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Linking Eligibility for Agricultural Subsidies to Water Quality

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ABSTRACT

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Improving water quality in agricultural landscapes is an ongoing challenge in the United States, and most agri-environmental programs rely on voluntary adoption of conservation practices that limit nutrient runoff. Conservation-compliance initiatives require producers to meet specific conservation standards related to runoff to qualify for payments from farm programs. However, these requirements are typically associated with individual management practices by producers and do not require actual improvements in observed water quality. In this study, we introduce policies to reduce nonpoint source pollution that link eligibility for agricultural subsidies to compliance with water quality goals. We then use economic laboratory experiments to provide empirical evidence related to the performance of these policies. In the policy treatments, participants risk losing some or all of their subsidies if the ambient level of group pollution exceeds an announced target. A novel feature of our experiment is that we test a policy treatment that ensures that no subsidies are lost if a producer implements a verifiable conservation technology that reduces emissions. We find that the policies that are implemented reduce pollution to less than the no-policy baseline and nearly achieve the socially optimal level of pollution. The results suggest that water quality policies that rely on the threat of subsidy reductions are a potentially viable option for reducing the ambient level of water pollution. Although the policy that allows polluters to avoid potential losses by implementing a verifiable conservation technology could increase political support for ambient-based policies, our results suggest that such policies may cost more overall for a comparable reduction in pollution.

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There is a growing consensus that nonpoint source (NPS) pollution generated as a byproduct of agricultural production is largely responsible for water quality problems such as eutrophication and algal blooms (Boesch, Brinsfield and Magnien 2001; Ribaudo 2003; Rabotyagov et al. 2010). Despite this recognition, state and federal policies in the United States seldom tie financial incentives to the environmental performance of agricultural firms. There is, however, growing use of conservation-compliance policies that require agricultural firms to meet certain environmental standards to receive payments associated with federal agricultural support programs.

By merging a conservation-compliance framework with a penalty that is based on observed ambient pollution, this study contributes to the literature on innovative NPS pollution policies in four ways. First, we develop a theoretical framework to show how subsidy reductions can be used to provide incentives designed to improve ambient water quality. In this framework, producer subsidies decrease if water pollution is excessive, but unlike an ambient tax, which can potentially increase indefinitely as pollution rises, the total subsidy reduction is capped at the original subsidy level. This introduces additional equilibria that can undermine incentives to reduce pollution at the margin. Second, our laboratory economics experiment allows us to empirically analyze observed behavior and social welfare outcomes under the subsidy-reduction and traditional ambient-pollution tax policies. Such tax policies have generated positive social welfare outcomes in previous laboratory experiments (e.g., Spraggon 2004; Suter et al. 2008; Suter and Vossler 2014; Miao et al. 2016). It is an open empirical question whether the subsidy-reduction policy will generate similarly efficient outcomes, however, given the additional equilibrium and the change in framing (Tversky and Kahneman 1981). Thus, we are interested in determining whether this subsidy-reduction policy will generate similarly efficient outcomes. The third primary contribution of this study is the inclusion of a treatment where participants can avoid the subsidy-reduction policy by making an individual investment in a conservation technology. This feature addresses concerns related to political influence and fairness often associated with policies to control ambient pollution that impose penalties on individual firms based on group-level outcomes. Finally, we conduct an experiment in which firm-level emissions are determined both by a technology decision and a production decision. This feature of the experiment is in response to a recent review of economic experiments addressing mitigation of ambient pollution (Shortle and Horan 2013) that highlights the need for more realistic experimental designs in which participants make more than one abatement choice.

The theory that underlies ambient-based pollution-control policies related to NPS water pollution was first introduced in the economics literature by Segerson (1988) and Xepapedeas (1991) and subsequently expanded by Hansen (1998) and Horan, Shortle, and Abler (1998). Given a lack of real-world opportunities to empirically test the performance of incentive-based policies based on ambient levels of pollution, economists have generally approached the problem using test-bed laboratory experiments designed to assess how human decision-making in a controlled setting compares to theoretical predictions (Alpízar, Carlsson and Naranjo 2011; Cason and Gangadharan 2013; Cochard, Willinger and Xepapadeas 2005; Miao et al. 2016; Poe et al. 2004; Spraggon 2002; 2004; 2013; Spraggon, Oxoby and others 2010; Suter et al. 2008; 2010; Suter, Vossler and Poe 2009; Vossler et al. 2006).

Results from previous experiments illustrate some key tradeoffs in the design of policies based on ambient pollution levels. For example, Suter et al. (2008) found a potential for collusive behavior when policies subsidize over-compliance, and results of the experiments by Suter, Vossler, and Poe (2009) revealed that predatory behavior by large-scale polluters could push small-scale polluters toward bankruptcy. Nearly all of the studies, however, have shown that appropriately designed, ambient-based pollution-control policies can consistently incentivize groups to achieve pollution objectives even when individual behavior diverges from theoretical predictions. Recent research by Cason and Gangadharan (2013), for example, showed that formal penalties based on ambient pollution are significantly more effective in achieving pollution targets than informal peer-sanction mechanisms. These positive results also seem to translate to groups of professionals. For example, Alpízar, Requate, and Schram (2004) identified relatively efficient outcomes from a penalty based on ambient pollution in an experiment using a participant pool composed of managers of coffee mills. Similarly, Suter and Vossler (2014) found that managers of dairy farms who participated in an experiment were as likely as student participants to achieve the objectives of a program that imposed taxes based on the ambient level of water pollution.

Despite the demonstrated positive performance of ambient-based policies in the laboratory, few policies implemented in the field have used group-based water quality outcomes to determine penalties. Arguments against policies based on the ambient level of pollution have typically focused on the political feasibility (e.g., Cason and Gangadharan 2013) of imposing financial penalties on individuals based on a group outcome. As Shortle and Horan (2001) pointed out, with such a policy an individual firm that made a significant investment to improve its environmental performance could still be subjected to penalties if nearby firms did not similarly reduce their pollution or if stochastic changes in natural sources of pollution and/or weather caused the ambient pollution level in the waterbody to exceed the defined threshold.

Furthermore, agricultural firms traditionally have not been subjected to fees based on pollution outcomes. Shortle et al. (2012) noted that local, state, and federal initiatives in the United States aimed at improving water quality had typically followed a “pay the polluter” approach in which potential polluters are paid to take actions that seek to reduce their pollution. and that this approach so far had not led to the desired improvements in water quality in many watersheds. As previously noted, one exception to this reliance on paying agricultural producers for environmental stewardship is initiatives involving conservation compliance in which a producers’ eligibility for subsidy program payments is contingent on their implementation of specific environmental and conservation practices (Shortle et al. 2012).

For example, the Conservation Compliance Program was established by the 1985 Food Security

Act and was originally designed to protect environmentally sensitive land by limiting soil erosion and protecting wetlands (Claassen et al. 2004). To receive payments from some federal programs, agricultural producers had to use a specific set of soil conservation practices on highly erodible land and were prohibited from draining wetlands for agricultural use. Conservation-compliance provisions have been credited with providing numerous nonmarket benefits for agricultural landscapes but have been criticized for their typically narrow focus on soil erosion and wetland conversion (Arbuckle 2013; Perez 2007; Claassen et al. 2004). Expanding the scope of compliance programs could lead to cost-effective reductions in nutrient losses and improved water quality, and numerous agricultural and environmental groups have expressed support for such an expansion, including the American Farmland Trust (2011) and the Environmental Working Group (Perez 2007). A survey of Iowa producers found that the majority of them (69% of those surveyed) supported expanding the Conservation Compliance Program to include management of nutrients deposited in waterways (Arbuckle 2013).

The 2014 Farm Bill expanded the scope of conservation compliance by making producers' eligibility for federally subsidized crop insurance dependent on their complying with the requirements for highly erodible land and wetland conservation (Coppess 2014). Nearly 90 percent of the crop land in the United States is insured, and those producers rely on approximately $7 billion in annual federal subsidies of the premiums (Farrin, Miranda and O'Donoghue 2016; O'Donoghue 2014). Other federal agricultural programs that now require conservation compliance include loan and disaster assistance programs managed by the Farm Service Agency (FSA) and conservation programs managed by FSA and the Natural Resources Conservation Service (NRCS). Several state-level conservation-compliance policies have recently been implemented as well. The Wisconsin Farmland Preservation Program, for example, has tied eligibility for farmland tax credits to compliance with specific soil and water standards (Wisconsin Department of Agriculture, Trade, and Consumer Protection 2016).

Although conservation-compliance policies currently are not connected directly to environmental performance outcomes, policymakers are increasingly interested in tying the benefits of agricultural support programs to agricultural management decisions that influence environmental quality. Using an economics experiment, we test two such policy mechanisms that link receipt of subsidies to water quality goals, reducing or eliminating producers' subsidies when water pollution exceeds a target level. Under both policies, the reduction in subsidies is determined by aggregate pollution emissions. In addition, one of the policies assures individual producers that they will not lose any of their subsidies if they adopt a costly conservation technology that reduces pollution. We compare the effect of these policy mechanisms with the effects a linear ambient-pollution tax and a no-policy control. Unlike a tax, which would penalize each individual in a specific watershed, a subsidy-reduction policy would only affect individuals who receive the subsidy. Our research assumes that each participant is a subsidy recipient. Future research that allows individuals to select into subsidy programs would provide additional insight into the effectiveness of the subsidy-reduction policy.

The results from this research provide several important insights. First, we find that the subsidy-reduction policy is as effective as the tax policy in motivating pollution abatement. In the experiment, both policies reduced pollution to less than the no-policy baseline and nearly achieved the socially optimal level of pollution. Second, when participants receive individual assurances that they will not lose their subsidies if they invest in a conservation technology, we observed a significant increase in the number of participants who invested in the technology. This did not change the overall performance of the policy, however, in reducing the ambient level of pollution and resulted in a significant decrease in social welfare because the pollution reductions cost more than they would without the assurance option. For policymakers, the results suggest that water quality policies that rely on the threat of subsidy reductions are a potentially viable option for reducing ambient water pollution in a cost-effective way. Additionally, allowing polluters to avoid penalties by making a conservation investment could increase political support for policies based on ambient pollution levels, but our results suggest that such policies could cost more overall for a comparable reduction in pollution.

