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Abstract

Non-point source (NPS) water pollution from agricultural runoff is a leading cause of impairment for many water bodies in the United States; however, sources of NPS pollution are difficult to identify because of hidden actions and asymmetric information. Theoretical and experimental research has shown that ambient pollution policies can induce groups to reduce pollution to socially efficient levels, but many of these studies have imposed restrictive assumptions about farmer homogeneity and management choices. In reality, agricultural firms differ in both size and location, and farmers make numerous management decisions that can affect runoff and nutrient loss, including decisions about production intensity and pollution abatement technologies. Researchers have shown that introducing either size or location heterogeneity affects the efficiency of ambient pollution policies, but no research has analyzed policy performance while considering several sources of heterogeneity and multiple management decisions. Furthermore, despite multiple examples in using non-pecuniary incentives to promote environmental conservation, little research has examined how to use information nudges, like social comparisons or information about peer actions, to induce better NPS pollution abatement decisions.

In this study, we designed an economic experiment to test the effects of multiple layers of heterogeneity, information nudges, and an extended decision space on the performance of the classic ambient tax/subsidy policy. Experiment participants (n=192) were recruited from a large public university in the U.S. In the experiment, each individual was assigned a firm and asked to make individual decisions that affected the profitability of his/her firm and ambient water pollution of their group. In each round of the experiment, participants selected their production intensity and chose one of two production technologies—a conventional technology or a more expensive technology that generated less pollution.

Eight within-subject treatments were tested, including two policy variations (no policy and a tax/subsidy policy) and four size/location variations (homogeneous, location heterogeneity, size heterogeneity, and both location and size heterogeneity). Three between-subject information treatments were also tested, including a no information control. In information treatment 1, we tested how individual decisions were affected by information nudges about decisions that similar individuals had made in past sessions. In information treatment 2, participants were provided with information about the average production and technology adoption rate in their group during the last round. A unique dominant strategy Nash Equilibrium was calculated for both the adoption decision and production decision based on location and size.

Our results demonstrate that, without information nudges, more firm heterogeneity reduces the effectiveness of ambient tax/subsidy policies and target pollution levels are achieved less frequently. However, the tax/subsidy policy was effective under different heterogeneity scenarios when information is provided about peer and group decisions in past rounds. Furthermore, information treatment 1 and information treatment 2 generate higher policy efficiency than no information treatment. Lastly, participants are able to find and retain their dominant strategy better in the information 1 treatment, suggesting that providing individually targeted information is more effective than providing information about aggregate group-level decisions. Our findings suggest that traditional ambient pollution policies may be less effective when agents are heterogeneous and make multiple decisions that affect pollution, but information nudges can improve policy performance.

JEL: C9, Q52, Q53

Keywords: Non-point source pollution, Ambient based policy, Heterogeneous agents, Information nudges

1. Introduction

Regulation of non-point source (NPS) water pollution is a difficult task since it involves hidden actions and asymmetric information from individual polluters, making it impossible or prohibitively costly to track and set up individual-based policies (Xepapadeas, 2011; Miao et al., 2016). Segerson (1988) showed that policy instruments could be designed to overcome these problems and reduce pollution to near an exogenously determined ambient pollution level. However, ambient-based policies have not been carried out in reality on a large scale due to obstacles such as political feasibility and fairness concerns (Cason and Gangadharan, 2013; Xepapadeas, 2011). Therefore, researchers primarily use experimental or theoretical methods to investigate how ambient pollution policies can be used to improve water quality (Xepapadeas, 1992; Spraggon, 2002; Poe et al., 2004).

In these ambient-based policy schemes, the regulator usually compares the pollution reading to a target level of pollution, and imposes monetary policy instruments (tax and/or subsidy) to everyone in the watershed. Researchers have shown that ambient-based policies can induce groups to reduce pollution to socially efficient levels, but many of these studies are based on restrictive assumptions about farmer homogeneity and their management decisions. In reality, agricultural firms may differ in both production capacity and location relative to the sensor, which may result in different pollution behavior. Studies have shown that introducing either size or location heterogeneity affects the efficiency of ambient pollution policies, but no research has analyzed policy performance while considering multiple sources of heterogeneity.

Additionally, as water pollution has intensified in many watersheds, pollution abatement technologies that reduce nutrient runoff are increasingly promoted by local, state, and federal conservation initiatives. For example, a technology (e.g., conservation buffers) could remove up to 50% or more of nutrients and pesticides in runoff (Conservation Technology Information Center, Purdue University, 2016). Unlike individual pollution levels, which are difficult to measure and observe, the adoption of a certain abatement technologies is visible to others and shows a producer's commitment to environmental stewardship. Regulators may also be able to gather information on the status of adopting certain abatement technologies. However, such technology decisions have seldom been explicitly considered in the past (Palm-Forster, Suter and Messer, 2017). Along with size and location heterogeneity, management decisions including production intensity and pollution abatement technologies may affect runoff and nutrient loss.

Furthermore, in recent years, both the public and private sectors realize the benefits of using behavioral economic principles to influence people's behavior. Behavioral-based policies are especially attractive to policy makers because they are more cost-effective compared to pecuniary policies. It has been shown in various domains that using behavioral insights, especially information nudges, can improve private as well as social welfare [[add citations]]. But in NPS pollution management, most studies focus on various monetary policies, not much attention has been paid on using information nudges, such as social comparisons or peer actions, to affect people's pollution behavior. We explore how information nudges could be used to induce better behavior in a NPS pollution context.

In this study, we design an economic experiment to test the effects of multiple layers of heterogeneity, information nudges, and an extended decision space on the performance of the classic ambient tax/subsidy policy. We find that in general the policy becomes less effective as heterogeneity is introduced, but restores its effectiveness with the aid of information nudges.

2. Literature Review

Segerson (1988) showed that the non-point-source pollution problem could be solved by creating policy incentives based on the ambient level of pollution. Because of the collective nature of these ambient schemes, efficiency of the policy may become a concern (Xepapadeas, 2011). However, since ambient policies have not been carried out on a large scale in practice, the lack of empirical data leads to the use of economic experiments as test beds for these policy schemes. A stream of literature has shown both theoretically and experimentally that various types of ambient schemes could lead to effectively attaining the target level of pollution (Xepapadeas, 1992; Spraggon, 2002; Alpízar, Requate, and Schram, 2004; Poe et al. 2004).

Most of the research in this area has focused on homogenous agents partly for simplicity, and partly due to the suggestion that watershed settings that mostly consist of a small number of homogenous farmers would be most conducive to the application of ambient-based policies (Weersink et al., 1998; Suter, Vossler, and Poe, 2009). A few researchers have made efforts to add heterogeneity in different directions. Spraggon (2004, 2013) and Suter, Vossler, and Poe (2009) consider the heterogeneity in the size of the polluters. Spraggon (2004) concluded that ambient policies could be designed to induce target pollution levels for heterogeneous sized farmers at the cost of substantial inefficiency and inequality. Suter, Vossler, and Poe (2009) extended Spraggon (2004) by adding a watershed context and showed size heterogeneity has an impact on group decisions and may generate desirable or undesirable outcomes depending on specific conditions.

Another type of heterogeneity that has drawn more attention recently is spatial heterogeneity of agents. In reality, environmental monitoring is generally done at certain fixed spatial locations. The spatial location of a polluter relative to the monitoring point has significant impact to the tested environmental damage since pollutants will be diluted in the course of travel. A growing body of research has shown that spatial heterogeneity could influence agent decisions especially in common pool resource settings (e.g., Schnier 2009; Suter et al. 2012; Li et al. 2014; Liu et al. 2014). Cason and Gangadharan (2013) included spatial heterogeneity in terms of proximity to the monitoring station to study the effectiveness of informal neighbor punishment versus a formal ambient tax. In an ambient tax/subsidy experiment that included a realistic physical nutrient transport model to calculate the marginal damage of each spatially explicit polluter, Miao et al. (2016) tested the effect of increasing the frequency of water monitoring on firm decisions.

Informal ways to reduce non-point source pollution have also been investigated in laboratory experiments. Cason and Gangadharan (2013) reported that a formal ambient tax is more effective than empowering neighbors to be able to punish each other after observing their group members' emissions and the formal mechanism can be improved by adding peer punishment. Suter et al. (2008) showed communication would lower the emission level to below the social optimal level.

However, past research has not focused much on using information nudges to improve the performance of ambient based policies. Such information nudges usually use narrative messages – especially about how their behavior compare with others – to influence human behavior. These nudges originate from social comparison theory by Festinger (1954), which posits that people evaluate the appropriateness of their behavior by comparing with others. Past research has demonstrated that this principle could be used to promote environmental conservation, such as reducing power consumption (Allcott, 2001), reducing water usage (Ferraro and Price, 2013; Bernedo, Ferraro and Price, 2014), and environmental conservation behavior in hotels (Goldstein et al., 2008).

It is reasonable to assume that such information nudges could be utilized in non-point source pollution management to induce better decisions, but few work focused on this topic. Spraggon (2013) varied the information the participants have on the number of other polluters and their payoffs. His study concluded that while information and heterogeneity do not affect aggregate level policy effectiveness, they both reduce policy efficiencies. In Spraggon and Oxoby (2010), they show that providing participants with a description of marginal decision making increases optimal strategy behavior, thus increases policy efficiency. This “recommended play” still focuses mainly on the private decision of the participants themselves.

We are interested in exploring how information on others’ or the group’s behavior would influence participant’s own decision making. We examine the effect of two types of information nudges on participants’ behavior. Specifically, we explore if information on past group technology adoption rate and group average production would impact participant behavior, and if testimonial information on what others have done in the same situation would serve as a guideline on individual decisions. Corresponding policy schemes could be designed to improve the effectiveness and efficiency of existing policies.

