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Incentives for Protecting Farm Workers from Pesticides

John U. Davis, Julie A. Caswell, and Carolyn R. Harper

Three regulatory incentive systems that may induce farmers to protect farmworkers from pesticide-related harm are modeled: *ex post* regulation via tort liability and workers' compensation systems, respectively, and *ex ante* regulation (fines) by administrative agencies. An empirical application examines the farmer's decision whether to comply with required precautions as well as penalties for noncompliance. Results indicate tort liability and administrative agency regulation, as practiced, provide relatively insignificant incentives, while a workers' compensation system, if fully experience-rated, may offer a more effective incentive. Nevertheless, penalties in all cases may be too small overall to have much influence on farmers' compliance decisions.

Key words: farmworkers, pesticide harms, regulatory incentives, workers' compensation.

Agricultural workers are generally exposed to more dangerous doses of pesticides in the workplace than consumers are in their intake of food (Ames, Magaw, and Gold, US EPA). The U.S. Environmental Protection Agency (EPA) has identified worker exposure to chemicals in agriculture as a major source of human health risk. Data supporting this concern are also more robust than those associated with human risk resulting from pesticide residues on food (EPA). Nevertheless, only limited research has been done on farmworker safety issues. Research on regulatory incentive systems that may induce farmers to protect farmworkers from pesticide-related harm is particularly sparse.

The goal of policy makers is to establish regulatory incentives that induce farmers to take precautions against pesticide risks. Previous work, notably that of Johnson and Ulen (1986, 1988) and Kolstad, Ulen, and Johnson, has examined in other contexts the joint use of *ex ante* and *ex post* incentives provided by administrative agency regulation and the tort liability system respectively. Johnson and Ulen investigated such government-based incentives to generators of hazardous waste to protect community health. This paper is the first to apply such a model to the issue of farmworker safety. It is also the first

application of workers' compensation in this context.

The analysis focuses on two principal questions. First, the farmer has a choice between complying, partially complying, or not complying with regulations mandating protection of farmworkers from pesticide-related harm. Given these alternatives, what course of action would the risk-neutral, cost-minimizing farmer choose? Second, comparing the incentives provided by different combinations of government regulatory efforts, which systems appear to be most effective from the policy maker's standpoint in inducing protective behavior?

The Farmer's Optimization Problem

Three incentive structures are considered, two of which are *ex post* and one *ex ante*. Kolstad, Ulen, and Johnson define *ex ante* policies as those that affect an activity before an externality is generated. They define an *ex post* policy as one that regulates an externality only after it has been generated and harm has occurred. The first *ex post* incentive considered here is a negligence tort liability standard. The second is experience-rated workers' compensation.¹ The single *ex ante*

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¹ It could be argued that workers' compensation is a form of *ex ante* regulation because premiums are paid before any harm occurs. We consider it to be an *ex post* regulatory mechanism because experience rating of premiums is based on the firm's past safety record.

structure considered is administrative agency regulation. We introduce these structures individually and then examine the farmer's complete decision problem under the joint use of all three incentives.

Ex Post Incentive: Negligence Tort Standard

Tort liability law is one means of ensuring that those engaged in economic activities do not generate external costs. We consider negligence rather than strict liability, because precaution against pesticide-related harms is normally bilateral on the part of the farmer (the potential injurer) and the farmworkers (the potential victims). For example, while farmers may provide protective clothing, farmworkers bear part of the responsibility for its proper use. There are several sources of uncertainty in applying a negligence standard: (i) determination of the proximate cause of injury; (ii) definition of the legal standard of care (adequate precaution); (iii) monitoring of compliance with the standard; and (iv) diligence of enforcement (likelihood of a successful lawsuit). We focus primarily on the implications of the last source of uncertainty.

We assume that if the legal standard of care is not met, a farmer who allows workers to suffer pesticide-related harms will be liable for perfect compensation, which is the monetary amount that leaves the injured worker indifferent between having been harmed and never having been harmed at all. The following notation is used by Kolstad, Ulen, and Johnson: let x be the level of the farmer's precaution in protecting farmworkers against such harms. In the absence of any liability rule (or with the existence of a no liability rule) and any significant costs for replacing harmed workers, the rational decision maker is assumed to minimize costs by setting x equal to zero. Establishment of a negligence rule imposes a legal standard of care, i.e., an obligation to take a specified amount of precaution, x^L .² A decision maker who meets or exceeds the court's standard (i.e., chooses $x \geq x^L$) escapes liability. One who does not meet the standard ($x < x^L$) is liable for compensation.