Theoretical Framework and Experimental Design

Emissions of NPS pollution by multiple agricultural operations increase the ambient level of pollution in a waterbody and cannot be traced back to their sources. Economists have conducted numerous investigations of typical U.S. environmental policies aimed at reducing such pollution, which typically measure changes in the level of pollution in the waterbody as a whole and require individual emitters to internalize the damage caused by their pollution (Segerson 1988). Inspired by the existing literature on ambient pollution policies and the growing interest in conservation compliance initiatives, this experiment tests two new policy mechanisms that link access to agricultural subsidies to ambient pollution levels. In this section, we describe the theoretical framework that underlies our experiments and our experimental design.

Individual producers can reduce their pollution emissions by adopting a conservation technology (e.g., planting cover crops) and/or reducing the quantity of crop output. However, under any policy based on the ambient level of pollution, a producer that reduces its emissions could still be subjected to a tax or reduction in subsidy if other producers in the watershed do not adequately reduce their emissions. One way to promote environmentally beneficial practices and address potential concerns about fairness associated with typical ambient-pollution-based policies is to protect agricultural producers who choose to adopt the conservation technology from the financial penalty regardless of whether the target pollution level is achieved.

Consider N identical, risk-neutral agricultural firms indexed by $i = 1, 2, \ldots, N$ that comprise a watershed. Each firm receives a government benefit, g, produces output y_i, and earns production income of $b(y_i)$ such that $\partial b_i \,/\, \partial y_i > 0$ and $\partial^2 b_i \,/\, \partial {y_i}^2 \leq 0$. The emission function for each firm is $e(y_i, a_i, \mathbf{v})$ where $\mathbf{v}$ is a vector of stochastic variables common to all firms (e.g., rainfall and temperature) and a_i is an indicator variable representing the producer's choice of production technology. In the model, emissions increase with the level of production such that $\partial e_i \,/\, \partial y_i > 0$ and $\partial^2 e_i \,/\, \partial {y_i}^2 \geq 0$. In addition, the firms can use either a conventional production technology (*Tech1*) or a conservation production technology (*Tech2*). We model the technology choice as a binary decision regarding adoption of the conservation technology: $a_i \in \{0,1\}$. When the conservation technology is adopted, $a_i = 1$; otherwise, $a_i = 0$. The conservation technology generates less emissions than the conventional technology for all levels of production: $e(y_i, a_i = 1, \boldsymbol{v}) < e(y_i, a_i = 0, \boldsymbol{v})\ \forall\ y_i$. We assume that there is no cost for using the conventional technology. The cost of adopting the conservation technology is denoted by c and the cost associated with the choice of technology is therefore $c * a_i$.

An individual firm's profit is a function of the subsidy it receives, income derived from its agricultural production, and the cost associated with the production technology chosen. The level of emissions generated by the firms in the watershed is assumed to have no direct impact on their individual profits. Formally, the firm's profit-maximization function is given by

$$\text{(1)} \qquad \max_{y_i, a_i} \pi(y_i, a_i) = g + b(y_i) - c * a_i.$$

Since adoption of the conservation technology imposes a cost without increasing income from production, a profit-maximizing firm is predicted to use the conventional production technology ($a_i = 0$) and produce a quantity of output that satisfies $\partial b_i \,/\, \partial y_i = 0$.

Total ambient pollution in the watershed is a function of the emissions from all N firms: $z(e_1, e_2, \dots, e_N)$. The total economic damage from ambient pollution is represented by $D(z)$ where $\partial D \,/\, \partial z > 0$ and $\partial^2 D \,/\, \partial z^2 \geq 0$. In the model, we assume that this damage affects downstream water users such as municipalities (as a loss of water quality) but does not directly affect the profits of the agricultural firms. In the experiment, we further assume that emissions are additive so that the ambient level of pollution, z, is $\sum_{i=1}^{N}(e_i)$ and that the amount of damage increases linearly with total emissions.

The social planner's objective is to maximize social welfare—total net profit for the group of producers minus the cost of damage from their emissions, by choosing the optimal level of output (y_i) and technology choice (a_i) for each firm,

$$\text{(2)} \qquad \max_{y_i, a_i} \quad \sum_{i=1}^{N}(g + b(y_i) - c * a_i) - E[D(z)]$$

where $E[D(z)]$ represents the expected damage from ambient pollution. If the level of ambient pollution is not a stochastic function of emissions, $E[D(z)]$ can be replaced with $D(\sum_{i=1}^{N} e_i(y_i, a_i))$.

Since economic damage from emissions does not enter the firm's profit function but has a negative impact on social welfare, emissions are predicted to exceed the socially efficient level, z^*, when there is no regulatory policy in place. Because the amount of damage is assumed to increase linearly with total emissions, imposing a constant tax rate of τ per unit of ambient pollution on each firm theoretically provides an appropriate incentive for profit-maximizing producers to reduce the amount of pollution they emit to the socially optimal level. Specifically, setting τ equal to $D'(z)$ aligns the social planner's problem with the firm's profit-maximization problem. A tax threshold of $\bar{z} \leq z^*$ can also be implemented to reduce the tax burden on individual firms. With that threshold, all of the firms in the watershed would pay tax rate τ on each unit of ambient pollution exceeding $\bar{z}$:

$$\text{(3)} \qquad T(z) = \begin{cases} \tau(z - \bar{z}) & if\ z > \bar{z} \\ 0 & if\ z \leq \bar{z}. \end{cases}$$

However, as previously noted, the feasibility of implementing a tax on ambient pollution is questionable. The alternative policy approach analyzed in this study links agricultural subsidies currently received by a producer from programs such as federal crop insurance to the level of ambient pollution in the waterbody. When the overall level of pollution exceeds the threshold, $\bar{z}$, the producer's subsidy is reduced by $R(z)$ where $R(z)$ is less than or equal to the amount of the subsidy, g. This reduction in the subsidy can be structured the same way as the emission tax but cannot exceed the amount of the original subsidy:

$$(4) \qquad R(z) = \begin{cases} g & if \;\; z \geq \bar{z} + \frac{g}{r} \\ r(z - \bar{z}) & if \; \bar{z} < z < \bar{z} + \frac{g}{r} \\ 0 & if \; z \leq \bar{z} \end{cases}$$

where r is the marginal rate of the subsidy reduction. When $r = \tau$, the theoretical incentives generated by the subsidy reduction are identical to the incentives under the tax when $z < \bar{z} + \frac{g}{r}$.

Under both the tax and the subsidy reduction, an individual firm's profit-maximization problem involves choosing the optimal production level, y_i, and technology, a_i:

$$(5) \qquad \max_{y_i, a_i} \; g + p_i(y_i) - c * a_i - E[X(z)]$$

where $E[X(z)]$ equals the expected financial penalty when $X(z)$ is either $T(z)$, the tax intervention, or $R(z)$, the subsidy-reduction intervention.

Consider a policy that insures that the firm's subsidy will not be reduced or eliminated if it adopts a verifiable conservation technology that will reduce its emissions. A profit maximizing firm will choose to adopt the new technology if its total expected profit (including subsidies) when using the technology is greater than its expected profit when it does not use the technology,

$$(6) \qquad g - c * a_i + b(y_i | a_i = 1) \geq g - E[R(z)] + b(y_i | a_i = 0).$$

Thus, the producer's technology choice depends on the expected reduction in subsidy, which depends on the expected level of total pollution. The firm's profit maximizing production decision, y_i, also depends on whether it adopts the conservation technology.

Incorporating the potential for protection from the penalty in the ambient-pollution mechanism introduces two important behavioral considerations. First, the firm's production decision becomes a function of the number of firms in the watershed that are likely to adopt the conservation technology and receive assurance. Those firms will have no incentive to reduce their agricultural production and can be expected to produce until $\partial b_i \,/\, \partial y_i = 0$. Firms that do not adopt the conservation technology and therefore do not receive protection from potential penalties must consider how emissions from the "unregulated" firms are likely to affect the probability that the ambient pollution level will exceed the threshold and trigger the tax or reduction in subsidies.

The second behavioral consideration is that the risk preferences of individual firms could play a role in their production and technology decisions and consequently in the overall outcome of the policy. To this point, we have been considering risk-neutral firms. Risk-averse firms, on the other hand, should be relatively more likely than risk-neutral firms to adopt the conservation technology and thus reduce uncertainty regarding the imposition of penalties. Furthermore, a firm's output is likely to be greater when it adopts the conservation technology than when it does not adopt and remains at risk of being penalized. Our experiment therefore incorporates a risk-preference test (Holt and Laury 2002) to empirically examine the relationship between participants' decisions in the experiment and their risk preferences.

Our theoretical framework directly informs the functional forms and parameters used in the experiment. Those functions and parameter values are presented in Table 1. Output (y_i) is generated by a quadratic production function such that $y_i = \alpha - \gamma(\varphi - e_i)^2$ where e_i is the firm-level emission that results from the production decision. The values for parameters α, γ, and φ equal 400, 10, and 6, respectively. In the experiment, the production/emission decision is determined directly by the participant's choice of one of ten management decisions labeled A through J (see Table 2), and the resulting emission ranges from 0 to 9 based on the management decision chosen. The participant maximizes production income by choosing management decision G, which results in emission, e_i, of six units. The firm's income from production is calculated by multiplying its output (y_i) by a constant price (p) that we assume to be one. The firm also obtains income from the subsidy (g), which is 400 experimental dollars. We assume that the cost (c) of using the conservation technology is 150 experimental dollars and that the use of that technology (a_i) reduces the amount of emission by the firm under each management decision by exactly half. The aggregate pollution function, z, is the linear summation of the individual firms' emissions. Social damage (D) increases linearly with pollution so that each unit of pollution generates an additional 52 experimental dollars of damage.