By combining all the previously mentioned pieces together, our study contributes to the literature in several ways. First, we extend participants' decision spaces to include both production and technology decisions. Second, unlike past literature where at most one type of heterogeneity is taken into account, our setting includes size heterogeneity, spatial heterogeneity and also the combination of both types of heterogeneity simultaneously. Third, we examine if and how information nudges could be used to improve policy performance in the NPS context. By including an extended decision space (production and adoption decisions), multiple layers of heterogeneity (size and location), and information nudges (social comparison and peer actions), our experiment evaluates the performance of ambient-based policies under these interactive effects.

3. Model

3.1 Model Background

Following the classic set up of NPS pollution experiments, participants play the role of farmers that operate within a single watershed and make farm management decisions that affect ambient water pollution. The farmers are price-takers of an exogenously determined price for their products. The production generates a byproduct, which we refer to as emissions (e.g., excessive fertilizers that run off the farm during rain), and incurs a social cost to the environment (e.g., pollution in downstream watersheds). The farmers have the option to choose to adopt a pollution abatement technology (e.g., buffers that could reduce runoff of excessive nutrients) at a fixed cost ratio relative to the size of the farm. The technology would reduce the pollution that farmer generates at a constant rate. Therefore, the farmers make two decisions, a production decision and an adoption decision. A regulator monitors the density of emission at downstream and has perfect information on the aggregate emission levels. We assume the regulator has no information on individual production/emission levels, but has knowledge on the average production and average adoption rate of people in the group. The regulator may impose an ambient tax or subsidy based on the observed downstream emission level.

3.2 Model Setup

We start the discussion with a homogenous case. Suppose there are N farmers along the river, the private income function for a farmer is identical among the participants, and the form is similar to the one used in Spraggon (2002) and subsequent literature (e.g., Suter, Vossler, and Poe 2009; Spraggon 2013; Cason and Gangadharan 2013; Miao et al. 2016):

$$B(x_i) = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2$$

Where γ_i are parameters and x is the decision variable. Individual profit is maximized when $x_i = \gamma_2$ and γ_2 can be regarded as firm's capacity.

By producing x_i the farmer also generates environmental damage. The damage function follows Spraggon (2002) and can be denoted as $D(x_i) = \beta_0 x_i$, therefore the total environmental damage is $TD = \sum_1^N D(x_i) = \sum_1^N \beta_0 x_i$

The social planner's problem is to maximize the social benefit (denoted as SP), where

$$SP = \sum_{i=1}^{N} B(x_i) - \sum_{i=1}^{N} D(x_i)$$

The first order condition indicates that the optimal level of production is at $x_i = \gamma_2 - \frac{\beta_0}{2\gamma_1}$, which is smaller than the private optimal for individual farmer γ_2 since β_0 and γ_1 are both positive parameters.

3.2.1 Tax/Subsidy Scheme:

Consider a government-imposed a tax/subsidy scheme designed in a manner similar to Segerson (1988) and other subsequent literature where the tax equals the environmental damage minus the target level of pollution,

$$t(TD) = (TD - \overline{D})$$

where $\overline{D}$ is the environmental damage target that the regulator sets.

Now the individual payoff function under the tax/subsidy scheme becomes:

$$\pi_i = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - \left(\sum_{1}^{N} \beta_0 x_i - \overline{D}\right),$$

Solving for optimal x_i we get $x_i = \gamma_2 - \frac{\beta_0}{2\gamma_1}$, note that this is a unique, dominant strategy Nash Equilibrium.

Under the tax/subsidy scheme, the social planner's problem remains unchanged, and the optimal $x_i = \gamma_2 - \frac{\beta_0}{2\gamma_1}$, meaning that the farmers produce at the socially optimal level.

3.2.2 Technology:

Now consider that we provide a technology that is available for adoption to the farmers at a fixed cost ratio τ relative to firm's capacity γ_2, the technology could reduce environmental damage to a rate of α <1 of the original level.

Specifically, by adopting the technology, the private income function of a farmer is now:

$$B(x_i) = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - \tau\gamma_2$$

and the environmental damage caused by each firm is reduced to $D(x_i) = \beta_0 \alpha x_i$

We find the equilibrium by backward induction. Consider firm i, given the pollution level of others in the group D_{-i}, its profit function from producing x_i and adopting the technology is:

$$\pi^A = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - (D_{-i} + \beta_0 \alpha x_i - \overline{D}) - \tau\gamma_2$$

$$\frac{\partial \pi^A}{\partial x_i} = 2\gamma_1(\gamma_2 - x_i) - \beta_0\alpha = 0$$

$$x_i^A = \gamma_2 - \frac{\beta_0 \alpha}{2\gamma_1}$$

Plug in the optimal production level to get the maximum profit of adopting the technology:

$$\pi^A = \gamma_0 - \frac{(\beta_0\alpha)^2}{4\gamma_1} - \left(D_{-i} - \overline{D} + \beta_0\alpha\gamma_2 - \frac{\beta_0^2\alpha^2}{2\gamma_1}\right) - \tau\gamma_2$$

Consider firm i, given the same pollution level from others D_{-i}, firm's profit function of not adopting the technology and producing at x_i is:

$$\pi^N = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - (D_{-i} + \beta_0 x_i - \overline{D})$$

$$\frac{\partial \pi^N}{\partial x_i} = 2\gamma_1(\gamma_2 - x_i) - \beta_0 = 0$$

$$x_i^N = \gamma_2 - \frac{\beta_0}{2\gamma_1}$$

The maximized profit of not adopting is:

$$\pi^N = \gamma_0 - \frac{{\beta_0}^2}{4\gamma_1} - \left(D_{-i} - \overline{D} + \beta_0\gamma_2 - \frac{\beta_0^2}{2\gamma_1}\right)$$

In order for the farmer to prefer adopting the technology, it requires $\pi^N < \pi^A$.

Solving for these conditions, we get the following restrictions on the parameters for the farm to adopt the technology:

$$\frac{\beta_0^2}{4\gamma_1}(1-\alpha^2) - \beta_0\gamma_2(1-\alpha) + \tau\gamma_2 < 0$$

Under this condition, we solved for a unique, dominant strategy Nash Equilibrium for this homogeneous case. At this equilibrium:

(1) Firms adopt the technology

(2) Firms choose production level

$$x_i = \gamma_2 - \frac{\beta_0\alpha}{2\gamma_1}$$

3.3 Heterogeneity

The above sections were the homogeneous case, in this part we introduce both spatial and production heterogeneity

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3.3.1 Spatial Heterogeneity:

We introduce spatial heterogeneity in a similar fashion as Cason and Gangadaran (2013). Specifically, the firms are positioned at different geographical proximity relative to the monitoring point, which is located at the downstream of the river. We assume the emissions from the firms closer to the monitoring point generate larger recorded environmental damage than firms further from the monitoring point. As explained in Cason and Gangadaran (2013), this is because the pollutants from the upstream firms are more diluted as they arrive at the monitoring point, while the emissions from the downstream firms are more concentrated. Miao et al. (2016) also introduces spatial heterogeneity by imposing a nutrient transport model to calculate the marginal damage of each farmer. The model includes two effects in determining pollutant concentration, the duration effect, which increases the marginal damage of upstream farmers, and the magnitude effect, which increases marginal damage of downstream farmers. Depending on parameterization of the model, either effect may dominate. We follow the heterogeneity introduced in Cason and Gangadaran (2013) since it would allow us to solve for a closed form solution and it creates less complexity for participants in the experiment.

Specifically, let β_i denote the marginal environmental damage from emissions generated by firm i. The environmental damage caused by firm i can thus be written as $D_i(x_i) = \beta_i x_i$, and the total environmental damage is $TD = \sum_{i=1}^{N} D_i(x_i) = \sum_{i=1}^{N} \beta_i x_i$.

Given the same private profit function as before, under no policy scheme, the profit maximizing firm would produce at $x_i = \gamma_2$.

The social planner's problem could be solved in a similar fashion, resulting in an optimal production level at $x_i = \gamma_2 - \frac{\beta_i}{2\gamma_1}$.

Imposing a tax/subsidy scheme as before, we would be able to solve for the private optimal production level under policy, which is $x_i = \gamma_2 - \frac{\beta_i}{2\gamma_1}$. The corresponding socially optimal level under tax/subsidy, which is the same as without tax, is $x_i = \gamma_2 - \frac{\beta_i}{2\gamma_1}$. Therefore, the private optimal agrees with the social optimal.

Now consider we apply a similar technology, which requires an installation cost $\tau\gamma_2$, but reduces environmental damage to a rate α of the original level.