The decision maker chooses the level of precaution that minimizes expected costs. The cost

of precaution is represented by $w(x)$. Precaution costs are increasing over the relevant region ($w'(x) > 0$). Expected harm to farmworkers is given by $p(x)A(x)$, where $A(x)$ represents the degree of harm from pesticide exposure, if it occurs, and $p(x)$ represents the probability that harm will occur. Expected harm is decreasing and convex over the relevant region, implying that each increment of precaution results in a smaller reduction in expected harm. The expected total social costs of the harm are determined by adding the precaution costs and the expected costs of harm ($w(x) + p(x)A(x)$).

Policy makers seek to establish a policy that induces farmers to act so as to minimize total social costs. The farmer simply acts to minimize private costs, which include precaution costs and any expected tort liability settlements resulting from a failure to meet the legal standard of care. Her decision criterion is

$$(1) \quad \min C(x) = w(x) + p(x)A(x)e_L(x)$$

where $A(x)e_L(x)$ is the injurer's liability conditional on harm occurring, with $A(x)$ representing the degree of harm and $e_L(x)$ the probability of being found negligent. Under perfect compensation, the harm term, $A(x)$, reflects both harm to an injured worker and the tort liability award or settlement required of the farmer if she were held negligent.

Ex Post Incentive: Workers' Compensation

Workers' compensation is a state-run social insurance program for workers injured "out of and in the course of employment" (Viscusi, p. 70). It is another *ex post* incentive structure that differs from tort liability, in that benefits are awarded to injured workers regardless of fault.³ Under many systems, a participating firm pays a fixed premium whether or not harm occurs. Fixed premium structures provide no incentive for increased precaution. However, experience-rated compensation systems are indexed so that firms pay according to their safety records.

The cost function for a farmer subject to an increase in the experience-rated premium as a result of injuries occurring can be modeled as

$$(2) \quad C(x) = w(x) + q(x)\Delta P(x)e_{wc}$$

where $q(x)$ represents the probability that harm

² The court is not bound to find negligence only with respect to an existing statutory or administrative standard. It could award damages if it found that a farmer knew that a statutory standard would not provide adequate protection to workers yet took no greater precaution.

³ This raises concerns about a lack of incentives for workers to take actions to protect themselves from harm.

will occur to one or more workers entering the field on a given day, and e_{WC} is the likelihood that an injured worker will file a workers' compensation claim.⁴ Falling below the legal standard will, over time, result in injuries and higher premiums. The premium, $P(x)$, therefore increases with the frequency and severity of worker injuries. The incentive from an experience-rated workers' compensation system lies in the potential change in premium, $\Delta P(x)$. The probability of any harm occurring, $q(x)$, is multiplied by the positive change in premium because the premium increases only if a worker is harmed. The probability of harm to one or more workers is used here, because we assume that premium shifts depend on the number of accidents, not the number of individuals affected. (Normally, only a few discrete premium levels are employed.)

Injured farmworkers may choose not to file a claim because of a lack of awareness of the workers' compensation system or unwillingness to accept a reduced income (compensation benefits normally do not fully compensate lost wages). The probability, e_{WC} , that an injured farmworker will file a workers' compensation claim is thus less than one.

Ex Ante Regulation: Administrative Agency Fine

The *ex ante* incentive considered here is a fine for noncompliance with safety regulations. The farmer wishes to minimize total costs, which consist of precaution costs plus the expected cost of any penalties for noncompliance with the statutory or administrative standard of care, x^S . A farmer facing the possibility of a fine wishes to

$$(3) \quad \min C(x) = w(x) + q(x)F(x)e_F(x)$$

$$(4) \quad \text{where } F(x) = \begin{cases} > 0, & \text{for } x < x^S \\ = 0, & \text{for } x \geq x^S \end{cases}$$

$F(x)$ is the expected noncompliance cost (i.e., fine), and $e_F(x)$ is the probability of being found in violation of the regulation. The probability that harm will occur to one or more workers on a given day, $q(x)$, is included because in practice fines are not levied unless harm occurs. The fine is a function of the level of precaution rather than fixed. This is consistent with Jones' finding

that, while "the majority of penalty systems historically has been (and still is) lump-sum fines, recent statutes and the associated administrative rules for the most part involve penalties that are increasing with severity" (p. 79).