< Insert Table 1 here >

< Insert Table 2 here >

Experimental Procedures

We analyze the effect of decisions about adopting a conservation technology on the ambient level of pollution in a waterbody using a laboratory economics experiment involving 156 undergraduate student participants in sessions conducted in the Spring of 2016 at a large East Coast public university in the United States. Each experiment session involved 18 or 24 students to allow for groups with six participants each. Participants were recruited via email using lists managed by the university's Economics Department. The emails stated that participants in the research would be paid an average of $30 to participate in a 90-minute experiment about decision-making; no other information about the experiment was provided prior to the session.

Each experiment session consisted of five phases: instruction, practice rounds, the experiment, an adapted Holt-Laury lottery, and a short survey. The practice rounds and experiment session were programmed using Willow software (Weel 2016), and students were randomly assigned a tablet computer to use during the session. Students were seated in desks equipped with privacy barriers that prevented participants from viewing the computer screens of other participants.

First, participants were given the experiment instructions as a paper handout (see Appendix) and time to read them independently. The instructions were then reviewed audibly via a prerecorded PowerPoint presentation. After reviewing the instructions, participants completed a short activity to make sure that they understood how the experiment worked and then participated in five unpaid practice rounds[1] to ensure that they were comfortable making decisions on the tablet before beginning the experiment.

Participants were told that they were managers of agricultural firms and they would make decisions for their firms in a series of rounds that would determine how much they earned and the amount of pollution emitted to a water source common to six participants/firms (the watershed group). They were further informed that all of the firms in their group were identical in terms of potential production output, profits, and pollution relationships. The participants were randomly assigned to a six-person watershed group and they were not able to identify the other members of their group. Participants were encouraged to ask administrators points of clarification about the experiment procedures. Otherwise, communication was not permitted.

Each experiment session involved four treatments in a within-subject design, and each treatment involved five decision rounds, resulting in twenty rounds. In each round, participants first chose the technology to use—the no-cost conventional technology or the conservation technology. The conservation technology cost 150 experimental dollars; this amount was deducted from their total earnings for the round. Participants were then informed of the number of members in their watershed group who had chosen each type of technology and could use that information when making the anonymous management (production) decision in which they chose one of the ten management approaches (A–J) shown in Table 2. The list of management approaches were shown on the participant screen and was identical in all rounds of the experiment.

In addition to earning income from production based on the management approach chosen, they were paid 400 experimental dollars as "general earnings" in each round. No additional information was provided about that money, which represented a subsidy paid to the firm. The participant's profit in each round consisted of the general income and production income minus the cost of the conservation technology if adopted. The relationship between the management decisions and resulting profits and emissions for each technology are shown in Table 2.

Prior to the first round of each treatment, the watershed groups were randomly re-assigned (imperfect stranger matching) and specific instructions related to the treatment were handed out to the participants, who first read them and then observed a prerecorded PowerPoint review. A Latin-square orthogonal design was used to determine the order in which the four treatments were presented in each experiment session to control for potential order effects, resulting in four treatment orders: [C1,T2,T3,T4], [T2,T3,T4,C1], [T3,T4,C1,T2], and [T4,C1,T2,T3].

Once the experiment phase was complete, the subjects participated in an adapted Holt-Laury (2002) risk-elicitation procedure (see Appendix) that provided a measure of their risk preferences. Participants chose option A or option B in each of ten decision rows, and the payout for each option was one of two amounts—$20 or $16 in option A and $39 or $1 in option B. The likelihood of earning the higher amount was low (*P*(high earnings) = 1/10) in the first decision row and increased by 1/10 in each consecutive row. By the tenth decision row, the higher payout was certain (*P*(high earnings) = 1) so it was always rational to choose option B and earn $39. In the other rows, option B was considered the riskier decision because of the large difference between the low and high payouts. Due to the large payments offered, one-sixth of the participants were randomly selected to receive a payout for one randomly selected decision row. Each decision was equally likely to be chosen to determine their payout, giving them an incentive to treat each decision seriously. An analysis of the choices characterized each participant as risk-averse, risk-neutral, or risk-seeking depending on the number of safe choices they selected in the ten decision rows.[2]

The participants' final take-home earnings consisted of their firms' total profits from the experiment, with 600 experimental dollars equal to $1, and their payouts from the risk-elicitation exercise. The final task for each participant was to complete a short survey that collected demographic data, such as their gender, age, race, academic major, home state or country, and number of economic courses taken.

Experimental Treatments and Hypotheses

The experiment involved four treatments: a no-policy control (C1), a linear tax (T2), a linear subsidy reduction (T3), and a linear subsidy reduction with an assurance of no penalty for participants who adopted the conservation technology (T4). In the control treatment, there were no penalties for the resulting emissions. In the policy treatments, participants were subject to a pollution threshold of 18 units per group and were subject to treatment-specific penalties when the group emissions exceeded that amount.

Under the linear tax treatment (T2), *all firms* in a watershed group pay a tax of 52 experimental dollars, which is the marginal social damage of pollution, for each unit of pollution over the threshold. Theory predicts that the tax will provide an incentive for each participant in the group to reduce their emissions to the socially optimal level of 18 units.

Under the policy treatments T3 and T4, participants lost some or all of their general earnings (the subsidy) when the pollution from their group exceeded the threshold. As with the tax, the amount of the subsidy reduction increased linearly with the number of units of pollution over the threshold at a rate that was equivalent to the unit tax. Unlike the tax, the subsidy reduction could not exceed the full amount of the subsidy (400 experimental dollars). These treatments both used the subsidy-reduction mechanism, but T4 gave the participants the option to avoid the risk of a subsidy reduction by adopting the conservation technology.

Hypothesis 1: The aggregate level of pollution from a group is not affected by the type of penalty—a tax (T2) versus a subsidy reduction (T3 and T4)—imposed on excess pollution.

For a marginal increase in pollution from the social optimum, the subsidy-reduction policy sustains the marginal incentive necessary for individuals to internalize the social damage caused by their emissions and thus incentivizes optimal reductions in emissions. However, once the full subsidy has been removed, no further marginal increases in the subsidy reduction are possible. In our experiment, the maximum subsidy reduction occurred when pollution from a group exceeded 25 units. Thus, the cap on subsidy reductions creates a second equilibrium in which all firms follow the competitive equilibrium that provides no reduction in pollution by choosing management decision G and the conventional technology (see Table 2). Given the existence of two equilibria in the subsidy-reduction treatment—one at the social optimum and one at the private, competitive optimum—it is not clear how the subsidy reduction will affect total pollution relative to the tax. We test the null hypothesis that there will be no significant differences in pollution under the three policy treatments.

Hypothesis 2: Participants are more likely to adopt the conservation technology when adoption protects them from penalties associated with excess pollution relative to when adoption does not affect the risk of penalties.

Firms can reduce their emissions (and thus reduce the risk that the group will be penalized) by choosing a management (production) option that produces fewer emissions (and less income) and by adopting the conservation technology. In some cases (e.g., management decision D), the firm can limit its emissions and retain a large profit by choosing to use the conventional technology. However, in practice, management choices can be difficult to observe, whereas use of a visible conservation technology can be verified more easily using remote sensing technology, which would reduce the cost for program administrators (Rees and Stephenson 2014). In T4, firms that use the conservation technology do not incur a subsidy reduction even if their groups' emissions exceed the threshold. So, though it costs the firm more to use the conservation technology, we hypothesize that firms are more likely to use the conservation technology (which reduces pollution) in T4 than in T3.

Hypothesis 3: Risk-averse individuals are more likely than risk-neutral and risk-prone individuals to adopt the conservation technology in T4.

Risk-averse individuals are particularly likely to want to limit their exposure to penalties. Although the conservation technology costs 150 experimental dollars, they would have to pay 156 dollars if the group emits 21 units of pollution, which is just three units over the threshold.

Hypothesis 4. The social net benefit will be lower under the subsidy-reduction policy that offers assurance that the individual will not be penalized if they adopt a conservation technology (T4) than under the tax policy (T2) and the subsidy-reduction policy without assurances (T3).

Firms that adopt the conservation technology choose a relatively costly way to reduce their emissions, perhaps to avoid the risk of a penalty. Given the high cost of the conservation technology, we hypothesize that social net benefit (SNB), defined as the total profit for the group minus the cost of damage from the pollution the group produces (see equation 2), will decline when individual assurances are offered (T4) because of the increase in the cost of emission reduction rather than because of excessive emissions.

Analytical Methods

We formally test the effects of the treatments on pollution and social welfare outcomes at the individual and group level. Hypothesis 1 is tested using a linear random effects model to analyze how the groups' emissions are affected by the policy treatments. We specify our model as

(7) $$POLLUTION_{gr} = \alpha_0 + \sum_{k=2}^{4} \beta_k TREAT_{k,gr} + \sum_{m=1}^{4} \gamma_m ORDER_{m,gr} + \theta_1 ROUND + \theta_2 1/ROUND + \varphi_g + \varepsilon_{gr}$$

where $POLLUTION_{gr}$ is a continuous variable that reflects the aggregate pollution by group g in round r. $TREAT_k$ represents binary variables that take a value of one when the treatment number corresponds to the k subscript, and $k \in (2,3,4)$ represents the three policy treatments. $ORDER_m$ is a binary variable that controls for the order in which the four treatments were presented to participants. $ROUND$ identifies the round number and takes an integer value between 1 and 20. We also include the reciprocal of the round ($1/ROUND$) to allow for potential nonlinear learning processes that would have a diminishing effect as the experiment progressed. The estimable parameters from this model are α_0, β_k, γ_m, θ_1, and θ_2. We specifically analyze β_k, which provides an estimate of differences in group pollution in each of the policy treatments relative to the control treatment to determine whether the policy treatments differentially affect the group's total pollution.