Similar as before, by adopting the technology, the private income function of a farmer is:

$$B(x_i) = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - \tau\gamma_2$$

and the environmental damage caused by each firm is reduced to $D_i(x_i) = \beta_i \alpha x_i$

We again find the equilibrium by backward induction. Consider firm i, given the pollution level of others in the group D_{-i}, its profit function from producing x_i and adopting the technology is:

$$\pi_i^A = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - (D_{-i} + \beta_i \alpha x_i - \overline{D}) - \tau\gamma_2$$

$$\frac{\partial \pi^A}{\partial x_i} = 2\gamma_1(\gamma_2 - x_i) - \beta_i \alpha = 0$$

$$x_i^A = \gamma_2 - \frac{\beta_i \alpha}{2\gamma_1}$$

Plug in the optimal production level to get the maximum profit of adopting the technology:

$$\pi_i^A = \gamma_0 - \frac{(\beta_i \alpha)^2}{4\gamma_1} - \left(D_{-i} - \overline{D} + \beta_i \alpha \gamma_2 - \frac{\beta_i^2 \alpha^2}{2\gamma_1}\right) - \tau\gamma_2$$

Consider firm i, given the same pollution level from others D_{-i}, firm's profit function of not adopting the technology and producing at x_i is:

$$\pi_i^N = \gamma_0 - \gamma_1(\gamma_2 - x_i)^2 - (D_{-i} + \beta_i x_i - \overline{D})$$

$$\frac{\partial \pi^N}{\partial x_i} = 2\gamma_1(\gamma_2 - x_i) - \beta_i = 0$$

$$x_i^N = \gamma_2 - \frac{\beta_i}{2\gamma_1}$$

The maximized profit of not adopting is:

$$\pi_i^N = \gamma_0 - \frac{{\beta_i}^2}{4\gamma_1} - \left(D_{-i} - \overline{D} + \beta_i\gamma_2 - \frac{\beta_i^2}{2\gamma_1}\right)$$

We parameterize the heterogeneity treatment of this experiment so that depending on β_i, half of the farmers prefer to adopt, and half of the farmers prefer not to adopt. In order for the farmer to prefer adopting the technology, it requires $\pi^N < \pi^A$.

Solving for these conditions, we get the condition for a farmer to prefer adopting:

$$\frac{\beta_i^2}{4\gamma_1}(1-\alpha^2) - \beta_i\gamma_2(1-\alpha) + \tau\gamma_2 < 0$$

By setting different β_i, we can create a unique dominant strategy Nash Equilibrium so that it is optimal for some farmers to adopt, some not to adopt, depending on their proximity to the monitoring point.

3.3.2 Production Heterogeneity:

We next introduce production heterogeneity by varying the size of the farmers, in a similar way as Spraggon (2002). Recall in the case of homogenous production functions under no policy schemes, the farmers maximize their own profit by setting production at $x_i = \gamma_2$. Now suppose the farms are of different sizes, meaning that their maximum capacities are different. The production function for farmer i who does not adopt the technology is $B_i(x_i) = \gamma_0 - \gamma_1(\gamma_{2i} - x_i)^2$, for farmer i who adopts the technology is

$B_i(x_i) = \gamma_0 - \gamma_1(\gamma_{2i} - x_i)^2 - \tau\gamma_{2i}$. Farmers maximize their profit by producing at $x_i = \gamma_{2i}$.

When there is no location heterogeneity, the environmental damage caused by each farmer is $D(x_i) = \beta x_i$ without using technology, and $D(x_i) = \beta\alpha x_i$ with technology.

Solving for the social planner's problem, the socially optimal production level for each farmer is $x_i = \gamma_{2i} - \frac{\beta}{2\gamma_1}$.

With the same tax/subsidy policy scheme, the private optimal production level is $x_i = \gamma_{2i} - \frac{\beta}{2\gamma_1}$ and the socially optimal production level remains to be $x_i = \gamma_{2i} - \frac{\beta}{2\gamma_1}$.

Consider the decision of whether or not to adopt the technology, solving it in a similar fashion, we can get the optimal profit for a firm to adopt the technology is $\pi_i^A = \gamma_0 - \frac{(\beta\alpha)^2}{4\gamma_1} - \left(D_{-i} - \bar{D} + \beta\alpha\gamma_{2i} - \frac{\beta^2\alpha^2}{2\gamma_1}\right) - \tau\gamma_2$, which is reached by producing $x_i^A = \gamma_{2i} - \frac{\beta\alpha}{2\gamma_1}$, and for the farmer to not adopt the technology is $\pi_i^N = \gamma_0 - \frac{\beta^2}{4\gamma_1} - \left(D_{-i} - \bar{D} + \beta\gamma_{2i} - \frac{\beta^2}{2\gamma_1}\right)$, which can be reached by producing $x_i^N = \gamma_{2i} - \frac{\beta}{2\gamma_1}$. The condition for a farmer to prefer to adopt compared with not adopt is $\frac{\beta^2}{4\gamma_1}(1 - \alpha^2) - \beta\gamma_{2i}(1 - \alpha) + \tau\gamma_2 < 0$.

By setting different β and γ_i, we can create a unique dominant strategy Nash Equilibrium so that it is optimal for some farmers to adopt, some not to adopt, based on their farm size and spatial location.

3.3.3 Spatial and Production Heterogeneity:

Now, we include production heterogeneity and spatial heterogeneity simultaneously. As before, the production function for farmer i who does not adopt the technology is $B_i(x_i) = \gamma_0 - \gamma_1(\gamma_{2i} - x_i)^2$, for farmer i who adopts the technology is $B_i(x_i) = \gamma_0 - \gamma_1(\gamma_{2i} - x_i)^2 - \tau\gamma_{2i}$. Farmers maximize their profit by producing at $x_i = \gamma_{2i}$.

Meanwhile, the environmental damage caused by each farmer is $D_i(x_i) = \beta_i x_i$ without using technology, and $D_i(x_i) = \beta_i \alpha x_i$ with technology.

Solving for the social planner's problem, the socially optimal production level for each farmer is $x_i = \gamma_{2i} - \frac{\beta_i}{2\gamma_1}$.

With the same tax/subsidy policy scheme, the private optimal production level is $x_i = \gamma_{2i} - \frac{\beta_i}{2\gamma_1}$ and the socially optimal production level remains to be $x_i = \gamma_{2i} - \frac{\beta_i}{2\gamma_1}$.

Consider the decision of whether or not to adopt the technology, solving it in a similar fashion, we can get the optimal profit for a firm to adopt the technology is $\pi_i^A = \gamma_0 - \frac{(\beta_i\alpha)^2}{4\gamma_1} - \left(D_{-i} - \overline{D} + \beta_i\alpha\gamma_{2i} - \frac{\beta_i^2\alpha^2}{2\gamma_1}\right) - \tau\gamma_{2i}$, which is reached by producing $x_i^A = \gamma_{2i} - \frac{\beta_i\alpha}{2\gamma_1}$, and for the farmer to not adopt the technology is $\pi_i^N = \gamma_0 - \frac{\beta_i{}^2}{4\gamma_1} - \left(D_{-i} - \overline{D} + \beta_i\gamma_{2i} - \frac{\beta_i^2}{2\gamma_1}\right)$, which can be reached by producing $x_i^N = \gamma_{2i} - \frac{\beta_i}{2\gamma_1}$. The condition for a farmer to prefer to adopt compared with not adopt is $\frac{\beta_i^2}{4\gamma_1}(1-\alpha^2) - \beta_i\gamma_{2i}(1-\alpha) + \tau\gamma_{2i} < 0$. Therefore, the optimal strategies of the farms depend on their farm size and spatial location.

We parameterize the experiment so that when there is no spatial or size heterogeneity, it is optimal for everyone in the same group to adopt; when at least one type of heterogeneity is introduced, it is optimal for half of the people to adopt the technology, and the other half to not adopt.

3.4 Information:

Besides the baseline where no information is provided to the participants, we conduct two information treatments. Both information treatments include narrative messages on how the participant's decisions compare with others. In information treatment 1, we provide participants testimonial information on what production and technology adoption decisions people "like them" have made in the past. The idea is to use this information nudge to help people find their optimal strategies. To ensure that the information participants receive are truthful, the information we provide is generated by behavior of participants in the "no information" treatments. Conditioning on their size and location, we find the actual decisions made by participants that are closest to the Nash Equilibrium. Therefore, this information differs by the location and the size of the firm and approximates the actual Nash Equilibrium. This resembles some policy recommendation on what people should consider doing based on their location and size. In information treatment 2, we give participants information on the technology adoption rate and average production in their group in the last round. With this information, participants will have knowledge on their group members' peer actions and how they compare with others in the group. This is similar to a policy that provides information on what the majority of people in a neighborhood are doing and has a self-evolving nature.

Since our experiment features a dominant strategy Nash Equilibrium in each of the treatments, the optimal strategies are not influenced by the information treatments.

Therefore, if participants are fully rational, neither of the information treatments should influence their behavior. However, as demonstrated by previous studies, people evaluate the appropriateness of their behavior by comparing to others and may change their behavior accordingly [[cite which studies demonstrate this result]]. We are interested in see if these nudges could be used to increase the performance of ambient based policy.

4. Experimental Design

4.1 Treatments:

The basic setup of our experiment is a three by two design. As shown in Table 1, on the between subject level, we conduct three information treatments (including no information as the baseline). On the within subject level, we vary whether an ambient-based policy scheme is being implemented. Within each policy treatment, we further break up by heterogeneity treatments: homogeneous (H); heterogeneous type 1 (HT1) with only spatial heterogeneity; heterogeneous type 2 (HT2) with only production heterogeneity; and heterogeneous type 3 (HT3) with both spatial and production heterogeneity. We vary the order of the heterogeneity treatments that were presented. Four sessions were conducted for each information treatment resulting in 12 total sessions. Within each session, we have two groups of participants and each group consists of eight people.

[Table 1 here]

During the experiment, each participant makes five decisions in each policy/heterogeneity treatment. The groups are randomly reassigned after each policy/heterogeneity treatment. A five-round practice part is conducted at the beginning of each session to help participants familiarize themselves with the computer program.

After the experiment, we gather a few quick survey questions on participants' basic demographics.

4.2 Parameterization

The parameters of the experiment are shown in Table 2:

[Table 2 here]

Most of the parameters follow previous experiments in the literature. The parameters for size heterogeneity stem from Spraggon (2002) and location heterogeneity are based on Cason and Gangadaran (2013). For the homogeneous treatment, it is optimal for all the participants to choose to adopt; for the heterogeneous treatments, it is optimal for half of the participants to adopt, and the other half to not adopt. The social planner's optimal strategy to maximize social welfare agrees with the dominant strategies of each participant.