Combined Effects of Ex Ante and Ex Post Incentives

The expected total cost function for a farmer facing all three incentive systems is

$$E(TC) = w(x) + p(x)A(x)e_L(x) + q(x)\Delta P(x)e_{WC} + q(x)F(x)e_F(x)$$

where, to summarize,

- x = Farmer's chosen level of precaution
- $w(x)$ = Precaution cost
- $p(x)$ = Probability of harm to a single worker
- $A(x)$ = Harm from pesticide exposure
- $e_L(x)$ = Probability of a farmer being required to pay a tort penalty
- $q(x)$ = Probability of harm to one or more workers
- $\Delta P(x)$ = Change in workers' compensation premium
- e_{WC} = Probability of an injured farmworker filing a workers' compensation claim
- $F(x)$ = Administrative agency penalty
- $e_F(x)$ = Diligence of administrative agency enforcement.

In principle, the farmer may face any or all three incentive systems included in this expression. In practice, there are significant variations among incentive systems across states. This is because administrative agency regulation begins at the federal level but is enforced by the states, while workers' compensation and tort liability systems are based at the state or local level.

Application: Massachusetts Apple Production

The safety incentive model is applied to the incentives facing Massachusetts apple growers. Specifically, we consider compliance with the protective clothing requirements for workers entering fields during the EPA-mandated no reentry interval for the pesticide Guthion. Numerous difficulties are encountered in quantifying the complex incentive system modeled in the pre-

⁴ The opposite case, where the experience-rated premium decreases as a result of a good safety record, is not addressed here.

vious section. Simplifying assumptions are made throughout in order to facilitate this task.

The hypothetical cost-minimizing farmer operates a 75-acre farm with a corresponding annual payroll of \$68,949.45. This is the mean payroll in the lowest payroll class that is experience-rated by the Workers' Compensation Rating and Inspection Bureau of Massachusetts. The size of operation determines the farmer's workers' compensation premium and the number of workers in the field during a given period.

The principal apple orchard activity occurring in the northeast during July and August, when Guthion is applied, is summer pruning. This activity requires about 25 labor hours per mature acre, so a 75-acre orchard requires approximately 1,875 hours. Summer pruning is generally performed from July 15 to August 31, a period of about 41 work days given a six-day work week. A 75-acre farm thus requires an average of 4.573 employees per day for a 10-hour work day (Autio). The Guthion 35% WP label states that workers must "not enter treated areas for 24 hours after application unless protective clothing is worn, as described in the product labeling." The mandated clothing is as follows: "wear . . . a protective suit of one or two pieces that covers all parts of the body except the head, hands, and feet. Wear chemical resistant gloves and chemical resistant shoes, shoe coverings, or boots" (Mobay Corporation).

If summer pruning takes place during the reentry interval, the precaution cost per-day to fully satisfy the label requirements is \$2.38 per worker; this is the total per-day cost of a coverall, latex gloves, and rubber boots.⁵ The total average precaution cost is thus \$10.88 (for 4.573 workers) to comply fully and zero otherwise. Throughout this example, the farmer either takes full precaution or no precaution, so that the level of precaution, x , equals x^S , the administrative standard, or zero (table 1).⁶

Tort Liability Exposure

Under a negligence tort standard, a farmer taking reasonable precaution to minimize the probability of harm to farmworkers will not be held liable for any harm. In practice, the tort system is better suited to handle harms connected with "discrete, easily traceable causes" (Viscusi, p.

⁵ Per day costs are calculated by dividing the retail price of the protective clothing by its usable life in days. For example, a Tyvek regular-duty coverall has a retail price of \$4.05 and a manufacturer's recommended usable life of five days for a per day cost of \$0.81.

⁶ Partial compliance strategies are also possible. Compared to full compliance, precaution costs decrease while regulatory costs increase. The opposite is the case when partial is compared to no compliance. Given the lack of data on the relationship between degree of compliance and size of regulatory penalties, we did not attempt to quantify any partial compliance strategies.

Table 1. Data Summary

Variable	Mathematical expression	Values
<i>Precaution cost</i>	$w(x)$	\$10.88 0.00
<i>Probability of harm</i>	$p(x)$	0.25
<i>Harm per worker</i>		\$2,044.12 1,000.00 571.43
<i>Harm per average number of workers (4.573)</i>	$A(x)$	\$9,347.76 4,573.00 2,613.15
<i>Likelihood of tort settlement</i>	$e_L(x)$	0.008300 0.000830 0.000083
<i>Probability of any harm</i>	$q(x)$	0.7317
<i>Change in workers' compensation premium</i>	$\Delta P(x)$	\$526.00
<i>Probability of worker filing workers' compensation claim</i>	e_{WC}	0.20
<i>Administrative agency fine</i>	$F(x)$	\$7,000.00 4,250.00 1,500.00
<i>Diligence of enforcement</i>	$e_F(x)$	0.06225 0.00623 0.00062

70). Thus our data pertain to cases of acute injury arising from pesticide exposure. We assume that the court's standard of care corresponds to the pesticide label requirements, so that $x^S = x^L$. Expected harm levels are determined by multiplying representative tort liability settlements by a probability of harm, defined as the probability that a farmworker entering a field without protective clothing during the reentry interval will suffer pesticide-related injury.