To test hypotheses 2 and 3, we use a random effects probit model to examine how individual technology adoption decisions are affected by the policy intervention treatments:

(8) $$TECH_{ir} = \alpha_0 + \sum_{k=2}^{4} \beta_k TREAT_{k,ir} + \sum_{m=1}^{4} \gamma_m ORDER_{m,ir} + \theta_1 ROUND + \theta_2 1/ROUND + \varphi_i + \varepsilon_{ir},$$

where $TECH_{ir}$ is a binary variable that equals zero when individual i uses the conventional technology and one if the individual uses the conservation technology in round r. In this case, we only compare the three policy treatments so $k \in \{2,3,4\}$. We analyze β_k to test whether the treatments affect the likelihood that an individual will adopt the conservation technology.

In this analysis, we also incorporate data about risk preferences from the Holt-Laury test to determine whether the participants' risk attitudes change their likelihood of adopting the conservation technology in T4 in which adopters are protected from financial penalties (hypothesis 3). Risk-aversion is introduced as a continuous variable ($SAFECHOICES_i$) that reflects the number of safe choices the participant selected during the Holt-Laury exercise.[3]

We test hypothesis 4 using a random effects model to compare group-level social welfare for the control policy versus the treatment policies. This model is similar to equation 7, but the group-level SNB (SNB_{gr}) is used as the dependent variable. We also compute a measure of social efficiency as described in Spraggon (2004) and Suter et al. (2008) to compare social efficiency across policy treatments. In the model, social efficiency measures the percentage of the SNB attributable to the policy intervention. Social efficiency for treatment k is computed as

$$\text{(9)} \qquad \text{Social Efficiency}_k = \frac{SNB_{observed} - SNB_{status\ quo}}{SNB_{SO} - SNB_{status\ quo}}.$$

$SNB_{observed}$ is the actual SNB achieved in a given group and round while $SNB_{status\ quo}$ is the SNB that results when there is no policy intervention and firms maximize their private net benefits (competitive equilibrium). SNB_{SO} is the SNB that occurs when firms reduce their emissions to the socially optimal level using the least-costly method of abatement.

Results

We analyze the impacts of the three policy interventions on the level of ambient pollution, firms' technology choices, and social welfare. Table 3 reports mean values for group emissions, the proportion of individuals who chose the conservation technology, group profits, the SNB, and social efficiency in each treatment. Based on the descriptive statistics, it is evident that pollution is greatest when there is no policy (C1) and significantly less under each of the three policy treatments. A similar trend is evident when comparing the SNB for the four treatments, although the relative differences are smaller. As expected, the proportion of participants who chose the conservation technology is highest under T4 (subsidy reduction with assurance). The mean group profit is highest under the control treatment because it does not penalize excessive pollution. Among the policy treatments, T2 and T3 generate similar mid-level profits, and the profit is lowest under T4 because of the increased cost of the conservation technology. These results, in conjunction with the parameter estimates from the formal econometric models described in the previous section, allow us to assess our four hypotheses related to the effects of the policy treatments.

<Insert Table 3 here>

Result 1: Subsidy-reduction policies (with and without individual assurance) are as effective as the tax

policy in reducing aggregate pollution.

Compared to the no-policy control treatment, all three policy treatments reduce the level of ambient pollution to just above the socially optimal level of 18 units (Figure 1). Table 4 reports the results from the random effects model in equation 7. The parameter estimates indicate the differences in group pollution under each policy treatment relative to the control treatment. Group emissions in each of the policy treatments were statistically different and lower from the control treatment ($p < 0.01$). Analysis of variance in the outcomes for group pollution for each round indicates that there are no statistically significant differences in the amount of ambient pollution from the groups across the treatments ($N = 390$; $Prob > F = 0.220$). However, the amount of pollution generated under each policy treatment is statistically different from the social optimum of 18 ($p < 0.01$ in each case). Average group pollution for T2, T3, and T4 is 19.48, 19.66, and 20.03, respectively (Table 3). This result is promising for policymakers interested in using a subsidy-reduction policy to reduce ambient pollution since it suggests that the effects of the policies on behavior do not vary with how they are framed or the existence of degenerate equilibria. However, in order to reduce pollution to the social optimum, policymakers would need to reduce the pollution threshold that triggers the penalty or increase the penalty rate.

< Insert Figure 1 here >

< Insert Table 4 here >

Table 4 also provides evidence regarding any potential order effects in the sequence of presentation of the treatments. The results reveal no significant ordering effect and no evidence that the group level of emissions was influenced by experience (learning) during the experiment. Thus, the results uniformly point to there being no significant differences in total emissions of pollution across the policy treatments.

Result 2: Individuals are more likely to adopt a costly technology to reduce emissions when they are offered individual assurance that limits their exposure to penalties for excessive group emissions (T4).

In the experiment, firms could reduce their emissions (and boost the likelihood that the group's pollution not exceed the threshold) by choosing a management approach with relatively low production and by adopting the conservation technology. And in T4, adopting the costly conservation technology would protect them from being penalized for excessive group pollution. As shown in Figure 2, participants were substantially more likely to adopt the conservation technology when offered the individual assurance.

< Insert Figure 2 here >

To evaluate differences in technology decisions more formally, we estimate the random effects model specified in equation 8 with and without a variable representing participants' risk preferences and compare the results, which are reported in Table 5. When risk preferences are not considered, the parameter estimate for T4 ($p < 0.01$) is significantly different and larger than for T2 ($p < 0.01$) and T3 ($p < 0.05$). The marginal effects of the parameter estimates imply that participants were 3.9% more likely under T2 and 2.3% more likely under T3 to adopt the conservation technology than participants in the control treatment. Under T4, participants were 47.6% more likely to adopt the conservation technology, an increase of approximately 44% over participants in T2 and T3.

The order in which the treatments were presented appears to have had an impact on the technology decision. In particular, participants were significantly less likely ($p < 0.10$) to choose the conservation technology when T4 was the first treatment in a session. This result suggests that observing pollution outcomes and the resulting penalties in prior treatments increased the likelihood that participants would choose to guarantee their immunity from the subsidy reduction.

<Insert Table 5 here>

The choice of technology also had the expected impact on the management decisions selected by participants. Figure 3 shows the distribution of management-decision selections by participants in the fourth of the five rounds in each treatment.[4] The distribution in the policy treatments T2 and T3 are clearly uni-modal, with most participants choosing management option D. In contrast, the distribution of management choices it T4 is bi-modal, with the majority of participants with technology 1 choosing D and the majority of participants with technology 2 choosing management option G. Across all five rounds, under the control treatment with no policy intervention, 86.8% of the participants chose the private profit-maximizing combination of decision G (involving the highest output, 400 units) and the conventional technology. Under both T2 and T3, approximately 54% of participants reduced their production and emissions by selecting decision D (output of 310 units) and the conventional technology 1, while nearly 18% chose decision E (output of 360 units) and the conventional technology. Of the minority of participants who chose the conservation technology in T2 and T3, almost 50% chose decision G, which provided the greatest net profit for that technology. The largest shift in management and technology decision is evident in the subsidy reduction *with assurance*. Under T4, 50% of participants selected the conservation technology and management choice G. Furthermore, unlike under T2 and T3, when almost 90% of participants chose outputs of 390 or less, only 45.8% participants in T4 reduced their emissions by producing less than 400 units.

<Insert Figure 3 here>

Result 3: Participants' risk preferences have a small effect on their likelihood of adopting the conservation technology when individual assurance is offered (T4).

Based on the results reported in Table 5 for the model that incorporated risk preferences, participants who made more safe choices (risk-averse) were slightly more likely to adopt the conservation technology than individuals with other risk preferences. The average marginal effect of the parameter estimate of ω implies that an individual who makes an additional safe decision is 0.2% more likely to choose the conservation technology (*Tech 2*). The interaction between the number of safe choices selected and the policy treatment produces a surprising result that suggests that risk averse individuals are actually less likely to use the conservation technology in treatments T2 and T4 relative to C1; however, the magnitude of the effect is small and only marginally significant for T4 ($p < 0.10$). The histogram in Figure 4 shows the distribution of the total safe choices made by each participant. Almost 93% made five or more safe choices during the risk-preference exercise and were classified as risk-averse, and 60% were classified as strongly risk-averse because they chose seven or more safe choices. The lack of variation among risk classifications limits our ability to draw strong conclusions about the impact of risk preferences from these data.

Result 4: The three policy treatments all increase the SNB and social efficiency relative to the control treatment, but the SNB and social efficiency are significantly lower under the subsidy reduction with assurance (T4) than under the tax (T2) and subsidy reduction (T3).

Table 3 presents group mean SNB and social efficiency measures by treatment. Relative to the control treatment, the mean SNB is more than 9% greater in T2 and T3 and 4% greater in T4. Social efficiency for the policy treatments, defined as the percentage of SNB under the treatment that exceeds the SNB of the no-policy control treatment (equation 9), is approximately 70 percent higher in T2 and T3. This supports our previous finding that the subsidy-reduction policy had a similarly positive impact on social welfare as the tax policy. Under T4, social efficiency was 32% higher than the control on average, but this is significantly lower than the efficiency achieved in T2 ($t = 11.72$; $p < 0.000$) and T3 ($t = 11.68$; $p < 0.000$).

The results of the random effects regression in which the dependent variable is the observed level of SNB are presented in Table 6. The coefficients indicate that, relative to the control, the SNB was approximately 270, 277, and 125 experimental dollars greater under T2, T3, and T4, respectively. Neither the order of the treatments nor experience (learning) had a significant effect as indicated by the insignificant γ and θ coefficients. Because firms could reduce their emissions by reducing their output, the high rates of adoption of the relatively costly conservation technology in T4 were enough to reduce social welfare significantly even though the pollution-reduction objective was achieved.