5. Hypotheses

We summarize the hypotheses in Table 3.

[Table 3 here]

5.1 Hypothesis 1

Hypothesis 1 focuses on the group-level effect of the ambient based policy. Without the Tax/Subsidy policy, subjects will pollute at their maximum level. With Tax/Subsidy in place, group level pollution would be reduced to the target level despite heterogeneity or information treatments.

5.2 Hypothesis 2

Hypothesis 2 deals with group-level policy efficiency. In information treatment 1, participants are given individual level information on what others like them have done, and such information relate to their optimal strategies. We posit this information nudge should improve policy efficiency. In information treatment 2, the average adoption and production levels in each group are provided to the participants. It is likely that participants would anchor their decisions to the group averages, but the direction that this nudge changes policy efficiency is ambiguous and we test it empirically.

5.3 Hypothesis 3

Hypothesis 3 aims at individual level decision making. Compared to no information baseline, we anticipate to observe an increase in optimal decision-making at the individual level for information treatment 1. However, for information treatment 2, the effect is unclear. Participants' decisions should be anchored towards the group average. If this anchoring is in the direction towards private optimal decisions, this information should increase the frequency of individual dominant strategies; however, if the anchoring effect biases decision making to a non-optimal direction, people should be further away from optimal.

6. Results

Twelve sessions were conducted in November and December, 2016 at a large public university in Northeastern United States with 192 participants. We analyze how the treatments affected individual and aggregate group pollution levels and policy efficiency.

6.1 Result 1

Without any information, group-level pollution is not significantly different from the target level under homogeneous case with ambient tax/subsidy. As more heterogeneity is introduced, group level pollution exceeds the target. Both information treatments make the group level pollution closer to the target level.

Figure 1 and Figure 2 depict the group aggregate pollution levels for the no policy and policy treatments. The four segments in each figure means four size and location homogeneity/heterogeneity treatments. The x-axis denotes round number (in total five) and y-axis represents environmental damage level. The red, green and blue lines indicate the average group pollution level for no information baseline, information treatment 1, and information treatment 2 scenarios, respectively. The segregated dots represent outliers. In the no policy treatments, the theoretical predicted pollution level is 240, which happens when everyone produces at their maximum without adopting the technology. In the no policy treatments, all groups are polluting close to their maximum level without much variation among the treatments. In Figure 2, when ambient policy is introduced, the black dotted lines represent the target group pollution level. In general, as more heterogeneity is introduced, the lines deviate more from the target pollution level. Besides, the green line (denoting information treatment 1) is generally closer to the target, especially compared to the red line.

[Figure 1 and Figure 2 here]

We next compare group pollution levels quantitatively. Table 4 suggests that aggregate pollution levels are not significantly different from the target levels in homogeneous cases for all information scenarios. With location heterogeneity only (Hetero1), the policy would still induce group level pollution to meet the target in no information and information treatment 2; Under information treatment 1, the group marginally under pollutes. When instead size heterogeneity is introduced (Hetero2), group pollution marginally exceeds the target level under no information, and does not significantly differ from the target under either information treatments. When two layers of heterogeneity are combined together, group level pollution significantly exceeds the target level in the no information case. With information treatment 2, the group level is marginally significantly different from the target while with information treatment 1 it is not significantly different.

[Table 4 here]

The aggregated results reinforce our findings. When all information treatments are combined, we find that the group level pollutions are not significantly different from the target in homogeneous and heterogeneity 1 treatments, but are significantly different from the target at 5% level in heterogeneity 2 and at 1% level in heterogeneity 3 treatments, as shown in the last column of Table 4. When we instead combine homogeneous/heterogeneous treatments and compare the effects of information treatments (as shown in the last row of Table 4), we find that overall the group pollution level is significantly different from the target level at 5% in no information treatment, but not significantly different from the target level in the other two information treatments.

6.2 Result 2

From a social planner's perspective, policy efficiency decreases as more heterogeneity is introduced, however both information treatments increase efficiency.

Similar to Spraggon (2013), efficiency is defined as the change in the value of the social planner's problem as a percentage of the optimal change in the social planner's problem. The social planner's problem for a group could be formulated as follows:

$$SP = \sum_{i=1}^{8} [\gamma_0 - \gamma_1 * (\gamma_2 - x_i)^2 - a_i * \tau * \gamma_2 - a_i * \alpha * \beta_i * x_i - (1 - a_i) * \beta_i * x_i]$$

Efficiency is calculated as:

$$E = \frac{SP_{Actual} - SP_{StatusQuo}}{SP_{Optimal} - SP_{StatusQuo}}$$

where SP_{Actual} is the actual value of the social planner's problem when calculated using the actual decisions of the participants; $SP_{Optimal}$ is the optimal value of the social planner's problem when the participants all choose their optimal production and technology decisions; $SP_{StatusQuo}$ is the value of the social planner's problem when all participants choose to produce at their maximum and do not adopt the technology. Theoretically, $SP_{Optimal}$ and $SP_{StatusQuo}$ should correspondingly be the upper and lower bounds of the social planner's problem. Therefore, efficiency is a value between 0 and 1. Table 5 presents efficiency values by heterogeneity and information treatments. Only the treatments with policy are presented here since there is no policy efficiency in the no policy treatments.

[Table 5 here]

We observe that policy efficiency is highest for information treatment 1, then followed by information treatment 2, and the lowest is no information treatment. Meanwhile, as more heterogeneity is introduced, policy efficiency decreases. In the homogeneous treatments, on average the tax/subsidy policy achieved 88.13% efficiency, while in heterogeneous 3 treatments where both location and size heterogeneities were introduced, the average policy efficiency was only 72.77%.

We also construct a random effects regression model at the group level to understand how efficiency is influenced by treatments. The regression is written as:

$$Efficiency_i = \alpha + \beta_1 * Hetero1_{it} + \beta_2 * Hetero2_{it} + \beta_3 * Hetero3_{it} + \beta_4 * Info1_{it} + \beta_5 * Info2_{it} + \beta_6 * Hetero1\_info1_{it} + \beta_7 * Hetero1\_info2_{it} + \beta_8 * Hetero2\_info1_{it} + \beta_9 * Hetero2\_info2_{it} + \beta_{10} * Hetero3\_info1_{it} + \beta_{11} * Hetero3\_info2_{it} + \beta_{12} * round_{it} + \beta_{13} * round\_sq_{it} + v_i + e_{it}$$

where v_i is individual level random effects, e_{it} is individual and time specific error term.

[Table 6 here]

As shown in Table 6, heterogeneous treatment 1 increases efficiency by 0.002 percentage points, heterogeneous treatment 2 and 3 decrease efficiency by 14.14 and 13.39 percentage points, respectively. Meanwhile, information treatment 1 increases efficiency by 10.08 percentage points and information treatment 2 increases efficiency by 8.69 percentage points (marginally significant); however, a Wald test suggests that we cannot reject that these effects are statistically the same. The interaction terms of information and heterogeneity, round and round-squared controls are not significant at the 5% level.

This result suggests that policy efficiency decreases as more heterogeneity is introduced, and increases in either of the information treatments. Though it appears that information 1 generates higher policy efficiency compared to information 2, this effect is not statistically significant.

6.3 Result 3

At the individual decision level, introducing more heterogeneity leads to larger deviations of pollution from theoretical pollution predictions, and both information treatments reduce deviations from theoretical values.

As discussed in previous sections, there exists a unique dominant strategy Nash Equilibrium for each of the participant's decisions. We calculate the predicted pollution levels based on theoretical predicted production and adoption decisions. We are ultimately interested in how people's decisions deviate from theoretical predictions (which is also the socially optimal decisions) and how to induce better behavior by reducing this deviation from both directions (over and under pollute). Therefore, instead of simply taking the difference of the individual pollution level to the theoretical level, we calculate the absolute deviation of the two values. To standardize the deviation across all treatments, we calculate a percent absolute difference from the actual pollution level, predicted pollution level and the maximum pollution level, similar to the metric used in Spraggon (2013). Specifically,

$$\text{PerAbsDiff}_i = \left|\frac{p_i - p_i^*}{p_i^{max}}\right|$$

where p_i represents the actual pollution level by participant i; p_i^* stands for the theoretical predicted Nash Equilibrium pollution level of participant i; p_i^{max} is the maximum pollution level of participant i.

6.3.1 Individual Results by Treatment

We run a random effects model that includes indicators for treatments and their interactions, as well as round and round squared variables to control for learning effects. The regression model is as follows:

$$PerAbsDiff_i = \alpha + \beta_1 * Hetero1_{it} + \beta_2 * Hetero2_{it} + \beta_3 * Hetero3_{it} + \beta_4 * Info1_{it} + \beta_5 * Info2_{it} + \beta_6 * Hetero1\_info1_{it} + \beta_7 * Hetero1\_info2_{it} + \beta_8 * Hetero2\_info1_{it} + \beta_9 * Hetero2\_info2_{it} + \beta_{10} * Hetero3\_info1_{it} + \beta_{11} * Hetero3\_info2_{it} + \beta_{12} * round_{it} + \beta_{13} * round\_sq_{it} + v_i + e_{it}$$

where v_i is individual level random effects, e_{it} is individual and time specific error term.

We conduct separate regressions for the no policy treatments and policy treatments and the results are listed below:

[Table 7 here]

In the no policy treatments, the heterogeneity and information treatments alone do not affect the deviation of actual pollution levels to the theoretical predictions. However, for information treatment 1, deviations decrease significantly for heterogeneity 2 and heterogeneity 3 treatments, meaning that in hetero2 and hetero3 treatments with individual information, participants are less likely to deviate from their Nash Equilibrium.

