.e., wormy apples. If the apples are treated with an organophosphate insecticide, the moths will be killed before they lay eggs and damage will be avoided. If the crop is left untreated, about 10 percent of the crop typically becomes infested and is therefore unsalable. These insecticides decay exponentially over time. Residue data from citrus and apples suggest that ethyl parathion, the insecticide considered in this study, decays at a rate of 80 percent per day. Treating the crop an additional day before the arrival of the pest thus increases survivorship and damage exponentially up to a maximum of 10 percent of the crop.

With these parameters, the additional damage incurred by treating the crop a day earlier far exceeds the revenue lost from delaying the harvest by a day; thus, the grower should follow a reactive pesticide use strategy.

Residue Poisoning From Parathion Exposure Among Apple Harvesters

The risk of clinical illness in workers as a result of exposure to residues of parathion applied to apples at various locations was modelled as a process with several stages. First, the pesticide is applied. Second, a decay process takes place in which some of the parathion is converted to the oxygen analog, paraoxon. Residue levels may be reduced by rainfall as well. Exposure takes place days or weeks after application when crews enter the field to harvest the crop. Clinical illness is usually due to a dermally absorbed dose of paraoxon, since after three days the parathion residues have practically disappeared.

The decay of parathion, its conversion to paraoxon and the decay of paraoxon were assumed to follow exponential processes, as suggested by data from citrus and apple orchards. The dermal dose was assumed to be proportional to the residue levels on the leaves and the time spent working in the field. The fractional inhibition of red blood cell cholinesterase was modeled as a function of dermal dose using a cumulative exponential distribution. The probability of clinical illness was modeled using a function of cholinesterase inhibition using a logistic distribution. The parameters of the decay model were estimated utilizing data obtained from citrus crops, but limited data on apples suggests a similar pattern. The reduction in residue levels from rainfall was assumed to be proportional to an exponential function of cumulative precipitation. The constant of proportionality relating dermal dose to residue levels and the parameters of the cholinesterase inhibition function were taken from experiments conducted by the School of Public Health of the University of California at Berkeley. An eight hour workday was taken as the time of exposure. Two types of clinical illness were considered: mild cases and severe ones. The parameters of both models were derived from clinical experience with farmworker poisoning incidents in California.

Tradeoffs Between Grower Revenue and Worker Poisonings

We used the models presented in the two preceding sections to evaluate the impact of re-entry regulations on apple growers' revenues and apple harvesters' safety in three major apple-producing states: Washington, Michigan and California. We assumed that a flight of coddling moths arrived four days before the optimal harvest date, that parathion was applied at a rate of 2.0 pounds of active ingredient per acre, and that, as is typical, the crop produced on a 50-acre block would be harvested in one day by a crew of 500 (10 workers per acre). Losses in growers' revenues were compared to the risk of severe and mild poisoning to each individual worker. Rainfall levels of 0, 0.5 and 1.5 inches during the re-entry period were used to take into account the differences in weather conditions encountered in the different regions under investigation: California receives virtually no rainfall during the harvest period, Washington receives an average of 0.5 inches and Michigan receives an average of 1.5 inches under normal conditions. Orchards in all three states were assumed to have yields of 10 tons/acre. The price of apples in California was taken as $300 per ton, corresponding to a maximum revenue of $150,000 for a 50-acre block. Regression analysis suggested that price levels in Michigan and Washington were about 17 percent and 32 percent above that of California. Since Michigan harvests about 4 weeks after California and Washington, 2 weeks, the maximum price in these states should be 9.8 percent and 28.2 percent higher than California, respectively, giving estimates of about $165,000 per 50-acre block in Michigan and $192,000 per 50-acre block in Washington.

Table 1 shows the expected numbers of severe and mild parathion poisoning cases plus the fraction of revenue lost due to harvest delays. The risk of poisoning is quite serious. With a pre-harvest interval of four days or less, there will be an average of 2.5 severe cases and 43 mild cases under California conditions, 1.6 severe and 29 mild cases under Washington conditions and 0.8 severe and 15 mild cases under Michigan conditions. (At any given time, there will be almost 19 times as many mild as severe cases.) Each additional day entry is prohibited reduces the number of mild and severe cases by about 13 percent. Each additional inch of rainfall reduces the total number of expected cases by about 75 percent. Even so, the risk of poisoning remains rather high for a lengthy period of time: If re-entry is prohibited for as much as 2 weeks, there will still be an average of one severe poisoning incident for roughly every 2 50-acre blocks harvested in California, one severe incident for every 3 50-acre blocks harvested in Washington and one severe incident for every 4 50-acre blocks harvested in Michigan.

At the same time, the losses imposed by re-entry regulation can be considerable. Each additional day's delay in harvesting reduces total revenue by about 0.24 percent, corresponding to $360 per 50-acre block in California, $460 per 50-acre block in Washington and $395 per 50-acre block in Michigan. Total harvesting labor costs, by contrast, amount to about $425 per 50-acre block in Washington. A pre-harvest interval of 2 weeks would result in a revenue loss on the order of 2.5 percent; since profit margins in apple production range from 3 to 10 percent, such a loss would represent a sizable fraction of net income.