<Insert Table 6 here>

Discussion and Conclusion

The results of our experiment suggest that subsidy reductions tied to the level of ambient pollution of a water resource can potentially reduce NPS emissions to near the socially optimum level. The subsidy reduction in this experiment is similar to a tax on the level of ambient pollution at the margin because the reduction is equal to the marginal social damage from each unit of pollution. There is, however, a cap on the subsidy reduction; once pollution reaches a level that completely dissipates an individual's subsidy, there is no additional penalty for further emissions. Under the parameters of our experiment, two equilibria exist—one in which abatement of emissions results in a socially optimal level of pollution and another in which emissions remain at a higher privately optimal level. Despite the multiple equilibria, emissions declined under the subsidy reduction to the same level achieved by the tax. However, when participants had the opportunity to ensure that their subsidies would not be reduced by adopting a lower-emission production technology, many chose to secure that assurance even though the cost to do so was significant. We found that participants' risk preferences had little effect on which technology they adopted, although other risk-elicitation procedures could be used in future research to test the robustness of this result.

The subsidy examined in this study represents benefits from federal farm programs that producers currently receive regardless of the outcome of efforts to improve water quality. By linking subsidies and payments to the level of ambient pollution, the subsidy reduction policies can be viewed as analogous to the policy that progressively taxes producers when the level of ambient pollution does not meet program objectives. Such tax-based policies have faced hefty opposition in the past (Boyd 2003), in part because producers do not want to be held responsible and penalized for the actions of others. One way to ameliorate such concerns is to include provisions that protect producers from penalties when they demonstrate a commitment to improving water quality using a visible technology[5]—so-called assurances that protect producers from being fined if water pollution fails to reach the target threshold.

In this study, subjects could reduce pollution by adopting a costly production technology. They were significantly more likely to choose that technology when offered assurance that they would not be liable for excessive group pollution. Without such an assurance, subjects chose the lowest-cost abatement method available—they reduced emissions by selecting a less-intensive management approach (production level) and foregoing the cost of the conservation technology.

Although the results indicate that providing individual assurances increases the likelihood that producers will adopt a costly technology to reduce pollution, it is not clear how adoption of the conservation technology affects social welfare relative to other policy interventions. Under the parameters chosen for this experiment, adoption of the visible technology to reduce pollution was more costly than adjusting the level of production. While the level of ambient pollution declined as a result, so did the producers' relative profits. Given this setup, one could view the reduction in welfare associated with providing assurance relative to the other interventions as the policy cost associated with creating a process seen as more equitable. Varying the parameters used in the experiment would provide additional information about the effects of such policies on firms' abatement behavior. For example, if adoption of the technology led to excessive abatement (far below the target level), some firms generally and risk-prone firms in particular might attempt to under-abate their own emissions in an effort to free-ride on the effort and expense of others.

A limitation of this research is that the experiment does not fully account for the voluntary nature of programs that provide subsidies to producers. For example, producers are not required to participate in federally subsidized crop insurance programs or other programs that provide tax credits or subsidies. Therefore, a pollution policy tied to receipt of subsidized crop insurance would not affect those who do not participate in the program. This research also does not account for heterogeneity in the program benefits actually received by individual producers based on various attributes. We examine a situation in which all firms receive the same initial subsidy. Tying the policy to a benefit that is proportionally distributed would be an important consideration for promoting greater equity in the policy.

The policy mechanisms that we implement in the experiment do not currently exist in reality. Decisions made by participants in a laboratory economic experiment provide insight into people's behavioral responses to policy mechanisms, but there is still much to learn about how the policies would be implemented and the actual responses of stakeholders. A recent study (Arbuckle 2013) found general support among producers for extending conservation-compliance programs to water quality and other environmental concerns but did not investigate preferences for policies that would link eligibility for subsidies to ambient water quality. Future research should engage key stakeholders, including producers and program administrators, to gain a fuller understanding of the feasibility and acceptance of the types of agri-environmental policies explored in this study.

Endnotes

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Table 1. Functional forms and parameters used in the experiment

Description	Functional form	Parameter values
Production function	$y_i = \alpha - \gamma(\varphi - e_i)^2$	$\alpha = 400;\ \gamma = 10;\ \varphi = 6$
Production income	$b(y_i) = py_i$	$p = 1$
Subsidy *(General Earnings)*	g	g = 400
Cost of conservation technology	c	$c = 150$
Pollution function	$X = \sum_{i=1}^{N} (1 - \frac{a_i}{2}) * e_i$	$e_i \in (0, 9); a_i \in \{0, 1\}$
Damage function	$D(X) = dX$	$d = 52$

Table 2. Emissions and profits related to experimental decisions

Management Decision	General Earnings	Production Income	Technology 1		Technology 2	
			Profit	Emissions	Profit	Emissions
A	400	40	440	0.0	290	0.0
B	400	150	550	1.0	400	0.5
C	400	240	640	2.0	490	1.0
D	400	310	710	3.0	560	1.5
E	400	360	760	4.0	610	2.0
F	400	390	790	5.0	640	2.5
G	400	400	800	6.0	650	3.0
H	400	390	790	7.0	640	3.5
I	400	360	760	8.0	610	4.0
J	400	310	710	9.0	560	4.5

Table 3. Mean group outcomes for four policy treatments

Treatment	Group Emissions	Proportion using Technology 2	Group Profits	Social Net Benefit	Social Efficiency
C1: No policy	34.20	0.027	4,730	2,952	0.061
	[33.78, 34.62]	[0.015, 0.039]	[4,711, 4,750]	[2,942, 2,961]	[0.038, 0.085]
T2: Tax	19.48	0.085	4,239	3,226	0.75
	[19.03, 19.92]	[0.067, 0.103]	[4,215, 4,263]	[3,213, 3,240]	[0.720, 0.787]
T3: Subsidy reduction	19.66	0.068	4,255	3,233	0.77
	[19.15, 20.16]	[0.049, 0.087]	[4,228, 4,282]	[3,217, 3,248]	[0.730, 0.808]
T4: Subsidy reduction with assurance	20.03	0.504	4,120	3,078	0.38
	[19.63, 20.42]	[0.458, 0.550]	[4,097, 4,142]	[3,057, 3,099]	[0.326, 0.433]

Note: The 95% confidence intervals are shown in brackets; n = 26 groups.

Table 4. Random effects regression on group emissions

Variable	Parameter	Coefficient	Robust SE
Treatment Effect			
C1 (no policy)	β_1	base group	
T2 (tax)	β_2	–14.710***	0.611
T3 (subsidy reduction)	β_3	–14.686***	1.011
T4 (subsidy reduction with assurance)	β_4	–14.492***	1.269
Order			
2 (T2 first)	γ_2	0.254	0.454
3 (T3 first)	γ_3	–0.703	0.540
4 (T4 first)	γ_4	–0.136	0.357
Round	θ_1	0.038	0.089
1/Round	θ_2	0.616	0.567
Constant	α_0	33.990***	0.575
N		520	
Groups		26	

***, **, * Denotes statistical significance at the 1% level, 5% level, and 10% level, respectively.

Table 5. Random effects probit regression on technology adoption

Variable	Parameter	Model 1	Model 2
Treatment Effect			
C1 (no policy)		base group	base group
T2 (tax)	β_2	0.939*** (0.299)	3.577*** (1.234)
T3 (subsidy reduction)	β_3	0.729** (0.361)	2.536** (1.191)
T4 (subsidy reduction with assurance)	β_4	2.630*** (0.450)	4.775*** (1.239)
Risk preferences			
Safe choices selected in Holt Laury	ω		0.299** (0.146)
Safe choices * T2	δ_2		-0.361** (0.164)
Safe choices * T3	δ_3		-0.23 (0.154)
Safe choices * T4	δ_4		-0.287* (0.152)
Order			
2 (T2 first)	γ_2	-0.084 (0.242)	-0.056 (0.240)
3 (T3 first)	γ_3	-0.068 (0.242)	0.088 (0.244)
4 (T4 first)	γ_4	-0.361* (0.217)	-0.347 (0.216)
Round	θ_1	0.020 (0.029)	0.020 (0.029)
1/Round	θ_2	0.683 (0.420)	0.785* (0.454)
Constant	α_0	-2.911*** (0.382)	-5.178*** (1.144)
N		3120	3120
Individuals		156	156

***, **, * Denotes statistical significance at the 1% level, 5% level, and 10% level, respectively.

Robust standard errors are in parentheses.

Table 6. Random effects regression on social welfare

Variable	Parameter	Coefficient	Robust SE
Treatment Effect			
C1 (no policy)	β_1	base group	
T2 (tax)	β_2	269.826***	16.377
T3 (subsidy reduction)	β_3	277.347***	28.874
T4 (subsidy reduction with assurance)	β_4	125.142***	38.941
Order			
2 (T2 first)	γ_2	-29.311	20.881
3 (T3 first)	γ_3	-33.250	23.357
4 (T4 first)	γ_4	-6.711	24.049
Round	θ_1	-0.491	2.841
1/Round	θ_2	-20.892	24.223
Constant	α_0	2983.157***	24.041
N		520	
Groups		26	