Factors such as time elapsed since spraying, dosage of pesticide sprayed, type of work being performed, and the innate susceptibility of individuals to poisoning determine the probability that a given worker falls ill as a result of pesticide exposure. Very little data exist on the proportion of workers harmed who enter a Guthion-treated field within the reentry interval. In one recorded California case involving the spraying of Guthion on peaches, 6 of 24 workers fell ill after entering an orchard recently sprayed with Guthion (Dervin). In the absence of other evidence, we assume here that the probability of harm ($p(x)$) is 25% for each exposed worker (table 1).

No precedents could be found for public tort liability awards or settlements granted in Massachusetts for pesticide-related harm to farmworkers. The few precedents that exist nationwide, all involving acute illness, are used to estimate the potential cost of a lawsuit for farmers who fail to meet standards of precaution. Total settlement awards are divided by the number of workers involved to yield an estimate of per worker harm. For a low estimate, we use the \$4,000 settlement in the *Chacon v. Miller* case (No. 84-4017, C.D. Ill. Sept. 1986), where seven farmworkers were involved for a calculated harm per worker of \$571.43 (*Migrant Legal Action Program* 1987). For a middle-range estimate, we use the \$5,000 settlement in the *Ramirez v. Adamucci* case (No. 85-2374, D.N.J. 1986), where five workers were involved for a per worker harm of \$1,000 (*Migrant Legal Action Program* 1987). For a high estimate, we use the *Flores v. Mobay* settlement (Civ. No. 84-20025, N.D. Cal., Sept. 15, 1983). Because that settlement required four defendants, including the farmer, to pay a total of \$278,000 (*Migrant Legal Action Program* 1985), we assess the farmer's total liability at \$69,500. There were 34 injured farmworkers bringing the per worker award to \$2,044.12 (table 1).

When these values are multiplied by $p(x)$, the probability of harm to each farmworker, and by

4.573, the average number of workers exposed each day, the products represent a range of values for expected harm to the work crew. These values are multiplied by $e_L(x)$, the probability that a farmer is found negligent, to obtain the expected tort liability cost. Quantifying $e_L(x)$ is difficult. As few as 1% of all pesticide-related injuries in agriculture are reported (Coye, p. 364). It is widely believed that few farmers who could be held liable for pesticide-related harms are actually brought to court, and even fewer are found liable for damages or choose to settle. However, no quantitative estimates of this proportion are available. Nor are there sufficient cases to judge whether differences exist between settlements awarded by judges and by juries.

A range of three probabilities is used to estimate the likelihood that a farmer is held liable or chooses to make a cash settlement with plaintiffs out of court. Each probability is the product of two terms—the probability the farmer will be sued once harm occurs, and the probability he will be forced to pay damages or a settlement once a suit is brought:

$$e_L(x) = p(\text{suit}|\text{harm}) p(\text{payment}|\text{suit}).$$

According to sources familiar with farmworker tort liability suits, chances of a cash settlement or award are high when a suit is brought. The principal barrier to farmworker compensation is the very low probability that a suit will be brought (Lightstone). No estimates of this probability are available, however. Based on conversations with legal professionals at the Migrant Legal Action Fund and the California Rural Legal Assistance Fund, we estimate the probability of payment given a suit at 83%. This value is in turn multiplied by a range of values that reflect the low but unknown probability that a suit will be brought: 0.01, 0.001, and 0.0001. Overall, the range of probabilities that a farmer will pay anything for pesticide-related harms to farmworkers are 0.0083, 0.00083, and 0.000083 (table 1).

Workers' Compensation

The farmer's expected change in workers' compensation costs is $q(x)\Delta P(x)e_{WC}$, where $q(x)$ is the probability of any harm occurring (one or more workers being injured), $\Delta P(x)$ is the change in the farmer's experience-rated premium resulting from a successful claim, and e_{WC} is the probability of a farmworker filing a claim. It is assumed that a filed claim will be successful, because this is usually the case.

