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## The effect of legacy pollution information on landowner investments in water quality: lessons from economic experiments in the field and the lab

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The effect of legacy pollution information on landowner  
investments in water quality: lessons from economic experiments  
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## Abstract

To address the legacy effects of human activity on water quality, it is helpful to understand how land managers make decisions that directly impact legacy sources of pollution generated by previous generations, as opposed to current practices. Using data from an economic field experiment, we examine the effect of information about the cause and relative quantity of streambank erosion on rural landowners' willingness to invest in stream restoration initiatives. Data from the field is supplemented with data from laboratory sessions in which students are presented with similar decision scenarios. We find that landowners assigned to legacy sediment sites characterized by high erosion rates relative to others in the community increased investment levels by 29%–40% of their budget in comparison to the control, with similar results observed among students. Our results suggest that informational outreach targeted to pollution hot spots, including those created by legacy sources, would significantly increase investments in mitigation efforts that improve water quality.

## 1. Introduction

Nitrogen, phosphorus, and sediment pollution from nonpoint sources (NPS) is a major cause of impairment in water bodies across the United States and globally. Addressing NPS pollution has proven to be difficult, in part due to complex temporal dynamics by which legacy NPS pollutants continue to impact the environment for decades or even centuries after being emitted (Walter and Merritts 2008, Garnache *et al* 2016, Inamdar *et al* 2017). Legacy NPS pollutants include nitrates in groundwater, phosphorus in soils, and sediments that have accumulated behind historic stream impediments such as milldams.

The primary policy tools used to limit NPS pollution are voluntary financial incentive programs. These programs have historically focused on subsidizing best management practices that mitigate contemporary NPS emissions, such as runoff from agricultural fields. Yet given growing recognition of the importance of legacy NPS pollutants for water quality, mitigation actions that directly address these

sources may prove necessary to achieve improved water quality goals.

Mitigating legacy sources of water quality impairment is challenging, but increasingly possible. For example, restoration of legacy sediment-impaired streams often involves extensive excavation of sediment coupled with wetland restoration, yet is highly cost-effective when targeted to legacy sediment 'hot spots' and other high-polluting source areas (Fleming *et al* 2019). Similar results have been found for the installation of denitrifying bioreactors to treat legacy nitrates in groundwater (Easton *et al* 2019). Thus, to directly mitigate legacy sources of water pollution, there is a need to better understand how farmers and other rural land managers make decisions that specifically address pollutant sources generated by previous generations, as opposed to current practices.

In this article, we examine the effect of legacy pollution information on rural landowners' willingness to pay for stream restoration initiatives. We present data from economic experiments in the lab and the field—in which participants are assigned to treatment

and control groups to analyze how specific information about pollution affects behavior when real economic stakes are involved<sup>3</sup>. In this experiment, participants were provided with differing explanations of the cause of erosion problems on their assigned properties. Specifically, some were informed that streambank erosion problems are caused by current agricultural or land management practices, and others were given information about legacy sediment streambank erosion. We test the effect of information about the cause and relative quantity of erosion—framed as a peer comparison in which participants were told how much erosion occurred on their assigned parcel relative to others in their community—on willingness to invest in stream restoration in a framed field experiment. To identify the effect of this information, we compare the behavior of landowners in the two treatment groups to landowners in a control group that received no information on the quantity of streambank erosion generated on their properties, representing the status quo of imprecise or even nonexistent NPS pollution data at the parcel scale.

Empirical evidence derived from an experimental session with rural landowners is supplemented with sessions in the laboratory in which student participants were presented with similar decision scenarios. A benefit of laboratory economic experiments with students is that researchers can more carefully test theoretically derived hypotheses about behavior by introducing treatments incrementally with high levels of control (Cason and Wu 2019). By conducting experiments with both students and landowners, we can compare the behavior of groups with different attitudes, beliefs, and experiences to demonstrate the sensitivity of our results to context. This latter benefit is particularly relevant for environmental decision-making, where prior knowledge of an environmental issue may strongly influence behavior.

We find several important results. First, both landowners and students who are informed about legacy pollution sources did not decrease their level of monetary investment in stream restoration. Prior economic studies have shown that people are more willing to pay to mitigate environmental problems when they feel a sense of moral responsibility for the problem (Bulte *et al* 2005, Ellis *et al* 2016). Yet in this case, personal culpability for NPS pollution was not necessary to encourage investment in restoration projects that improve water quality.