***, **, * Denotes statistical significance at the 1% level, 5% level, and 10% level, respectively.

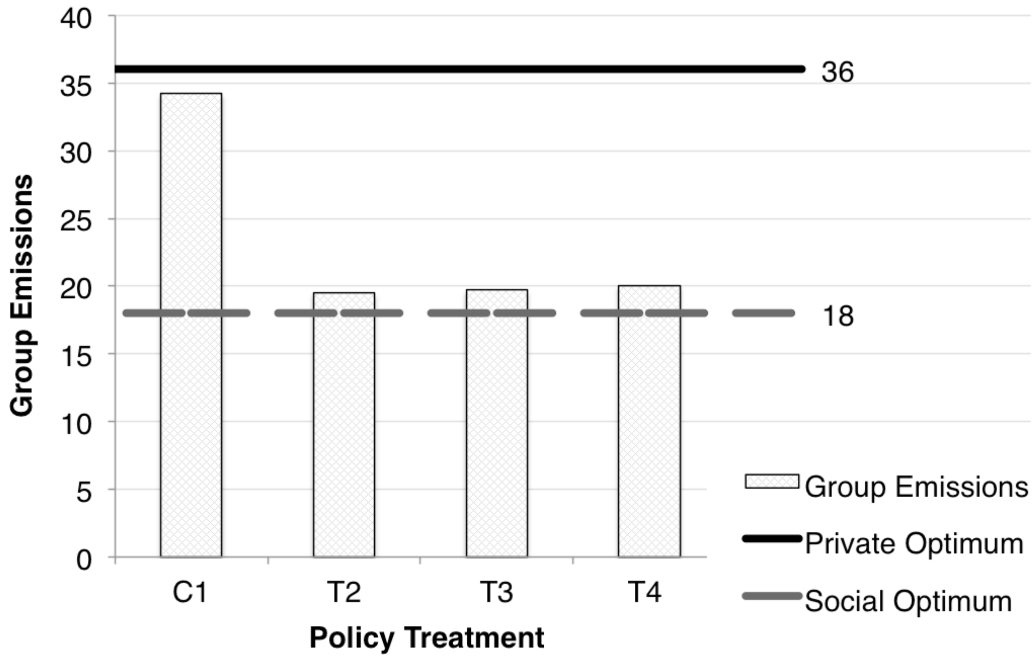

Figure 1. Mean group emissions for each treatment: Control (C1), Tax (T2), Subsidy reduction (T3), Subsidy reduction with assurance (T4)

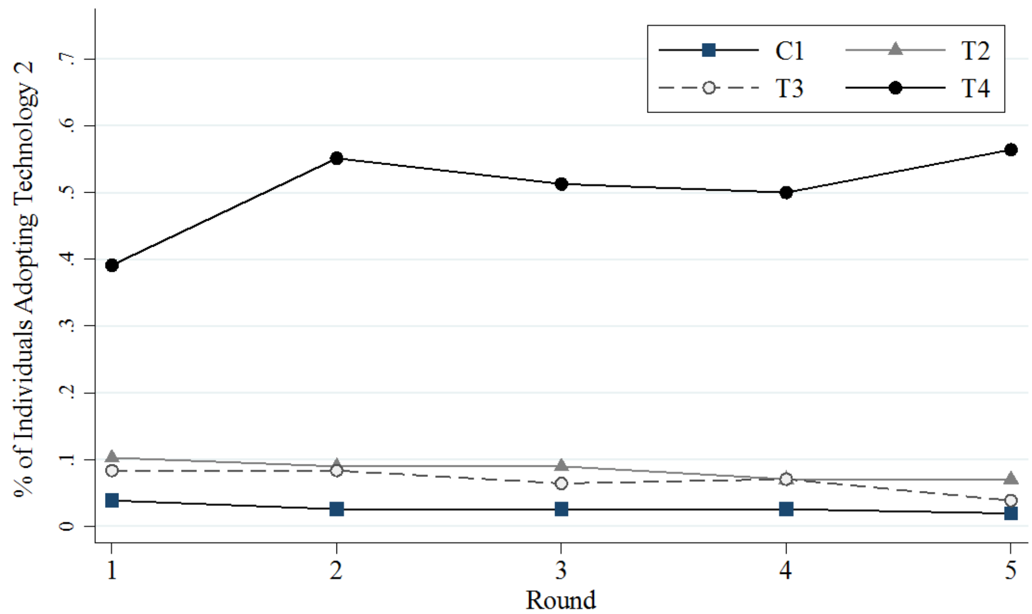

Figure 2. Adoption of the costly, pollution-reducing technology by round for each treatment: Control (C1), Tax (T2), Subsidy reduction (T3), Subsidy reduction with assurance (T4)

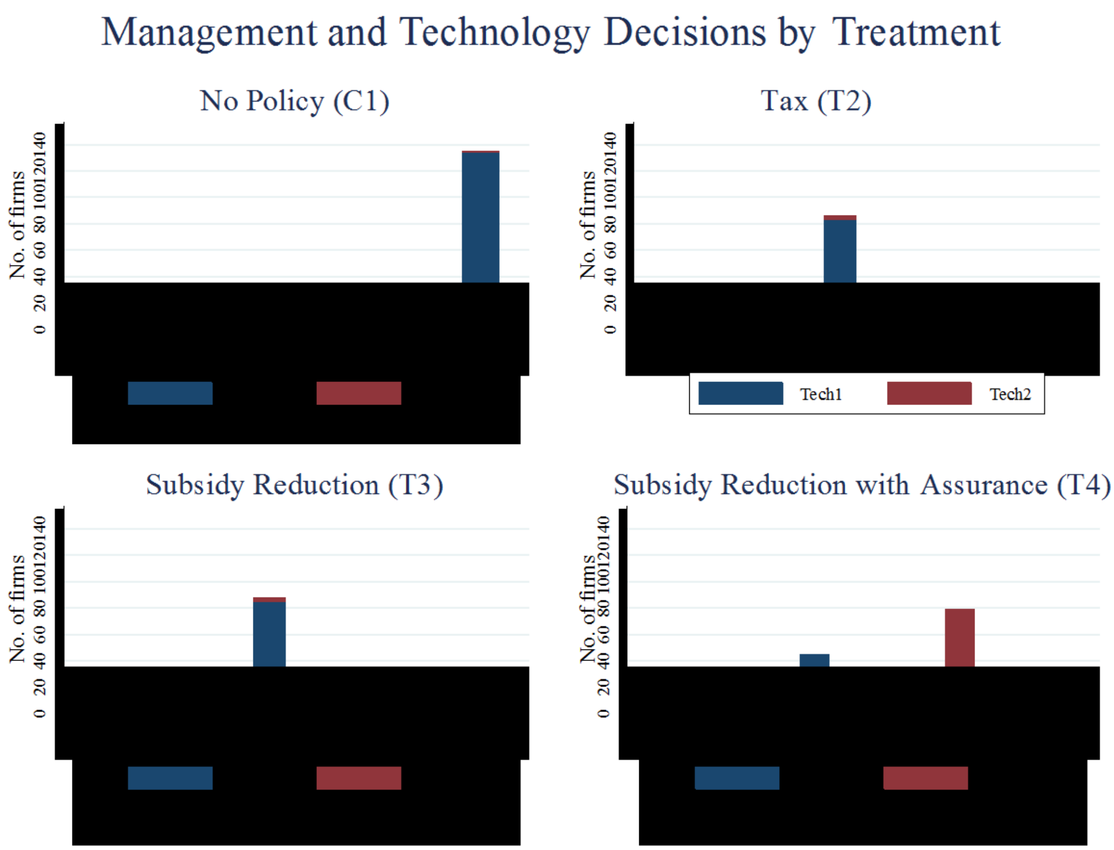

Figure 3. Management and technology decisions of firms in each treatment

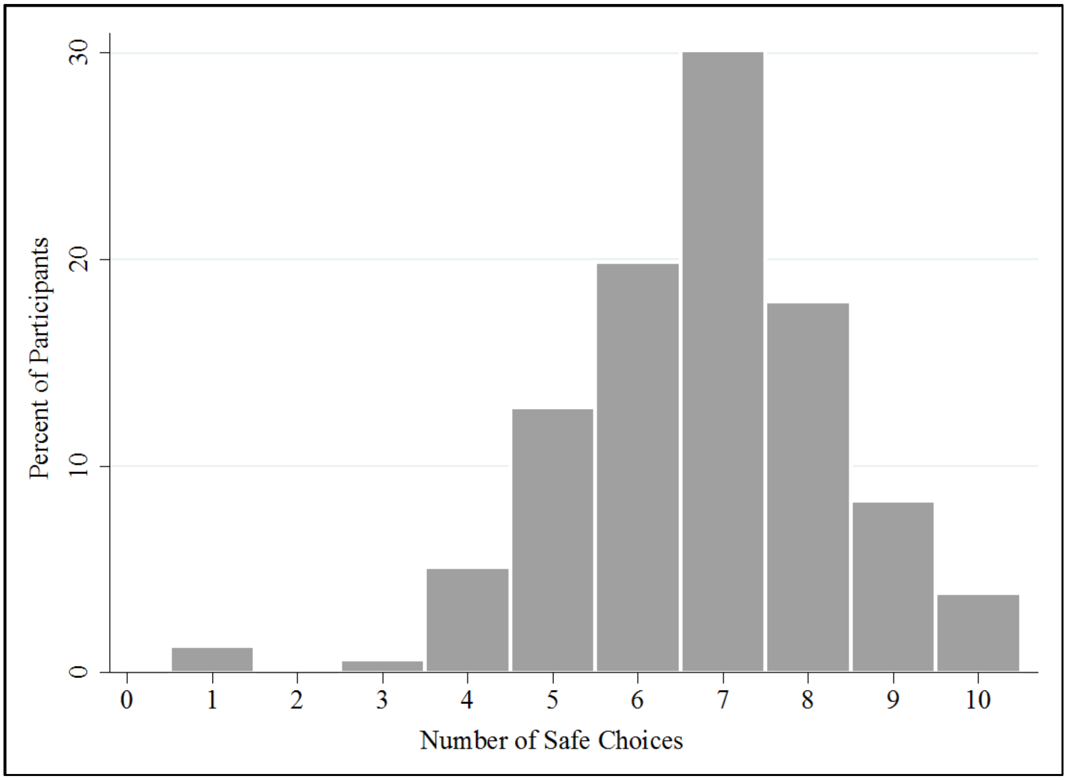

Figure 4. Distribution of safe choices made during the Holt-Laury risk elicitation procedure

Appendix – Experiment Instructions

This is an experiment about decision making. Deception is not allowed in economic research, so you will always be given truthful information during this experiment.