The annual payroll assumed here is at approximately the eightieth percentile among Massachusetts orchards. Depending on his recent loss experience (the number and magnitude of claims), such a farmer pays one of three annual premiums: \$6,718, \$5,666, or \$4,567 (Liu). We assume the farmer is initially paying the medium level premium, but would be bumped to the upper premium if the insurer were forced to pay more than one additional worker claim. This closely models the actual Massachusetts workers' compensation system. The farmer is concerned with the per incident increase in his premium of \$526.

The probability that one or more workers is harmed, $q(x)$, is one minus the probability that no one is hurt. Assuming that the probability of harm for each worker is independent and that the average number of workers (4.573) is in the orchard,

$$q(x) = 1 - [1 - p(x)]^{4.573}.$$

With $p(x)$ set at 0.25, $q(x)$ equals 0.73 (table 1).

We assume that no uncertainty exists in the granting of workers' compensation benefits but that uncertainty does exist over whether an injured farmworker will file a claim. According to Wilk (1986), "even in states where workers' compensation covers agricultural workers, many farmworkers do not understand that medical expenses and lost wages due to illness or injury are due them" (p. 109). Other factors may deter an injured farmworker from filing a claim; for example, failure to link the illness symptoms to pesticide exposure, fear of retaliation by the employer, and preferring to work rather than accept the lower compensation associated with temporary disability (Ellenberger). One expert on farmworker health suggests that the percentage of farmworkers filing claims as a result of injury, e_{wc} , is significantly below 50% (Wilk 1991). We use a rough estimate of 20% for this probability (table 1).

Administrative Agency Regulation

The EPA, which is charged with administering and enforcing the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), delegates much of the enforcement to state governments. According to the Enforcement Division of the Pesticide Bureau, Massachusetts Department of Food and Agriculture, a farmer found violating laws regulating the use of pesticides will normally first

be warned. If a letter or administrative order fails to stop the violation, the Department of Food and Agriculture can either take action to suspend the farmer's license to apply pesticides or pursue civil or criminal prosecution. In Massachusetts, legal cases involving defendants whose actions resulted in harm to farmworkers are extremely rare, but examples exist of firms being prosecuted for violating administrative orders in other ways. We assume the penalties for these violations are roughly equivalent to those that would be assessed when farmworkers are harmed. These fines have ranged from \$1,500 to \$7,000 in criminal cases and have gone as high as \$30,000 in civil cases. Because the \$30,000 fine was levied under exceptional circumstances, \$7,000 is used as a high estimate of potential administrative agency fines, and \$1,500 as a low estimate. The mean of these two potential penalties, \$4,250, serves as a middle range estimate (table 1).

We make the following assumptions about the administrative agency component of the model: First, fines vary according to the egregiousness of the violation, so $F'(x) < 0$ for $x < x^s$. Second, if the farmer meets or exceeds the legal standard, no fine is levied. Third, because farmers are highly unlikely to be caught violating a mandated reentry interval unless farmworkers are harmed (Wilk 1991), we assume that a fine for a violation is levied only if harm occurs. The probability of harm occurring to one or more workers is $q(x)$, as before. Fourth, according to experts in litigation on behalf of farmworkers, administrative agency fines against farmers whose misuse of pesticides results in harm are 5–10 times more common than tort liability awards or settlements (*Migrant Legal Action Program* 1991). We specify that fines are 7.5 times more probable than settlements or awards ($e_F = 7.5e_L$). This yields administrative agency enforcement probabilities of 0.06225, 0.00623, and 0.00062 (table 1).

Comparative Compliance Incentives Under Different Regulatory Regimes

The influence on farmer decision making of interactions among these incentive systems can now be examined by comparing the cost of precaution that fully meets the legally-mandated standard of care with the expected cost of noncompliance. Because precise data for many variables do not exist, the value ranges employed represent informed approximations and results are

simulations of the actual incentives provided by different incentive combinations. The inquiry is centered on two principal questions. First, given existing incentive structures, what course of action can farmers be expected to take? Second, from a policy maker's viewpoint, what regulatory structures are most effective in eliciting farmer compliance with worker protection regulations?