When we look at the data with the tax/subsidy policy instrument (the last three columns of Table 7), participants deviate more from the Nash predictions in HT2 and HT3 treatments compared to the homogeneous (H) treatment, and the deviation decreases in both info 1 and info 2 treatments. The interaction terms suggest that in treatments under information 1, the deviation from Nash in hetero 1 treatment is significantly more than the homogeneous treatment. Similarly, under information treatment 2, hetero1, 2 and 3 treatments all have significantly higher deviation than the homogeneous treatment under information 2. This suggests that people are able to find and retain their Nash equilibrium better in both information treatment 1 and information treatment 2, compared to no information baseline. Also, heterogeneity has less effect on deviation from Nash in information treatment 1 than in information treatment 2, meaning that individual level more tailored information helps people better overcome the heterogeneity.

An explanation for the more robustness of information treatment 1 to heterogeneity compared to information treatment 2 is that in information treatment 1, the social comparisons are individual level, which takes into account heterogeneity by providing different information based on different sizes and locations. However, information 2 provides group level information about average peer actions. As more heterogeneity is introduced, the span of every individual's optimal strategy is wider. Anchoring to the group average values no longer accounts for heterogeneity, and therefore we observe more deviations from the theoretical predictions.

6.3.1 Individual Results by Information, Location and Size

Next, we test how information treatments affect deviations from theoretical predicted values across different sizes and locations of farms.

The first three columns of Table 8 denote results from the No Policy treatments. Almost all of the variables are insignificantly different from zero. This means that regardless of the information treatment, size or location, people are generally polluting at the maximum level, which is in line with the theoretical prediction.

[Table 8 here]

The last three columns demonstrate results from treatments with the ambient based policy. Several results are worth pointing out: first, compared to medium sized farms, small farms deviate more from the target pollution level; second, farms at the most downstream marginally deviate more from the predicted level compared to a farm in midstream; third, both information treatments reduce deviations from the theoretical prediction; forth, interactions of information and size, interactions of information and location are widely insignificant, meaning that information treatments are equally effective to participants with different farm size or location.

Compared to results from the previous subsection, these results demonstrate that both types of information nudges have impacts on people's decision making. Moreover, the impact appears to have identical effects for farms at different locations or with different sizes, meaning that people's responses to information nudges are robust to their relative size and location. This result adds confidence in using information nudges based on social comparison theory as a policy intervention since it is equally effective to different subgroups of people.

7. Conclusions

In our study, we conduct an experiment on non-point source water pollution with location and size heterogeneity and an extended decision space that includes both a production and a technology decision. We find that as more heterogeneity is introduced, the ability for the tax/subsidy policy instrument to reduce group pollution to the target level decreases. However, the tax/subsidy policy increases its effectiveness with the introduction of two information nudges based on social comparison theory. In information treatment 1, people are provided with information on what others like them have done in the past, based on the size and location of their farm. In information treatment 2, we give people information on the mean production and adoption levels in their group in the past round. We further demonstrate that policy efficiency is negatively affected by heterogeneity but can be improved by either information treatment. Comparing individual pollution levels to Nash predictions, besides the findings that heterogeneity increases deviations from Nash and information decreases them, we observe that individual level information is more robust to heterogeneity compared to group level information. Furthermore, we find that both information treatments are equally effective to individuals possessing farms at different sizes or locations.

As a conclusion, the results suggest that introducing more heterogeneity and a more complex decision space result in ineffectiveness of the classic tax/subsidy ambient policy, but information nudges based on social comparison and peer actions are able to help the performance of the policy and more individually targeted information works better in terms of policy efficiency and individual level decision making. From a policy perspective, it is important to consider multiple layers of heterogeneity as well as a more complex decision space when designing ambient based policies, but information nudges have the potential to improve the performance of ambient based policies in a cost–effective way.

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Table 1. Treatment Orders

No Info	Session 1	No Policy				Policy			
		Homo	Hetero1	Hetero2	Hetero3	Homo	Hetero1	Hetero2	Hetero3
	Session 2	No Policy				Policy			
		Hetero3	Hetero2	Hetero1	Homo	Hetero3	Hetero2	Hetero1	Homo
	Session 3	Policy				No Policy			
		Homo	Hetero1	Hetero2	Hetero3	Homo	Hetero1	Hetero2	Hetero3
	Session 4	Policy				No Policy			
		Hetero3	Hetero2	Hetero1	Homo	Hetero3	Hetero2	Hetero1	Homo
Info 1	4 sessions identical to No Info but with Information Treatment 1								
Info 2	4 sessions identical to No Info but with Information Treatment 2								

Table 2. Parameter Choice

Parameter	Value	Parameter	Value
γ_0	40	γ_1	0.0025
γ_2	75, 100, 125	τ	0.082
α	0.5	β_i	0.24,0.28,0.32,0.36
β	0.30		

Table 3. Hypotheses Table

Topic	Hypotheses	Results
Group Level Pollution	H_0: 1. $Pollution_{NP} = Pollution_{Max}$ 2. $Pollution_{P\_Homo} = Pollution_{Target\_Homo}$ 3. $Pollution_{P\_Hetero1} = Pollution_{Target\_Hetero1}$ 4. $Pollution_{P\_Hetero2} = Pollution_{Target\_Hetero2}$ 5. $Pollution_{P\_Hetero3} = Pollution_{Target\_Hetero3}$ 6. $Pollution_{P\_NoInfo} = Pollution_{Target}$ 7. $Pollution_{P\_Info1} = Pollution_{Target}$ 8. $Pollution_{P\_Info2} = Pollution_{Target}$	 1. Fail to reject H_0 2. Fail to reject H_0 3. Fail to reject H_0 4. Reject H_0 5. Reject H_0 6. Reject H_0 7. Fail to reject H_0 8. Fail to reject H_0
Group Level Efficiency	H_0: 1. $Efficiency_{NoInfo} = Efficiency_{Info1}$ 2. $Efficiency_{NoInfo} = Efficiency_{Info2}$ 3. $Efficiency_{Info1} = Efficiency_{Info2}$	 1. Reject H_0 2. Reject H_0 3. Fail to reject H_0
Individual Level Pollution	H0: 1. $Pollution_{NP} = Pollution_{Predicted}$ 2. $\beta_{Deviation\_P\_Hetero} = 0$ 3. $\beta_{Deviation\_P\_Info1} = 0$ 4. $\beta_{Deviation\_P\_Info2} = 0$	 1. Fail to reject H_0 2. Reject H_0 3. Reject H_0 4. Reject H_0

Table 4. Mean Group Total by Treatment

	Target	No information	Information treatment 1	Information treatment 2	Total
Homo (no heterogeneity)	84	89.96 (5.13) [8]	83.90 (2.44) [8]	81.89 (3.54) [8]	85.25 (2.25) [24]
Hetero1 (location hetero)	94.4	93.41 (6.49) [8]	90.79* (2.35) [8]	89.73 (4.32) [8]	91.31 (2.61) [24]
Hetero 2 (size hetero)	75	81.42* (3.43) [8]	76.39 (3.76) [8]	80.60 (4.15) [8]	79.47** (2.14) [24]
Hetero 3 (location & size hetero)	73	85.93** (4.99) [8]	78.47 (4.66) [8]	76.19* (1.93) [8]	80.20*** (2.42) [24]
Total		87.68** (2.56) [32]	82.38 (1.92) [32]	82.10 (1.93) [32]	84.06** (1.26) [96]

Each cell contains mean, (standard error) and [number of observations]. *, **, *** indicate significant at 10%, 5% and 1% level, respectively.

Table 5. Group Efficiency Level by Treatment

	No info	Info1	Info2	Total
Homo	81.87% (0.087) [8]	93.98% (0.046) [8]	88.53% (0.11) [8]	88.13% (0.096) [24]
Hetero1	79.61% (0.12) [8]	90.73% (0.038) [8]	83.41% (0.083) [8]	84.59% (0.094) [24]
Hetero2	67.91% (0.083) [8]	86.44% (0.066) [8]	71.47% (0.11) [8]	75.27% (0.12) [24]
Hetero3	66.81% (0.11) [8]	78.34% (0.13) [8]	73.18% (0.058) [8]	72.77% (0.11) [24]
Total	74.05% (0.12) [32]	87.37% (0.095) [32]	79.15% (0.11) [32]	80.19% (0.12) [72]

Each cell contains mean, (standard error) and [number of observations].

Table 6. Random Effects Model on Group Efficiency and Treatment Variables

	Coefficient	Std. Err.	P-Value
Hetero1	0.002	0.046	0.962
Hetero2	-0.141	0.040	0.000
Hetero3	-0.134	0.047	0.005
Info1	0.101	0.035	0.004
Info2	0.087	0.048	0.072
Info1_hetero1	-0.040	0.055	0.468
Info1_hetero2	0.052	0.058	0.371
Info1_hetero3	0.018	0.061	0.774
Info2_hetero1	-0.017	0.063	0.791
Info2_hetero2	-0.017	0.069	0.805
Info2_hetero3	-0.015	0.063	0.816
Round	0.002	0.010	0.833
Round_sq	-0.001	0.002	0.705
Constant	0.819	0.033	0.000
Num. of Obs.	480		
Num. of groups	96		
Wald chi2	111.52		
Prob > chi2	0.000		

All standard errors are clustered as group level.