Second, landowners at high-erosion legacy pollution sites who are informed about the erosion rates on their properties invested 29%–40% more of their budget in stream restoration than those not provided with such information. This information effect had a double-edged character. While

participants assigned to high-erosion parcels tended to invest more, landowners assigned to low-erosion parcels invested significantly less when provided information on their contribution to erosion relative to neighbors<sup>4</sup>. However, this unintended negative effect was not present among the group of student participants informed about legacy pollution sources. Little is known about the effect of norms and peer-comparisons on legacy pollution mitigation, partly because the basis for developing social norms in the context of legacy pollution is different than it is for environmental problems produced by current behaviors. This article presents the first empirical evidence that connects information on the relative rates of legacy pollution with mitigation behavior.

Policymakers have increasingly recognized that information provision—especially when paired with peer comparisons—is a powerful, low-cost type of outreach or ‘behavioral nudge’ that influences environmental decision-making (Allcott and Rogers 2014, Higgins *et al* 2017, Dessart *et al* 2019). Overall, our findings suggest that providing landowners and citizens with information about the magnitude of legacy sources of water pollution could lead to greater investments in mitigation action, as compared to the status quo of imprecise information about NPS pollution at the parcel-level. A critical component of outreach efforts seeking to increase mitigation efforts by the public may be to clearly convey information about the quantity and location of legacy pollution sources that affect water quality.

## 2. Experiment design and data

An economic experiment was designed to test the effect of information about the erosion of legacy sediments on investments in stream restoration. Economic experiments are powerful tools that can inform program and policy design by carefully testing how behavioral interventions affect decision making (Higgins *et al* 2017, Rosch *et al* 2020). Field experiments are particularly valuable because they allow researchers to observe how participants from a population of interest make decisions in a natural setting in response to an intervention (e.g. environmental information or peer comparisons). However, field experiments can be prohibitively expensive, and recruitment of rural decision makers is especially challenging (Rosch *et al* 2020, Weigel *et al* 2020). Due to the costs associated with field experiments, researchers and program administrators often seek evidence about the effect of behavioral interventions in addition to testing them in a field setting. Other types of experiments can be used to provide this evidence, including laboratory experiments with

<sup>3</sup> See Higgins *et al* (2017) for an overview of the value of using economic experiments to inform the design of environmental programs and policies.

<sup>4</sup> This is a phenomenon known as the ‘boomerang effect’ and has been noted in other contexts such as energy and water usage (Allcott 2011, Ferraro and Price 2013; *inter alia*).

student participants and artefactual and framed field experiments with field professionals (Harrison and List 2004, Cason and Wu 2019).

In this study, we use a framed field experiment with rural landowners to analyze how information treatments affect their willingness to invest in stream-bank restoration in a controlled, context-rich experimental setting. Participant decisions have real monetary consequences, in the sense that participants decide how much money to keep for themselves versus how much to invest in public goods. We also use laboratory experiments with student participants to further test how the information treatments affect environmental investments.

Decisions made within the bounds of the experiment sessions do not require additional action once the participants return home, but the monetary tradeoffs in the experiment make decisions more consequential than if we had simply asked participants to state their willingness to invest in a stated preference survey. Although decisions are consequential and investments in the experiment contribute to real public goods, a limitation of framed field experiments is that we do not observe real land management changes which would be impacted by myriad factors that are not fully captured in an experimental setting (e.g. constraints associated with budgets, time, and knowledge). Therefore, our study is not designed to elicit the dollar value of participants' maximum willingness to invest in legacy sediment mitigation efforts, nor adoption rates of stream restoration. Instead, we have designed a study to test the relative effects of information interventions on investment in a public good, which is presented to participants in the context of legacy sediment streambank restoration.

The experiments were conducted in the field and in the lab with landowners ( $n = 31$ ) and students ( $n = 46$ ), respectively. Twenty-five of the participating landowners were randomly selected from a list of properties containing streams with historic milldams in southeastern Pennsylvania, and six of the landowners were recruited from the email list of a local agricultural consulting group. All lab participants were students recruited via the University of Delaware's Center for Experimental and Applied Economics.