We examine three combinations of incentives that reflect existing state systems. Under case 1, a farmer is subject to all three types of incentives: i.e., may be held negligent in a tort liability suit and required to pay damages, must pay an experience-rated workers' compensation premium, and is subject to an administrative agency fine. In case 2, the workers' compensation premium exempts the farmer from any exposure to tort liability damages, but he still may be fined. This case reflects the fact that in many states workers covered by workers' compensation may not sue employers for work-related injuries. Case 3 is the opposite situation, where the farmer is not covered by workers' compensation but may be held liable for tort damages and is subject to fines. A spreadsheet program facilitated the examination of combinations of incentive systems for the penalty values and probabilities shown in table 1. Combinations of these values generated 64 cost scenarios (one compliance and 63 noncompliance) that permit a sensitivity analysis examining a wide range of regulatory policies.⁷

Scenarios

Case 2 is the most accurate reflection of the current incentive system in Massachusetts, because the required workers' compensation coverage normally precludes workers from seeking recourse through tort liability suits. Nevertheless, farmworkers who are insured under workers' compensation can sue if they can prove an intentional tort. Furthermore, a farmer could illegally choose not to be covered under workers' compensation (thus restoring the right of workers to resort to tort liability). Thus, cases 1 and 3 also have relevance in Massachusetts. All three cases are applicable in other states as well.

Expected costs under all noncompliance scenarios are compared with the precaution costs

of providing adequate protective clothing. Under the assumption that taking the EPA-mandated level of precaution protects the farmer from both negligence awards and administrative fines, the farmer's compliance cost per work day is \$10.88, the cost of protective clothing for an average 4.573 workers.

Ranges for the expected total cost of noncompliance for cases 1, 2, and 3 are shown in table 2. The expected total costs are calculated using in turn the low, middle, and high values of the relevant variables. The highest expected total noncompliance cost occurs when the farmer is subject to all three forms of regulation (case 1) at the highest penalties and probabilities. In this case, the farmer's expected total noncompliance cost is \$415.21. The lowest expected total noncompliance cost occurs in case 3, where the farmer faces tort liability and administrative agency fines but does not pay a workers' compensation premium. Using the lowest penalties and probabilities, the expected noncompliance cost is only \$0.73.

The risk-neutral grower will comply with regulations whenever the expected noncompliance cost exceeds \$10.88. Of the nine scenarios shown in table 2, only the low range scenario for case 3 results in the farmer choosing not to comply with regulations. These examples are representative of the full range of 63 noncompliance scenarios, 12 of which have expected costs less than \$10.88. All occur under case 3, where the farmer faces only tort liability and administrative agency regulation. The farmer chooses to disregard safety regulations only when not subject to an experience-rated workers' compensation premium. The lowest expected total noncompliance cost among case 1 and 2 scenarios is \$77.66, over seven times the compliance cost. Thus farmers covered under experience-rated workers' compensation would always comply with safety regulations.

Implications of Preliminary Results

These results suggest that farmers would normally choose to comply with reentry regulations. This runs counter to the common assertion that existing regulations give inadequate incentives for farmworker protection (see, for example, Dullinger). Possible reasons for this discrepancy are, first, that many states do not require workers' compensation coverage for farmworkers and thus do not have the strong incentives that result from Massachusetts' expe-

⁷ The complete results for all 64 scenarios can be obtained from the authors.

Table 2. Ranges of Expected Total Noncompliance Costs for Cases 1, 2, and 3

Variable	Low	Data values medium	High
Case 1 (Tort liability, Workers' compensation, and administrative agency regulation)			
$A(x)$	\$2613.15	\$4573.00	\$9347.76
$e_L(x)$	0.000083	0.00083	0.0083
$\Delta P(x)$	\$526.00	\$526.00	\$526.00
$F(x)$	\$1500.00	\$4250.00	\$7000.00
$e_F(x)$	0.00062	0.00623	0.06225
$E(TC)$	\$77.71	\$97.30	\$415.21
Case 2 (Workers' compensation and administrative agency regulation; no tort liability)			
$\Delta P(x)$	\$526.00	\$526.00	\$526.00
$F(x)$	\$1500.00	\$4250.00	\$7000.00
$e_F(x)$	0.00062	0.00623	0.06225
$E(TC)$	\$77.66	\$96.35	\$395.81
Case 3 (Tort liability and administrative agency regulation; no workers' compensation)			
$A(x)$	\$2613.15	\$4573.00	\$9347.76
$e_L(x)$	0.000083	0.00083	0.0083
$F(x)$	\$1500.00	\$4250.00	\$7000.00
$e_F(x)$	0.00062	0.00623	0.06225
$E(TC)$	\$0.73	\$20.32	\$338.23

rience-rated system. Second, precaution costs considered are incomplete. Protective clothing may be considered inconvenient, for example, or might reduce worker productivity. If this were the case, the decision "threshold" would be higher, possibly resulting in a greater proportion of the scenarios having noncompliance as the rational choice.