Table 7. Random Effects Model on Individual Pollution and Treatment Variables

	Without Policy			With Policy		
	Coeffi.	Std. Err.	P-value	Coeffi.	Std. Err.	P-value
Hetero1	-0.002	0.008	0.788	0.006	0.009	0.517
Hetero2	-0.002	0.008	0.762	0.032	0.009	0.000
Hetero3	-0.001	0.008	0.888	0.054	0.009	0.000
Info1	-0.008	0.018	0.671	-0.072	0.162	0.000
Info2	-0.018	0.018	0.310	-0.056	0.162	0.001
Info1_hetero1	-0.017	0.011	0.107	0.043	0.012	0.001
Info1_hetero2	-0.025	0.011	0.016	0.017	0.012	0.181
Info1_hetero3	-0.030	0.011	0.004	0.012	0.012	0.351
Info2_hetero1	0.006	0.011	0.580	0.028	0.012	0.027
Info2_hetero2	0.003	0.011	0.754	0.038	0.012	0.003
Info2_hetero3	0.002	0.011	0.824	0.028	0.012	0.026
Round	-0.006	0.006	0.250	-0.002	0.007	0.731
Round_sq	0.001	0.001	0.379	0.0004	0.001	0.708
Constant	0.063	0.015	0.000	0.137	0.014	0.000
Num. of Obs.	3840			3840		
Num. of groups	192			192		
Wald chi2	26.68			229.13		
Prob > chi2	0.0138			0.0000		

All standard errors are clustered at individual level.

Table 8. Random Effects Model on Individual Pollution, Size, Location and Information.

	Without Policy			With Policy		
	Coeffi.	Std. Err.	P-value	Coeffi.	Std. Err.	P-value
Info1	-0.0108	0.018	0.556	-0.060	0.017	0.001
Info2	-0.0166	0.020	0.407	-0.047	0.020	0.020
Large	0.0003	0.009	0.968	0.005	0.014	0.725
Small	-0.0017	0.011	0.876	0.075	0.017	0.000
Region1	0.0035	0.017	0.832	0.013	0.015	0.412
Region2	-0.0054	0.008	0.521	0.002	0.020	0.928
Region3	-0.0080	0.006	0.214	0.006	0.013	0.655
Region4	0.0082	0.013	0.525	0.034	0.018	0.065
Info1_large	-0.0193	0.011	0.072	-0.003	0.017	0.882
Info1_small	-0.0196	0.013	0.138	-0.012	0.024	0.610
Info1_region1	-0.0089	0.019	0.637	0.016	0.023	0.501
Info1_region2	-0.0148	0.012	0.220	0.024	0.026	0.361
Info1_region3	-0.0035	0.010	0.728	0.019	0.019	0.296
Info1_region4	-0.0164	0.016	0.315	0.017	0.026	0.507
Info2_large	-0.0074	0.014	0.584	0.016	0.018	0.387
Info2_small	0.0073	0.015	0.630	0.022	0.023	0.344
Info2_region1	-0.0123	0.018	0.488	0.023	0.022	0.286
Info2_region2	-0.0015	0.013	0.909	0.022	0.025	0.391
Info2_region3	0.0245	0.016	0.137	0.008	0.024	0.744
Info2_region4	-0.0008	0.021	0.968	-0.017	0.026	0.510
Round	-0.0065	0.006	0.290	-0.002	0.006	0.684
Round_sq	0.0008	0.001	0.366	0.0004	0.001	0.649
Constant	0.0618	0.018	0.000	0.133	0.018	0.000
Num. of Obs.	3840			3840		
Num. of groups	192			192		
Wald chi2	35.02			148.06		
Prob > chi2	0.0385			0.0000		

All standard errors are clustered at individual level.

Figure 1 Group Pollution Levels for No Policy, by Treatments and Round

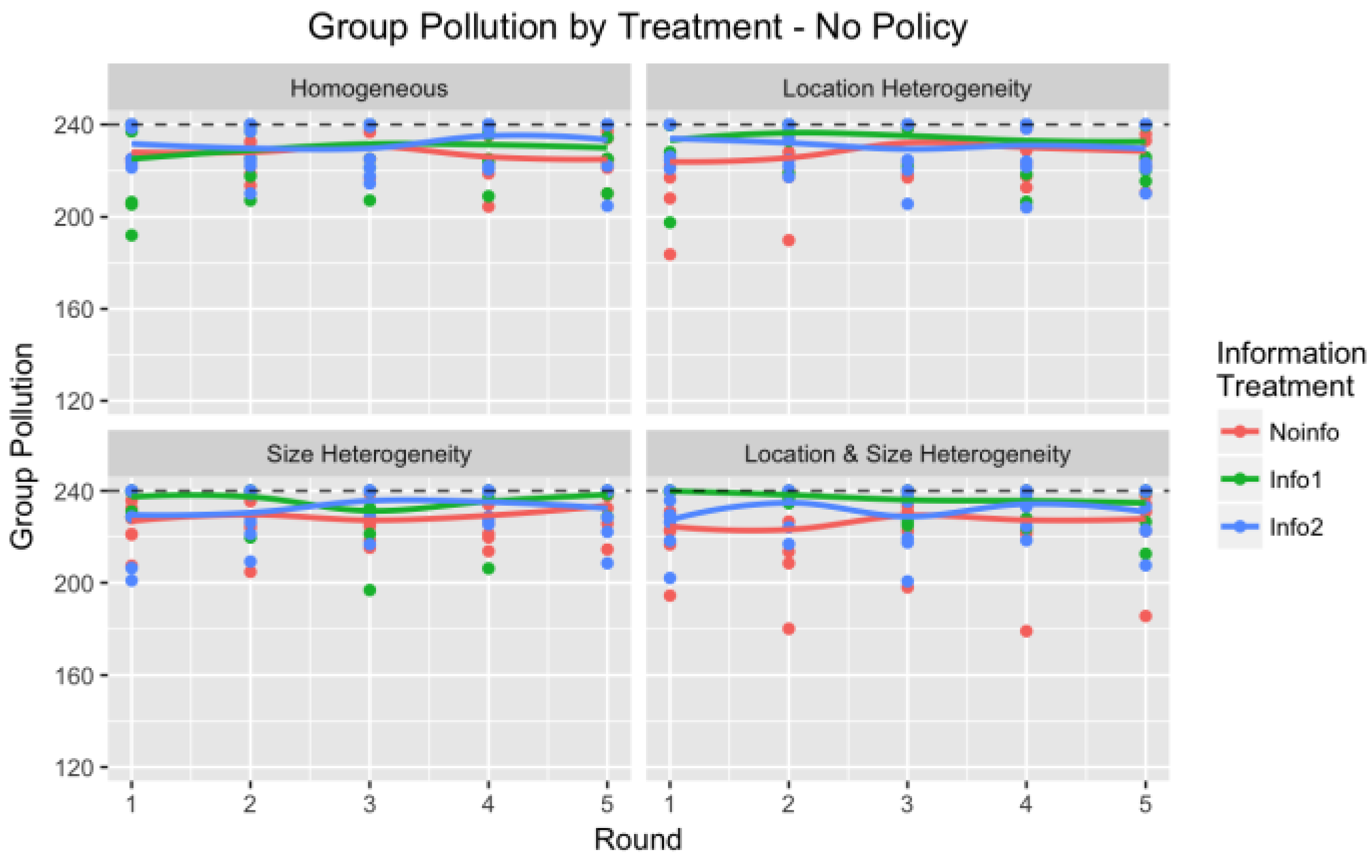
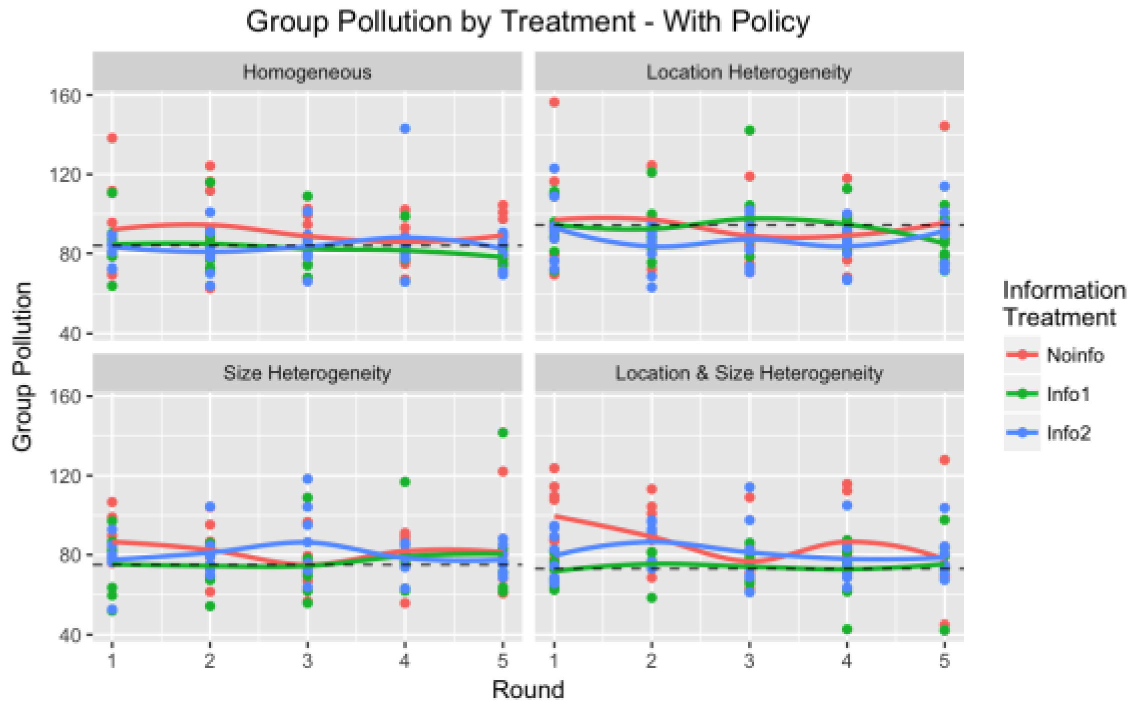


Figure 2 Group Pollution Levels for Policy, by Treatments and Round



Thank you for participating!