You will earn cash during this experiment if you follow these instructions carefully and make informed decisions. The amount you earn depends on your decisions and on the decisions of the other participants. Money you earn will be paid to you, in cash, at the end of the experiment.

There are five parts to the experiment. We will now review the instructions for Part 1 through Part 4. Part 5 will be explained later.

GENERAL INSTRUCTIONS FOR PART 1 through PART 4

Your role: You own and operate a firm. You will make decisions that affect the amount of money your firm earns. This money will be called your Firm Profit.

Earning money in the experiment: The money your firm makes (Firm Profit) will be denominated in "experimental dollars." Experimental dollars will be exchanged for cash at the end of the experiment at the rate of 500 experimental dollars to 1 US Dollar.

Decision Rounds: In Part 1 through Part 4, each part is divided into five decision "rounds." Each decision round is independent, meaning that the decisions you make in one round will not affect the decisions or outcomes of other rounds.

Decisions: You will make two decisions in each round. The two decisions are:

(1) **Management Decision** – You will choose one of ten management options, labeled "A" through "J"

(2) **Technology Decision** – You will choose one of two technology options, labeled "Technology 1" or "Technology 2"

The options for the two decisions will be the same in each round.

General Income: In each round, you will be given 400 experimental dollars of General Income regardless of the decisions that you make.

Production Income: In each round, your Production Income is determined by your decisions. The relationship between your decisions and Production Income is shown in the Decision Table on the attached page. Refer to the Decision Table before making your decisions.

Firm Profit: Firm profit equals Production Income plus General Income. Your Firm Profit in each round will be converted to US dollars to determine your take home earnings.

Groups: You will be in a group consisting of six players (firms). Think of your firm and the five other firms as being located near a common water resource. All firms in your group are identical. In Part 1 through

Part 4, groups are randomly assigned in each part of the experiment and you will not know who is assigned to each group.

Pollution: Each firm also generates pollution, and the amount of the pollution depends on the management and technology decisions of the firm. The relationship between your decisions, Production Income, and pollution is shown in the Decision Table. Refer to the Decision Table before making your decisions.

Total Pollution: Total Pollution is the combined pollution from all six firms in your group, including the pollution from your firm. The amount of Total Pollution lowers water quality and affects the wellbeing of water resource users. Remember, new groups are assigned in each part of the experiment.

Pollution Calculator: A Pollution Calculator is provided to test different scenarios to see how the decisions of other firms in your group could affect Total Pollution. This tool is for informational purposes as the scenarios you implement with the tool are hypothetical.

General comments:

- Each firm is identical and faces the same relationship between profit and pollution.
- A round of the experiment is complete when all six players have made their Management and Technology Decisions.
- In each part of the experiment, you will be given additional instructions and all calculations will be described.

HOW TO MAKE YOUR DECISIONS

In each round, you will be shown an interactive Decision Table like the one in the attached handout.

> **Management Decision:** You will choose a management option ('A' thru 'J') by clicking one of the buttons located in the rows of the *Decision Table*.
>
> **Technology Decision:** You make your technology decision ('1' or '2') by clicking one of the buttons located in the columns of the *Decision Table*.

You can use the Pollution Calculator tool to see how the decisions of others will affect Total Pollution. Scenarios you check with this tool are for informational purposes only and will not affect your earnings.

After you have made your decisions, click the CONFIRM button. Once you have clicked this button, the button will turn gray and it is no longer possible to change your decisions for that round.

Results – While you are waiting for the other players to make their decisions, you can review the results of past rounds, which will be shown on your screen. After all six players have clicked the CONFIRM button, the results of the current round will appear, including the Total Pollution from all members of your group, your Firm Profit, and the total experimental dollars you have earned up to that point in the experiment.

ID# _________

UNDERSTANDING THE EXPERIMENT

This short exercise is designed to help you understand how the experiment works. When you make your decisions in the actual experiment, the computer will make all relevant calculations.

In the table below, choose a Management Decision (A – J) and a Technology Decision (1 or 2). Use the Decision Table as a reference and write down the amount of General Income, Production Income, and Your Pollution that are generated by that decision.

Next, calculate your Firm Profit. This is the amount you would earn from your decisions in that round.

Look at the Decision Table and make sure the profit you have calculated matches the amount listed in the column labeled your Firm Profit.

Please let the experiment administrator know if you have any questions about this form.

Management Decision: *choose* A – J	
Technology Decision: *choose Technology* 1 or 2	
General Income: 400 experimental dollars	
Production Income*:* from the *Decision Table*	
Your Pollution: from the *Decision Table*	
Firm Profit	

We will review this form to check it for accuracy.

INSTRUCTIONS FOR PRACTICE

You will now play five practice rounds to learn how the experiment works. The outcomes of these rounds will not affect your cash earnings.

In each round of this part, you will make your Management Decision and your Technology Decision. Refer to the *Decision Table* to see how your decisions affect your Production Income and Pollution. Note that pollution does not affect firm profits.

After everyone makes their decisions, you will see the results screen that will display your Firm Profit and Pollution. In this part, your profit will be calculated as follows:

Firm Profit = General Income + Production Income.

MOVING on to PART 1 through PART 4

After you have finished the practice rounds, you will participate in Part 1 through Part 4 of the experiment. In these parts, the experimental dollars you earn from your firm's profits in each round will affect your cash earnings.

In each round of Part 1 through Part 4, you will make a Management Decision and a Technology Decision. Groups will be randomly reassigned for each part.

DECISION TABLE AND POLLUTION CALCULATOR

The image below is a screenshot of the interactive Decision Table and the Pollution Calculator that you will use on your computer.

Please make a Technology and Management Decision

Decision Table

Management Decision	General Income	Technology 1			Technology 2		
		Production Income	**Firm Profit**	**Pollution**	**Production Income**	**Firm Profit**	**Pollution**
A	400	40	440	0	-110	290	0.0
B	400	150	550	1	0	400	0.5
C	400	240	640	2	90	490	1.0
D	400	310	710	3	160	560	1.5
E	400	360	760	4	210	610	2.0
F	400	390	790	5	240	640	2.5
G	400	400	800	6	250	650	3.0
H	400	390	790	7	240	640	3.5
I	400	360	760	8	210	610	4.0
J	400	310	710	9	160	560	4.5

Pollution Calculator

My Pollution 0

Tech 1 Tech 2
Participant 2 Expected Pollution 0

Tech 1 Tech 2
Participant 3 Expected Pollution 0

Tech 1 Tech 2
Participant 4 Expected Pollution 0

Tech 1 Tech 2
Participant 5 Expected Pollution 0

Tech 1 Tech 2
Participant 6 Expected Pollution 0

Total Pollution 0

Based on the scenario you calculated above:

Your Firm Profit in this round would be $ 400

INSTRUCTIONS FOR PART 1

In each round, you will make a Management Decision and a Technology Decision. Note that pollution does not affect firm profits.

In this part, your profit will be calculated as follows:

Firm Profit = General Income + Production Income.

INSTRUCTIONS FOR PART 2

In each round, you will make a Management Decision and a Technology Decision. Note that Total Pollution in your group affects the profits of firms in your group.

In order to protect the water resource, the regulator requires you and everyone else in your group to make the following Tax Payment if the Total Pollution in your group is too high:

The **Tax Payment for each firm** in your group is calculated as follows:

Total Pollution ≤ 18	Tax Payment = 0
Total Pollution > 18	Tax Payment = 52 x (Total Pollution – 18)

In other words,

- If the Total Pollution in your group is less than or equal to 18, each firm in your group pays 0 in taxes.
- If the Total Pollution in your group is greater than 18, each firm pays 52 experimental dollars in taxes for every unit of pollution above 18 units.

The amount of the Tax Payment is determined by decisions of everyone in your group. The *Tax Payment Sheet* (on the back of this page) indicates the Tax Payment corresponding to different levels of Total Pollution. The Tax Payment, if any, will be deducted from your profit such that:

Firm Profit = General Income + Production Income – Tax Payment

Tax Payment Sheet					
Total Pollution	**Tax Payment**	**Total Pollution**	**Tax Payment**	**Total Pollution**	**Tax Payment**
0	0	21	156	41	1,196
1	0	22	208	42	1,248
2	0	23	260	43	1,300
3	0	24	312	44	1,352
4	0	25	364	45	1,404
5	0	26	416	46	1,456
6	0	27	468	47	1,508
7	0	28	520	48	1,560
8	0	29	572	49	1,612
9	0	30	624	50	1,664
10	0	31	676	51	1,716
11	0	32	728	52	1,768
12	0	33	780	53	1,820
13	0	34	832	54	1,872
14	0	35	884	55	1,924
15	0	36	936	56	1,976
16	0	37	988	57	2,028
17	0	38	1,040	58	2,080
18	0	39	1,092	59	2,132
19	52	40	1,144	60	2,184
20	104				

Note that each additional half unit of Total Pollution increases the Tax Payment by 26.
For example, if Total Pollution equals 18.5, the Tax Payment is 26. If Total Pollution is 19.5, the Tax Payment is 78.

INSTRUCTIONS FOR PART 3

In each round, you will make a Management Decision and a Technology Decision. Note that Total Pollution in your group affects the profits of firms in your group.

In order to protect the water resource, the regulator will deduct money from General Income for you and everyone else in your group if Total Pollution in your group is too high:

The **General Income Reduction for each firm** in your group is calculated as follows:

Total Pollution ≤ 18	General Income Reduction = 0
18 < Total Pollution < 26	General Income Reduction = 52 x (Total Pollution – 18)
Total Pollution ≥ 26	General Income Reduction = 400

In other words,

- If Total Pollution in your group is 18 or less, there is no General Income Reduction for firms in your group.
- If Total Pollution in your group is greater than 18, but less that 26, each firm in your group loses 52 of General Income for each unit of pollution above 18 units.
- If Total Pollution in your group is 26 or greater, each firm in your group loses 400 of General Income.