Setting an Appropriate Pre-Harvest Interval

According to economic theory, the optimal pre-harvest interval is found by equating the marginal cost of additional harvest delays in terms of revenue lost with the marginal benefits associated with reductions in the number of poisoning incidents. For illustrative purposes, we calculated these optimal pre-harvest intervals under the conservative assumptions that benefits were restricted to average avoided costs, that is, to the average costs of hospitalization plus average lost wages. We ignored other costs such as long-term losses due to chronic neurotoxic effects, the value of pain and suffering and the costs imposed on consumers by the presence of residues remaining at the time of ingestion.

A severe parathion poisoning case typically requires 3 days of hospitalization, with the first day spent in intensive care, followed by two weeks of recovery, i.e., lost work time. Assuming average costs of $1200 per day for intensive care and $500 per day for a standard hospital bed implies total hospitalization costs of $2200. Assuming an average wage of $10 per hour for an 8-hour day implies total lost wages of $800, for a total cost of $3000 per severe case. A typical mild case requires no hospitalization, a medical care cost of about $40 per case and 2 days of lost work time, for a total cost of $200 per case.

Figure 1 shows the marginal costs and benefits from severe and all poisoning cases associated with different pre-harvest intervals in California. According to the conservative criteria we used, the optimal pre-harvest interval for California is 15 days. Current EPA regulations require 14 days regardless of rainfall conditions for applications of parathion on apples such as the one considered here. Interestingly, the current pre-harvest interval is quite close to the optimal one calculated here for California.

Rainfall, and thus residue levels, are greater in Washington and Michigan, and the optimal pre-harvest intervals are correspondingly shorter: 12 days in Washington and 9 days in Michigan. Thus, as long as local rainfall can be monitored effectively, the same levels of safety implicit in the 14-day pre-harvest interval can be achieved at lower cost by making the pre-harvest interval dependent on rainfall. For example, lowering the pre-harvest interval from 14 to 9 days when there have been 2 inches of rain would cut the losses suffered by Michigan apple growers by $1944 per 50-acre block, almost 50 percent, while lowering it from 14 days to 12 days when there have been 0.5 inches of rain would cut the losses suffered by Washington growers by $904 per 50-acre block, almost 20 percent.

Conclusion

Pesticide regulation is becoming increasingly complex. Demands for protecting public health and the environment are growing, and greater protection can be achieved only at heightened cost. Society is thus confronted with increasingly difficult choices about pesticides. Our work shows that careful analysis integrating economics, agronomy, and the environmental and biomedical sciences can assist this decision process considerably. Modeling farm-level pesticide use decisions helped further understanding of how growers operate. Integrating agronomic and environmental health models into an economic context illustrated the magnitudes of the tradeoffs involved in setting policy and demonstrated the potential for improving policy performance by pegging re-entry interval length to rainfall. Clearly, further research integrating farm-level pesticide use decisions, industry-level market operations and the environmental and human health effects of pesticide exposures can help make decisions about pesticide use more informed and more efficient.

TABLE 1

HEALTH RISKS AND REVENUE LOSSES UNDER ALTERNATIVE RE-ENTRY INTERVALS

Re-entry interval (days)	Expected number of severe poisonings			Expected number of mild poisonings			Fraction of revenue lost
	California	Washington	Michigan	California	Washington	Michigan	
0-4	2.46050	1.63800	0.81650	42.6950	29.2650	15.0000	0
5	1.95600	1.33250	0.69100	34.5800	24.0600	12.7600	0.002397
6	1.57650	1.09650	0.59100	28.2250	19.9600	10.9500	0.004788
7	1.28550	0.91250	0.51050	23.2450	16.7150	9.4850	0.007174
8	1.06000	0.76750	0.44520	19.3150	14.1300	8.2900	0.009554
9	0.88350	0.65250	0.39155	16.2050	12.0600	7.3050	0.011928
10	0.74500	0.56000	0.34725	13.7200	10.3850	6.4900	0.014296
11	0.63400	0.48540	0.31045	11.7300	9.0250	5.8100	0.016659
12	0.54550	0.42450	0.27965	10.1200	7.9100	5.2350	0.019016
13	0.47340	0.37450	0.25370	8.8050	6.9900	4.7555	0.021368
14	0.41470	0.33315	0.23165	7.7300	6.2250	4.3460	0.023714
15	0.36960	0.29865	0.21290	6.8400	5.5900	3.9965	0.026054
16	0.32645	0.26970	0.19680	6.1050	5.0550	3.6965	0.028389
17	0.29305	0.24530	0.18295	5.4850	4.5995	3.4380	0.030718
18	0.26500	0.22450	0.17095	4.9515	4.2130	3.2135	0.033041
19	0.24125	0.20680	0.16000	4.5245	3.8825	3.0185	0.035359
20	0.22110	0.19155	0.15135	4.1495	3.5985	2.8480	0.037672
21	0.20385	0.17840	0.14335	3.8280	3.3530	2.6980	0.039978
22	0.18900	0.16700	0.13635	3.5515	3.1400	2.5660	0.042280
23	0.17620	0.15705	0.13010	3.3120	2.9540	2.4495	0.044575
24	0.16510	0.14835	0.12460	3.1040	2.7915	2.3465	0.046866
25	0.15540	0.14070	0.11970	2.9230	2.6485	2.2545	0.049150
26	0.14690	0.13400	0.11535	2.7640	2.5225	2.1725	0.051430
27	0.13945	0.12805	0.11145	2.6245	2.4110	2.0995	0.053704
28	0.12835	0.12275	0.10795	2.5010	2.3120	2.0340	0.055972

Figure 1
Optimal Re-Entry Interval in California