The landowners participated in a single in-person session conducted in December of 2018. Student sessions were conducted virtually via Zoom in June 2020 due to the Covid-19 pandemic during which the university prohibited in-person data collection. During the experiment, both participant groups made decisions individually via an online experiment platform and no communication was allowed among participants. Therefore, despite the differences in session location, the decision-making environment was similar for both groups<sup>5</sup>.

The structure of the experiment was also consistent across the landowner and student sessions. After reviewing the instructions, two practice rounds were implemented (not included in the results summarized below) followed by eight experimental rounds. At the beginning of each round, all participants were assigned a rural land parcel and provided with an aerial map of their assigned property. Ten properties were used in the experiment—each property was either adjacent to a stream or had a stream running through it, and erosion rates differed among the properties<sup>6</sup>. Participants were assigned each available parcel through the ten rounds of the experiment, including the practice rounds<sup>7</sup>. Assigned properties reflected real land parcels in southeastern Pennsylvania or Delaware, but they did not reflect the participants' actual properties and no information was provided that would indicate the exact location of the property. After receiving a new map in each round, participants decided how to use 50 000 Project Bucks, which represented income earned from their assigned parcel. Participants could either *keep* or *invest* some or all of their Project Bucks. Money they kept would be converted to US dollars that they would take home at the end of the experiment in cash. Money that was invested in restoration would reduce stream erosion on their assigned parcel by 1% for every 1000 Project Bucks invested. To reflect the public good nature of this decision, this money was converted to US dollars and donated to charity at the end of the experiment<sup>8</sup>.

A between-subject treatment design was used in which participants were randomly assigned to one of three treatment groups described in table 1. All participants received general information about the experiment and treatment-specific information depending on their group. Participants in group 1 received no additional information to reflect the status quo situation in which landowners know little about erosion rates on their individual parcels. Participants in groups 2 and 3 received erosion data overlaid on their parcel maps that displayed rates of stream bank erosion on their parcel (in tons per year), as well as a comparison with erosion rates on a typical

(Hendriks 2012, SoPHIELabs 2020) were used for the landowner and student sessions, respectively.

<sup>6</sup> Erosion rates (tons yr<sup>-1</sup>) for landowner experiments were 3, 15, 92, 127, 160, 194, 215, 240, 267, and 1640. In the laboratory experiment, parcels with 215 tons yr<sup>-1</sup> and 267 tons yr<sup>-1</sup> were replaced by similar parcels with erosion levels of 213 tons yr<sup>-1</sup> and 281 tons yr<sup>-1</sup>, respectively.

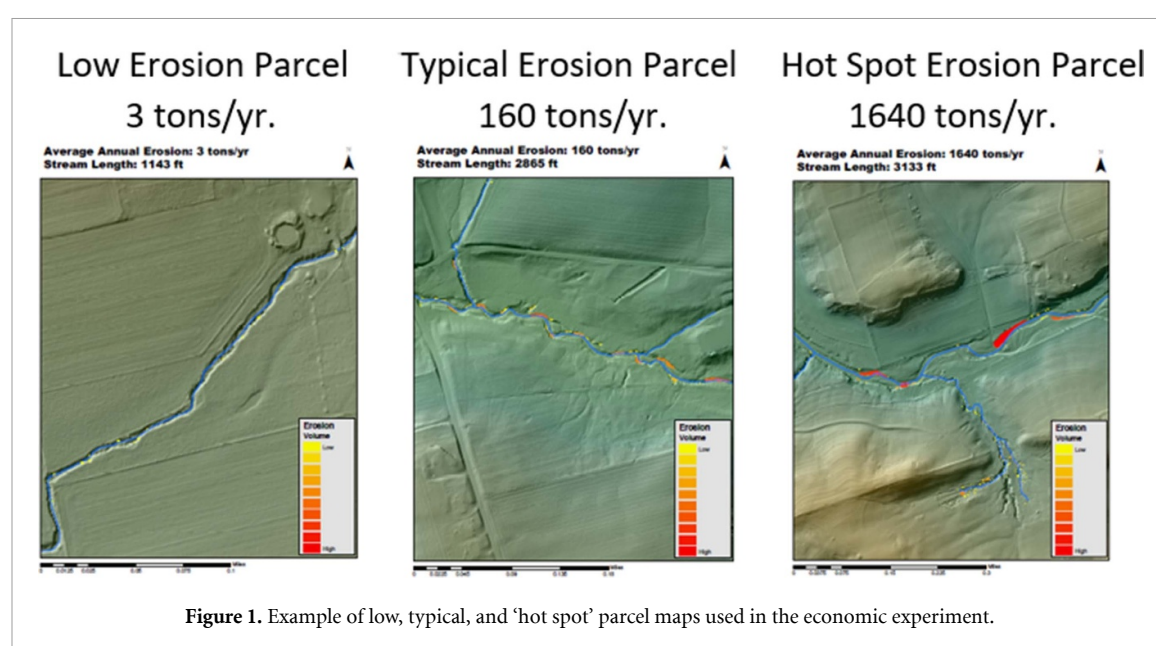
<sup>7</sup> Shares of observations for each parcel are not exactly equal in the results presented below, due to the fact that initial practice rounds are dropped for purposes of analysis.