Please return the signed consent form to the administrator.

Please read and follow the instructions carefully and do not communicate with others during the experiment.

INTRODUCTION

This is an experiment about the economics of decision making. You will earn money during this experiment if you follow these instructions carefully and make informed decisions; otherwise, you may end up losing money. Any money earned during this experiment will initially be recorded as experimental dollars. At the end of this experiment, we will convert your experimental dollars into actual US dollars that will be handed to you as you leave. The more experimental dollars you earn the more actual US dollars you will receive. At the end of the experiment, your earnings will be converted at a rate of $1 US dollar for 50 experimental dollars. Please read these instructions carefully and do not communicate with any other participants during the experiment.

General Instructions: Today's experiment has several parts. Each part will have five rounds. Each round is independent, meaning that decisions during a round do not affect future rounds in any way. The only value that gets carried over across rounds is the cumulative amount of money you earn, which will be used to calculate your cash earnings at the end of the experiment.

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**.

Groups: Throughout the experiment, you will be in a group of eight people, each will play the role of a firm. Think of your firm and the seven other firms as being located near a river. Groups are randomly reassigned after each part of the experiment and you will not know who is assigned to each group.

Production and Production Income: Each business owner produces output that creates **Production Income**. Production income only depends on how much is produced. The more a firm produces, the more production income the firm will get.

Pollution: Production also generates pollution that goes into the river. In general, the higher the output being produced, the more pollution is being generated. Some concentration of this pollution is harmless. However, if the concentration is too large, the pollution has negative effects to the environment.

Total Pollution: This is measured by a sensor downstream and is the sum of pollution for everyone in the same group.Capacity: The firms may have a different production capacity, which is the maximum amount your firm can produce. Each firm's capacity will be shown on the calculator in the corresponding part for that firm. There are three types of capacities: Large firms with a capacity of 125; medium firms with a capacity of 100; small firms with a capacity of 75.

Technology: At the beginning of each round, the firms may choose to adopt a technology at a cost proportional to your firm capacity. When adopted, the technology will reduce the firm's pollution to a certain percentage of the original level for that round.

Location: The firms may either be located in the same location or at different locations along a river. As shown in Figure 1, when the region is separated by lines, it means the region is being divided into Region 1 to Region 4. In this case, Region 1 is the most upstream and Region 4 is the most downstream. The further downstream your firm is the more pollution per unit of production will be recorded by the sensor. As shown in Figure 2, when there are no lines separating the region, it means all of the firms are placed in the same region. The actual capacity and location of the firm that you operate will be shown on your computer screen.

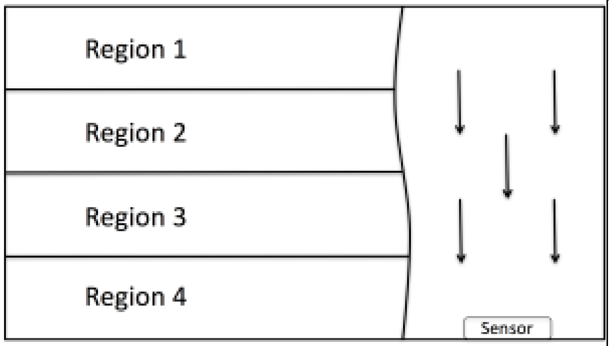


Figure 1. Different Locations

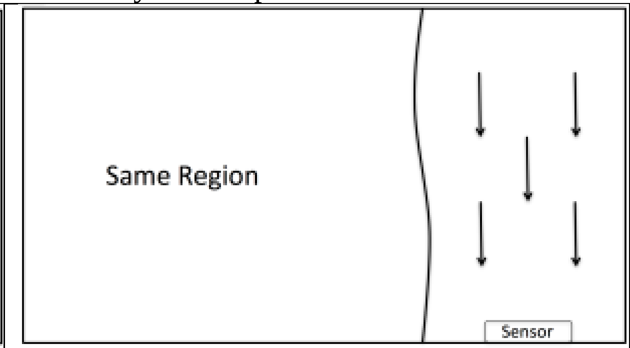


Figure 2. Same Location

Decisions: In each round, you will make two decisions:

(1) **Production Decision** – You will decide your firm's production level, between 0 and your firm's capacity.

(2) **Technology Decision** – You will choose whether to adopt a technology at a certain cost, labeled "Not Adopt" or "Adopt".

Pollution Table: To help you better understand the relationship of production, technology, location and pollution, you are given a **Pollution Table** that has pollution levels of a firm corresponding to different production decisions, technology decisions and location. Use this table to understand how your production would affect pollution based on your location and technology decision.

Firm Profit: Your **firm profit** is calculated based on your production decision and technology decision and will be explained to you in further details in each part of the experiment.

Decision Calculator: A **Decision Calculator** is provided to test different scenarios to see how the decisions of other firms in your group could affect Total Pollution and your Firm Profit. Follow the instructions on how to use this calculator provided on the next page.

In summary:

- In each part of the experiment, you will be given additional instructions and all calculations will be described.
- Your earnings from the experiment depend on your cumulative firm profit.
- Use the decision calculator to test out different scenarios and determine your own production and technology decision.
- Choose your own production and technology decision and click "Confirm".

- Your production income is affected by your production decision, technology decision, and firm capacity.
- Your pollution depends on your production decision, technology decision and firm location.
- A round of the experiment is complete when all eight players have made their production and technology decisions.
- After each part, participants will be randomly reassigned to a new group.

HOW TO USE THE DECISION CALCULATOR AND MAKE DECISIONS

In each round, you will be provided with a decision calculator like the one in the attached handout.

The layout of all firms and their corresponding capacity in your group is shown in the calculator.

Your firm is labeled "Your Firm" and marked with a black box.

Step 1. On the left part of the page, assume what everyone in your group will be doing by choosing a production and technology decision for every firm. To choose a production decision, move the slider or type in the amount that you think other firms will be producing; to choose a technology decision, simply choose between the "Not Adopt" and "Adopt" options. Note that your firm is labeled in the black box and you do not have to choose technology decision for your firm.

Step 2. On the top right part of the page, click "Calculate" and your pollution, total pollution and your profit of "Not adopt" and "Adopt" will be shown to you in the table right under the "Calculate" button.

Keep in mind that the decisions you make in the decision calculator are for informational purposes only and other firms can make their own decisions regardless of what you choose for them.

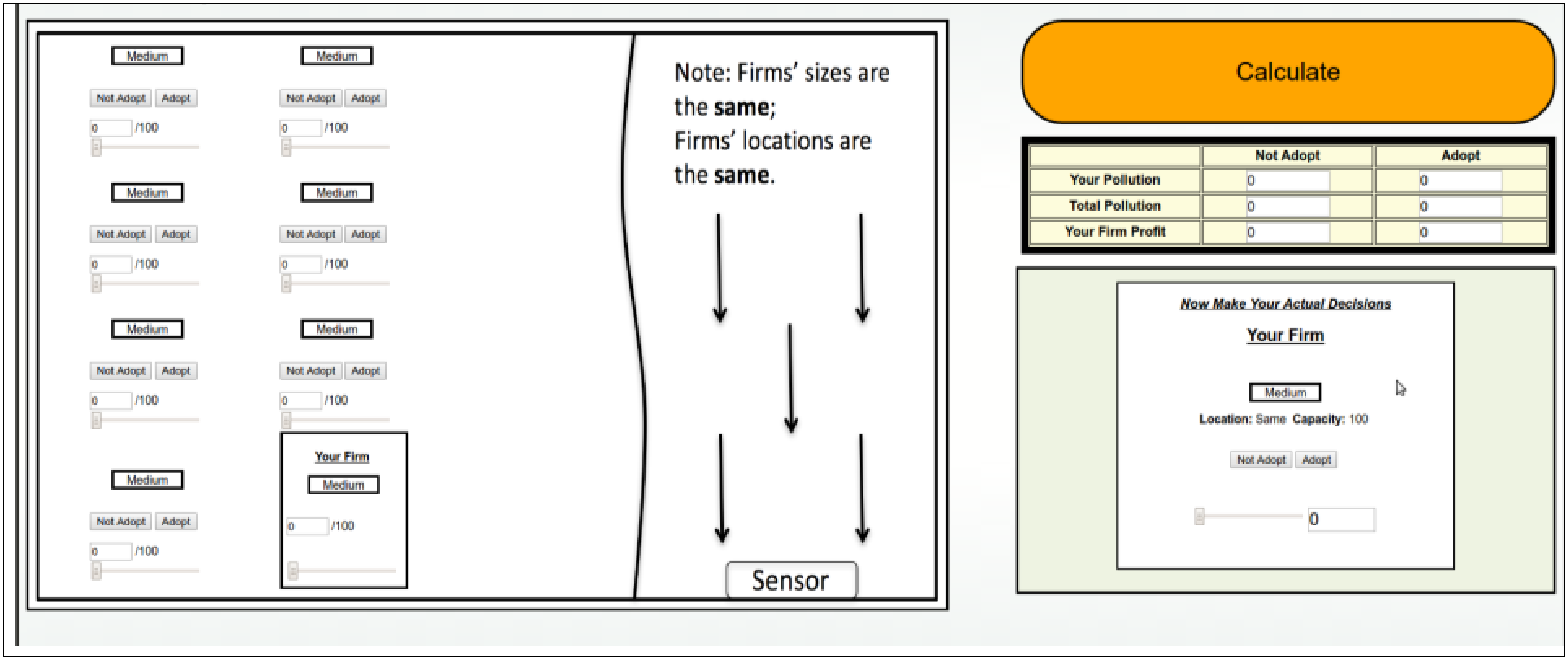
After you decide what your decision will be, make your actual decision in Step 3.