The amount of the General Income Reduction is determined by decisions of everyone in your group. The *General Income Reduction Sheet* (on the back of this page) indicates the General Income Reduction corresponding to different levels of Total Pollution. The General Income Reduction, if any, will be deducted such that:

Firm Profit = General Income + Production Income – General Income Reduction

General Income Reduction Sheet					
Total Pollution	General Earnings Reduction	Total Pollution	General Earnings Reduction	Total Pollution	General Earnings Reduction
0	0	21	156	41	400
1	0	22	208	42	400
2	0	23	260	43	400
3	0	24	312	44	400
4	0	25	364	45	400
5	0	26	400	46	400
6	0	27	400	47	400
7	0	28	400	48	400
8	0	29	400	49	400
9	0	30	400	50	400
10	0	31	400	51	400
11	0	32	400	52	400
12	0	33	400	53	400
13	0	34	400	54	400
14	0	35	400	55	400
15	0	36	400	56	400
16	0	37	400	57	400
17	0	38	400	58	400
18	0	39	400	59	400
19	52	40	400	60	400
20	104				

Note that each additional half unit of Total Pollution increases the General Income Reduction by 26. For example, if Total Pollution equals 18.5, the General Income Reduction is 26. If Total Pollution is 19.5, the General Income Reduction is 78.

INSTRUCTIONS FOR PART 4

In each round, you will make a Management Decision and a Technology Decision. Note that Total Pollution in your group affects the profits of firms in your group.

In order to protect the water resource, the regulator will deduct money from General Income for you and everyone else in your group if Total Pollution in your group is too high:

The **General Income Reduction for each firm** in your group is calculated as follows:

	If you use Technology 1	**If you use Technology 2**
Total Pollution ≤ 18	General Income Reduction = 0	General Income Reduction = 0
18 < Total Pollution < 26	General Income Reduction = 52 x (Total Pollution – 18)	General Income Reduction = 0
Total Pollution ≥ 26	General Income Reduction = 400	General Income Reduction = 0

In other words,

- If Technology 1 is chosen:
  - If Total Pollution in your group is 18 or less, there is no General Income Reduction for firms in your group.
  - If Total Pollution in your group is above 18, but less than 26, each firm in your group that chooses Technology 1 loses 52 of General Income for each unit of pollution above 18 units.
  - If Total Pollution in your group is 26 or greater, each firm in your group that chooses Technology 1 loses 400 of General Income.
- If Technology 2 is chosen:
  - There is no General Income Reduction for firms that use Technology 2.

The amount of the General Income Reduction is determined by decisions of everyone in your group. The *General Income Reduction Sheet* (on the back of this page) indicates the General Income Reduction corresponding to different levels of Total Pollution. The General Income Reduction, if any, will be deducted such that:

Firm Profit = General Income + Production Income – General Income Reduction

General Income Reduction Sheet					
Total Pollution	General Earnings Reduction	Total Pollution	General Earnings Reduction	Total Pollution	General Earnings Reduction
0	0	21	156	41	400
1	0	22	208	42	400
2	0	23	260	43	400
3	0	24	312	44	400
4	0	25	364	45	400
5	0	26	400	46	400
6	0	27	400	47	400
7	0	28	400	48	400
8	0	29	400	49	400
9	0	30	400	50	400
10	0	31	400	51	400
11	0	32	400	52	400
12	0	33	400	53	400
13	0	34	400	54	400
14	0	35	400	55	400
15	0	36	400	56	400
16	0	37	400	57	400
17	0	38	400	58	400
18	0	39	400	59	400
19	52	40	400	60	400
20	104				

Note that each additional half unit of Total Pollution increases the General Income Reduction by 26. For example, if Total Pollution equals 18.5, the General Income Reduction is 26. If Total Pollution is 19.5, the General Income Reduction is 78.

<u>INSTRUCTIONS FOR PART 5</u>

<u>**Part 5 is completely different from the other parts of the experiment. The money that you earned in Part 1 through Part 4 is yours to keep and those earnings will not be affected by the choices you make in Part 5.**</u>

You will make ten decisions in this part of the experiment. How much cash earnings you receive will depend partly on **chance** and partly on the **decisions** you make. <u>**In this part, the possible earnings are shown in actual U.S. dollars, not experimental dollars.**</u>

<u>**Your Task**</u>**:** Choose either Option A or Option B for each of the ten decisions shown on the attached handout.

For example, as shown below, if you choose Option A, you will have a 1 in 10 chance of earning $20 and a 9 in 10 chance of earning $16. Alternatively, Option B offers a 1 in 10 chance of earning $39 and a 9 in 10 chance of earning $1.

Decision	Option A	Option B	Your Choice *(circle one)*
1	$20 if the die is 1 $16 if the die is 2 – 10	$39 if the die is 1 $1 if the die is 2 – 10	**A** or **B**

<u>**Steps:**</u>

1. Each person makes ten decisions by circling either Option A or B for each decision in the attached handout.
2. A ten-sided die determines which decision will count for payouts. Only one decision will be selected as the “decision that counts.”
3. Another ten-sided die will determine how much money is earned in the “decision that counts” that was selected in Step 2. The cash payout depends on which option (Option A or B) was chosen in that decision.
4. Numbers will be randomly drawn from a bag to select one person from each group of six people to receive their payment. If you are not selected to receive payment for Part 5, you will still receive the money you earned in Part 1 through Part 4.

Since you do not know which decision will count or who will be selected to receive money, you should pay attention to the choice you make in every decision.

Example # 1

1. Each person chooses either Option A or Option B for each of the ten decision rows.
2. Decision that counts: Assume the first roll of the die lands on ‘9’; therefore, Decision 9 is the “decision that counts.”
3. Payout: A second roll of the die lands on ‘7’. The payout for rolling ‘7’ depends on the option chosen in Decision 9.
    a. If Option A was chosen in Decision 9, the payoff would be $20
    b. If Option B was chosen in Decision 9, the payoff would be $39
4. One person from each group of six people is selected to receive payment for the decision that they made. Numbers are drawn from a bag to randomly select participants.

Decision	**Option A**	**Option B**	**Your Choice** ***(circle one)***
9	$20 if the die is 1 – 9 $16 if the die is 10	$39 if the die is 1 – 9 $1 if the die is 10	**A** or **B**

Example # 2

If Decision 10 is the “decision that counts,” a second die throw will not be needed because the choice is between fixed amounts of money: $20 for Option A and $39 for Option B.

Decision	**Option A**	**Option B**	**Your Choice** ***(circle one)***
10	$20 if the die is 1 -10	$39 if the die is 1 – 10	**A** or **B**

<u>Please choose either A or B for each of the ten decisions below.</u>

Remember:	Each of the 10 decisions has an equal chance of being used to determine your earnings.
Take Home Earnings:	The choices that you make on this page will be used to determine your earnings if you are selected at random. Payouts will be paid in cash. The money payouts below are in US dollars – *not* experimental dollars.

Decision	Option A	Option B	Your Choice *(circle one)*
1	$20 if the die is 1 $16 if the die is 2 - 10	$39 if the die is 1 $1 if the die is 2 - 10	**A** or **B**
2	$20 if the die is 1 - 2 $16 if the die is 3 - 10	$39 if the die is 1 - 2 $1 if the die is 3 - 10	**A** or **B**
3	$20 if the die is 1 - 3 $16 if the die is 4 - 10	$39 if the die is 1 - 3 $1 if the die is 4 - 10	**A** or **B**
4	$20 if the die is 1 - 4 $16 if the die is 5 - 10	$39 if the die is 1 - 4 $1 if the die is 5 - 10	**A** or **B**
5	$20 if the die is 1 - 5 $16 if the die is 6 - 10	$39 if the die is 1 - 5 $1 if the die is 6 - 10	**A** or **B**
6	$20 if the die is 1 - 6 $16 if the die is 7 - 10	$39 if the die is 1 - 6 $1 if the die is 7 - 10	**A** or **B**
7	$20 if the die is 1 - 7 $16 if the die is 8 - 10	$39 if the die is 1 - 7 $1 if the die is 8 - 10	**A** or **B**
8	$20 if the die is 1 - 8 $16 if the die is 9 - 10	$39 if the die is 1 - 8 $1 if the die is 9 - 10	**A** or **B**
9	$20 if the die is 1 - 9 $16 if the die is 10	$39 if the die is 1 - 9 $1 if the die is 10	**A** or **B**
10	$20 if the die is 1 - 10	$39 if the die is 1 - 10	**A** or **B**

[1] Spraggon (2004) found that participants in an experiment required a minimum of five rounds to adequately understand how the experiment worked.

[2] Risk preferences were assigned to individuals based on the number of decision rows in which they chose the safe choice (option A). Rational individuals should switch from choosing option A to choosing option B only once between decision row 1 and 10. However, 14 participants chose option A after choosing option B in a prior decision row. This type of behavior has been observed in previous research and we do not remove the individuals from the analysis.

[3] We also test for effects of risk preferences using a model that employs a binary variable, $RISKAVERSE_i$, that classifies participants as risk-averse ($RISKAVERSE_i = 1$) when they made five or more safe decisions in the risk-elicitation exercise. This binary variable is included in the model independently and is interacted with the categorical treatment variable to identify any differential effects across treatments on the likelihood of choosing the conservation technology. Sensitivity analyses were conducted by reclassifying risk-aversion as participants who made six, seven, and eight or more safe choices. Results are robust to these different specifications.

[4] Production and technology decisions from round four of each treatment are presented in Figure 3 to show the relative frequency of the choices made in a single round. These results are representative of the decisions made across all rounds within each treatment.

[5] The type of technology connected to the assurance is important because it must both effectively reduce pollution and be easily observable to reduce the cost of monitoring and verification.

The Department of Applied Economics and Statistics
College of Agriculture and Natural Resources
University of Delaware

The Department of Applied Economics and Statistics carries on an extensive and coordinated program of teaching, organized research, and public service in a wide variety of the following professional subject matter areas:

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