Third, farmers may be more likely to violate reentry intervals that are longer than the one day used in this application. Compliance costs are likely to increase significantly with longer intervals, either in the form of protective clothing cost or in such costs as crop loss. For example, while the EPA-mandated and Massachusetts reentry interval for Guthion sprayed on apples is 24 hours, California law requires a 14-day interval (Wilk 1986, p. 63). The longer interval would provide far greater incentives to not comply. In addition, compliance could take forms other than use of protective clothing when entering the field. With a short interval, for example, little opportunity cost may be involved in waiting it out, which would not be the case with longer intervals. These latter two situations could involve considerably higher precaution costs and, *ceteris paribus*, greater incentives to not comply. On the other hand, it should be noted that noncompliance costs may exist outside those

modeled here, such as costs of replacing injured workers.

Relative Effectiveness of Incentive Systems

Comparison of expected total noncompliance costs for cases 1 and 2 reveals very similar costs (table 2). For example, using medium data values, the elements of the expected cost function are the same except that case 2 does not include expected tort liability penalties. Expected total cost is \$97.30 in case 1 and \$96.35 in case 2, a difference of only \$0.95. Only at the highest likelihood of settlement and harm per farm does tort liability offer much additional incentive to protect farmworkers beyond that provided by workers' compensation and administrative agency regulation.

This point is further explored in table 3, which shows the contribution to expected total noncompliance cost of each incentive system in case 1, where all three systems are in effect. Using high data values, for example, expected total noncompliance cost is \$415.21. Of this, \$318.84 is the expected administrative agency fine, \$76.97 is the expected increase in the workers' compensation premium, and \$19.40 is the expected tort liability penalty. Thus administrative agency

Table 3. Contribution of Different Incentive Systems to E(TC) of Noncompliance for Case 1

	Low	Data values medium	High
		<i>Dollar contribution</i>	
Tort liability	\$0.05	\$0.95	\$19.40
Workers' compensation	\$76.97	\$76.97	\$76.97
Administrative agency	\$0.68	\$19.37	\$318.84
Total	\$77.71	\$97.30	\$415.21

finer contribute the most to expected noncompliance costs in this case. Because the expected increase in the workers' compensation premium remains the same across scenarios (the associated probabilities do not change), it is more important in scenarios with lower probabilities of tort liability or administrative agency penalties. For example, using low data values, the expected total noncompliance cost is \$77.71, of which \$76.97 is associated with workers' compensation, \$0.05 with tort liability, and \$0.68 with administrative agency fines. Thus when low and middle range probabilities and penalties are in effect, workers' compensation provides farmers with the largest compliance incentive, followed by administrative agency regulation and tort liability.

Implications of Altering the Probabilities

Because accurate probability data are scarce, we perform a sensitivity analysis to examine the effects of different probabilities on compliance incentives. Many factors influence the probability ($p(x)$) that a worker becomes ill when exposed to a pesticide, including variability in human response to such exposure. The initial analysis set $p(x)$ equal to 0.25. Here we examine the effects of doubling this probability to 0.5 and halving it to 0.125.

Raising the probability of harm from 0.25 to 0.5 has little impact upon the farmer's original compliance decision, because it further increases expected total noncompliance costs, which are already high relative to compliance costs. The expected cost using middle range data values for case 1 increases from \$97.30 to \$128.04, while for cases 2 and 3 it increases from \$96.35 to \$126.15 and from \$20.32 to \$27.26, respectively. The increase in probability of harm does lift the expected cost of one of the case 3 scenarios above \$10.88, changing the farmer's choice from noncompliance to compliance. When the original probability of harm falls to 0.125, noncompliance costs under each case drop significantly. However, overall the farmer chooses not to comply in the same number of cases (12 out of 63) as in the baseline results.

The probability that an injured farmworker will file a workers' compensation claim (e_{wc}) is uncertain. We initially assumed a probability of 0.2 and here examine the implications of using probabilities of 0.4 and 0.1. Doubling the probability of a claim being filed to 0.4 for cases 1 and 2 greatly increases the mean expected noncompliance cost, but does not affect the farmer's compliance decision. Substituting a value of 0.1, the compliance decision is unchanged but the expected costs are considerably lower for cases 1 and 2. Holding the other original values constant, e_{wc} would have to drop below 0.026

Table 4. The Effect on Noncompliance Costs of Changing Original Probability Estimates

	Case 1 ^a	Case 2 ^a	Case 3 ^a
		<i>Noncompliance costs</i>	
Original results	\$97.30	\$96.35	\$20.32
$p(x) = 0.5$	\$128.04	\$126.15	\$27.26
$p(x) = 0.125$	\$60.65	\$60.18	\$12.57
$e_{wc} = 0.4$	\$174.27	\$173.32	\$20.32
$e_{wc} = 0.1$	\$58.81	\$57.86	\$20.32
$p(x) = 0.125$ and $e_{wc} = 0.1$	\$36.31	\$36.14	\$12.57

^a Medium data values scenario.

before the farmer would choose not to comply with requirements for protective clothing. As the farmer becomes more certain that noncompliance resulting in injury will not be reported, he becomes more likely to not comply.