Step 3. On the bottom right part of the page, choose your actual production decision with the slider, and pick your actual technology decision. When you are done, click "Confirm". 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 eight players have clicked the Confirm button, the results of the current round will appear, including Your Pollution, the Total Pollution from all members of your group, your Production Income, and Your Firm Profit.

DECISION CALCULATOR

The image below are examples of the interactive Decision Calculator that you will use on your computer.



Pollution Table

This Pollution Table helps you to better understand how your firm's production decision, technology decision and location affect your pollution. Use this table along with the Decision Calculator to help you make more informed decisions.

How to read this table?

1. The first column (Production) indicates how much is being produced.
2. Find where your firm is located from the Decision Calculator. If every firm is in the same region, use the last two columns (marked as "Same Region").
3. Your firm's pollution for each level of production under "Not Adopt" and "Adopt" are listed in the columns corresponding to your region.

	Your Firm Pollution									
Production	**Region 1**		**Region 2**		**Region 3**		**Region 4**		**Same Region**	
	Not Adopt	Adopt	Not Adopt	Adopt	Not Adopt	Adopt	Not Adopt	Adopt	Not Adopt	Adopt
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.20	0.60	1.40	0.70	1.60	0.80	1.80	0.90	1.50	0.75
10	2.40	1.20	2.80	1.40	3.20	1.60	3.60	1.80	3.00	1.50
15	3.60	1.80	4.20	2.10	4.80	2.40	5.40	2.70	4.50	2.25
20	4.80	2.40	5.60	2.80	6.40	3.20	7.20	3.60	6.00	3.00
25	6.00	3.00	7.00	3.50	8.00	4.00	9.00	4.50	7.50	3.75
30	7.20	3.60	8.40	4.20	9.60	4.80	10.80	5.40	9.00	4.50
35	8.40	4.20	9.80	4.90	11.20	5.60	12.60	6.30	10.50	5.25
40	9.60	4.80	11.20	5.60	12.80	6.40	14.40	7.20	12.00	6.00
45	10.80	5.40	12.60	6.30	14.40	7.20	16.20	8.10	13.50	6.75
50	12.00	6.00	14.00	7.00	16.00	8.00	18.00	9.00	15.00	7.50
55	13.20	6.60	15.40	7.70	17.60	8.80	19.80	9.90	16.50	8.25
60	14.40	7.20	16.80	8.40	19.20	9.60	21.60	10.80	18.00	9.00
65	15.60	7.80	18.20	9.10	20.80	10.40	23.40	11.70	19.50	9.75
70	16.80	8.40	19.60	9.80	22.40	11.20	25.20	12.60	21.00	10.50
75	18.00	9.00	21.00	10.50	24.00	12.00	27.00	13.50	22.50	11.25
80	19.20	9.60	22.40	11.20	25.60	12.80	28.80	14.40	24.00	12.00
85	20.40	10.20	23.80	11.90	27.20	13.60	30.60	15.30	25.50	12.75
90	21.60	10.80	25.20	12.60	28.80	14.40	32.40	16.20	27.00	13.50
95	22.80	11.40	26.60	13.30	30.40	15.20	34.20	17.10	28.50	14.25
100	24.00	12.00	28.00	14.00	32.00	16.00	36.00	18.00	30.00	15.00
105	25.20	12.60	29.40	14.70	33.60	16.80	37.80	18.90	31.50	15.75
110	26.40	13.20	30.80	15.40	35.20	17.60	39.60	19.80	33.00	16.50
115	27.60	13.80	32.20	16.10	36.80	18.40	41.40	20.70	34.50	17.25
120	28.80	14.40	33.60	16.80	38.40	19.20	43.20	21.60	36.00	18.00
125	30.00	15.00	35.00	17.50	40.00	20.00	45.00	22.50	37.50	18.75

For Example:

1. A firm in Region 1, producing 75 units. Firm Pollution for not adopt: 18; adopt: 9.
2. A firm in Region 4, producing 75 units. Firm Pollution for not adopt: 27, adopt: 13.5.
3. A firm in Same Region, producing 100 units. Firm Pollution for not adopt: 30; adopt: 15.

ID# _________

UNDERSTANDING THE EXPERIMENT

This short exercise is designed to help you understand how the experiment works. The profit you earn in this section does not affect your real earnings.

Please use the decision calculator on the computer in front of you to figure out what your firm profit will be under the following scenarios:

You will be guided through Scenario A, and you will complete scenario B by yourself.

Scenario A:
Please fill in your profit for the following hypothetical decisions. The steps listed below will guide you through scenario A.

Everyone else		You		
Technology	**Production**	**Your Production**	**Your Technology**	**Your Profit**
Not Adopt	80	50	Not Adopt	
Not Adopt	80	50	Adopt	

Step 1: On the left part of the page, select "Not Adopt" for everyone else except your firm.
Step 2: Use the slider or type in the boxes to change everyone else's production to 80 units.
Step 3: Still on the left part of the page, find the box that lists "Your Firm", change the production decision to 50 units.
Step 4: Click "Calculate". Your pollution, total pollution and your firm profit should be shown to you.
Step 5: Find "Your Firm Profit" for "Not Adopt", which should be "33.75" in this case. Type in "33.75" in the first row under profit for scenario A.
Step 6: Find "Your Firm Profit" for "Adopt", which should be "25.55" in this case. Type in "25.55" in the second row under profit for scenario A.
Step 7: Click "Check answer for scenario A" when you are done. If the program asks you to try again, please check answers for the highlighted parts.

Now please complete scenario B on your own, please raise your hand if you have any questions.

Scenario B:
Please fill in your profit for the following hypothetical decisions on the computer screen.

Everyone else Technology	Every else Production	Your Production	Your Technology	Your Profit
Not Adopt	80	50	Not Adopt	
Not Adopt	80	50	Adopt	
Not Adopt	80	80	Not Adopt	
Not Adopt	80	80	Adopt	
Everyone else		**You**		
Technology	**Production**	**Your Production**	**Your Technology**	**Your Profit**
Adopt	100	100	Not Adopt	
Adopt	100	100	Adopt	

You may refer to instructions for Scenario A to help you complete Scenario B.

Input your firm profit for Scenario B on the computer program and check if it is correct by clicking “check answers”. When the program asks you to “try again”, it means your answer is not correct and will be highlighted. In that case, please use the calculator to recalculate the answer.

When you get both scenarios correct, you may click the continue button to move on to the next part.

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 Production Decision and your Technology Decision. Use the Decision Calculator to see how your decision and others' decisions affect your earnings.

In this practice part, pollution does not affect firm profits. The more you produce, the more your firm profit will be.

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

Firm Profit = Production Income.

MOVING on to PART 1 through PART 8

After you have finished the practice rounds, you will participate in Part 1 through Part 8 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 8, you will make a Production Decision and a Technology Decision. Groups will be randomly reassigned after each part.

INSTRUCTIONS FOR PART 1-4

1. In these parts, your Firm Profit only depends on your production and technology decisions; the production and pollution generated by other firms do not affect your Firm Profit.

2. Note that the location and capacity of firms may or may not be different. The capacity of each firm is shown on the calculator. When firms have different locations, the region will be divided in 4 sub-regions by solid lines; when firms have the same location, the region will not be divided. Refer to the **Pollution Table** to see how location influences pollution. We will indicate each scenario at the beginning of each part.

3. Use the **Decision Calculator** to make more informed decisions. Although the results are for informational purposes only, the location and capacity of each firm is the same as the real decisions.

4. To make your actual decision for this round, choose a Production Decision and a Technology Decision. Once done, click "Confirm".

5. In these parts, pollution does not affect firm profits. The more you produce, the more your firm profit will be.

In these parts: **Firm Profit = Production Income**

INSTRUCTIONS FOR PART 5-8

In these parts, an **environmental regulator** has set a **target total pollution level**. There will be a tax or subsidy based on the total pollution of your firm compared with the target level. The target will change between parts and the specific value will be shown to you.

Your profit will be adjusted by a tax or subsidy (from here on referred to as **tax/subsidy**). This tax/subsidy can be either negative (a tax) or positive (a subsidy) and is determined based on how much pollution is in the river relative to the **Target** determined by the regulator. The pollution level in the river is the aggregation of pollution from all firms. There will be a subsidy for zero concentration, but the amount of subsidy gets smaller as concentration increases. If the measured concentration level is exactly the same as the target, there will be neither a tax nor a subsidy. As concentration increases beyond the target, the tax gets larger.

Pollution in one round does not affect pollution in other rounds. However, at the end of the experiment, your earnings will be the sum of the profits you earned from all of the rounds.

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

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

Total Pollution ≤ Target	Subsidy Received = Target – Total Pollution
Total Pollution > Target	Tax Payment = Total Pollution – Target

For example, if the target is set at 60, then

- If the Total Pollution in your group is less than or equal to 60, each firm in your group receives 1 experimental dollar in subsidy for every unit of total pollution under 60 units.
- If the Total Pollution in your group is greater than 60, each firm pays 1 experimental dollar in taxes for every unit of total pollution above 60 units.

The amount of the Tax/Subsidy Payment is determined by decisions of everyone in your group. Your Firm Profit in these parts will be calculated as:

If Total Pollution ≤ Target,
Firm Profit = Production Income + Subsidy Payment

If Total Pollution > Target,
Firm Profit = Production Income – Tax Payment

Use the Decision Calculator to help you make more informed decisions, otherwise, you may lose money. Note that in these parts, it is not true that the more you produce, the more profit you will get.

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