Simultaneously halving the probability of harm and of a worker filing a workers' compensation claim leaving all other values the same significantly lowers the expected noncompliance cost. The expected cost for case 1 drops to \$36.31 (see table 4), while the corresponding values for cases 2 and 3 are \$36.14 and \$12.57. Even with these changes, the farmer chooses noncompliance in the same number of cases as in the baseline results. Thus the compliance findings are insensitive to changes in the underlying probabilities used in the application.

Summary and Conclusions

This paper examines policies aimed at providing economic incentives for farmers to protect farmworkers exposed to pesticides. We extend previous work by incorporating incentives provided by workers' compensation along with those from tort liability and administrative agency regulation. We make the first application of this framework to the area of worker safety. The framework allows analysis of interactions between *ex ante* and *ex post* regulation systems, to examine in particular whether the systems are complements or substitutes. Quantification of farmers' incentives is made difficult by the lack of adequate data on pesticide-related illness and injury among farmworkers, and on the enforcement probabilities associated with tort liability, workers' compensation, and administrative agency regulation. The empirical analysis therefore takes the form of a set of simulations reflecting the range of possible incentives facing a Massachusetts apple grower.

One important factor limiting the impact of regulatory incentives is underreporting of injury and illness among farmworkers. Some states have begun requiring medical doctors to report all such illnesses or injuries they encounter. This is a step toward greater protection, but it assumes both that a farmworker sees a physician and that either the farmworker or the physician is able to link the symptoms to pesticide exposure. Ascertaining the degree of risk faced by workers is also problematic. Taking into account such factors as the number of hours since a pesticide application, climatic conditions, age, gender, and health of a given worker, it may be theoretically pos-

sible to derive a probability distribution for the risk level. In practice, however, the task is daunting. The enforcement probabilities and the probability that a farmworker files a workers' compensation claim should also in principle be calculable. The paradox is that these probabilities can be known only if one knows the number of cases not enforced or not reported. Such considerations underscore the difficulty in obtaining reliable data.

Despite data problems, the empirical analysis is instructive on several points involving the regulation of farmworker safety. First, the likelihood that a recalcitrant farmer will be penalized by the tort liability or administrative agency regulation systems is generally low because of low probabilities of suits being brought and of enforcement. Therefore, a system of complete experience-rated workers' compensation, making the employer bear the total costs of work-related harm to employees, may offer the most effective incentive to farmers to protect farmworker health. In contrast, where workers' compensation is imperfectly experience-rated, firms face considerably lower expected noncompliance costs and, consequently, lower incentives. A farmer facing a fixed workers' compensation premium is offered no incentive at all to protect farmworker health.

Second, for tort liability to have a significant deterrent effect on negligent behavior, the probability of a suit being brought would have to be significantly higher, the amount of settlements and awards would have to increase, or both. The assumption made here, that tort liability settlements and awards perfectly compensate farmworkers for harm they suffer, may be too strong, given the low per worker settlements observed in actual cases.

Third, the analysis suggests that unless the probability of enforcement is relatively high, administrative agency regulation is far inferior to an experience-rated workers' compensation system in providing farmers with incentives to ensure farmworker safety. Also of interest is the relationship between harm occurring and administrative agency fines being levied. To provide significant protection, regulations should penalize safety violations wherever they occur, not only after harm has been done.

Fourth, while this analysis showed incentive systems that usually induce compliance, the costs associated with workers' compensation dominated most scenarios. In themselves, tort liability and administrative agency regulation provided insignificant incentives to protect

farmworkers. Regulatory contexts not involving experience-rated workers' compensation may, therefore, yield quite different conclusions about the overall likelihood that farmers will take protective measures. This point is crucial when one considers that in many states farmworkers are not protected by workers' compensation laws.

Finally, even where noncompliance costs are highest, with all three incentive systems in effect, these costs are less than 1% of payroll, which in turn represents only a portion of the farmer's total production costs. Thus the penalties associated with the regulatory systems studied may be in general too small to have much influence on farmers' compliance decisions.

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