<sup>8</sup> Tons of erosion reduction were converted to charitable donations at a rate of 500 Project Bucks for every ton of erosion reduced. Landowners had the opportunity to allocate their total donations among five different charities, representing the public benefits accrued from erosion reduction. Student session donations were given to the Delaware Nature Society.

<sup>5</sup> Two online experimental economics platforms were used to conduct the sessions—oTree (Chen *et al* 2016) and SoPHIELabs

**Table 1.** Participants were assigned to one of three treatment groups.

Treatment group	Description
1 Control	<i>Information about the level of erosion:</i> participants received no specific information on the quantity of erosion generated on a streambank running through their assigned property. <i>Information about the cause of erosion:</i> participants were informed that streambank erosion was caused by current agricultural or land management practices.
2 Contemporary erosion information	<i>Information about the level of erosion:</i> participants received information on erosion rates generated on their assigned properties and the ‘typical’ erosion rate in their group. <i>Information about the cause of erosion:</i> participants were informed that streambank erosion was caused by current agricultural or land management practices.
3 Legacy erosion information	<i>Information about the level of erosion:</i> participants received information on erosion rates generated on their assigned properties and the ‘typical’ erosion rate in their group. <i>Information about the cause of erosion:</i> participants were informed that streambank erosion was caused by prior generations’ agricultural or land management decisions.

**Figure 1.** Example of low, typical, and ‘hot spot’ parcel maps used in the economic experiment.

parcel in their community. However, participants in groups 2 and 3 received differing accounts of the *causes* of erosion on their parcel as described in table 1. A sample of aerial maps with erosion data is shown in figure 1. Note the erosion information provided to participants was based on actual measurements from real parcels using point cloud and digital elevation model (DEM) differencing of aerial LiDAR imagery (Walter *et al* 2017, James *et al* 2019). All experiment instructions and information are provided in the appendix<sup>9</sup> (available online at [stacks.iop.org/ERL/16/045006/mmedia](https://stacks.iop.org/ERL/16/045006/mmedia)).

<sup>9</sup> Two additional treatments were used in the student sessions to separately test hypotheses about behavior in response to peer comparisons and information about erosion quantity. In one treatment, participants were told if their erosion rate was greater than, about the same as, or less than the ‘typical’ erosion rate, but they were not told their exact erosion rate in tons per year. In the other treatment, participants were told the exact erosion rate on their parcel, but were not told the ‘typical’ erosion rate. Since these treatments did not align with those in the landowner sessions, data from

After making decisions in the experiment, participants filled out a survey about their socio-demographic characteristics, values, and beliefs related to water pollution and environmental stewardship. Landowners also answered questions about their property or farm characteristics (26 of the 31 participants were farmers). Copies of the landowner and student surveys are provided in the appendix.

Participants were paid immediately after each experiment session using an exchange rate of 5000 Project Bucks to \$1 USD for landowners and 20 000 Project Bucks to \$1 USD for students<sup>10</sup>.

participants assigned to these two treatments are excluded from this analysis.

<sup>10</sup> Landowners were paid in cash and students were paid electronically via their preferred method (Venmo, PayPal, or Amazon Gift Card).



**Table 2.** Descriptive statistics from landowner and student sessions.

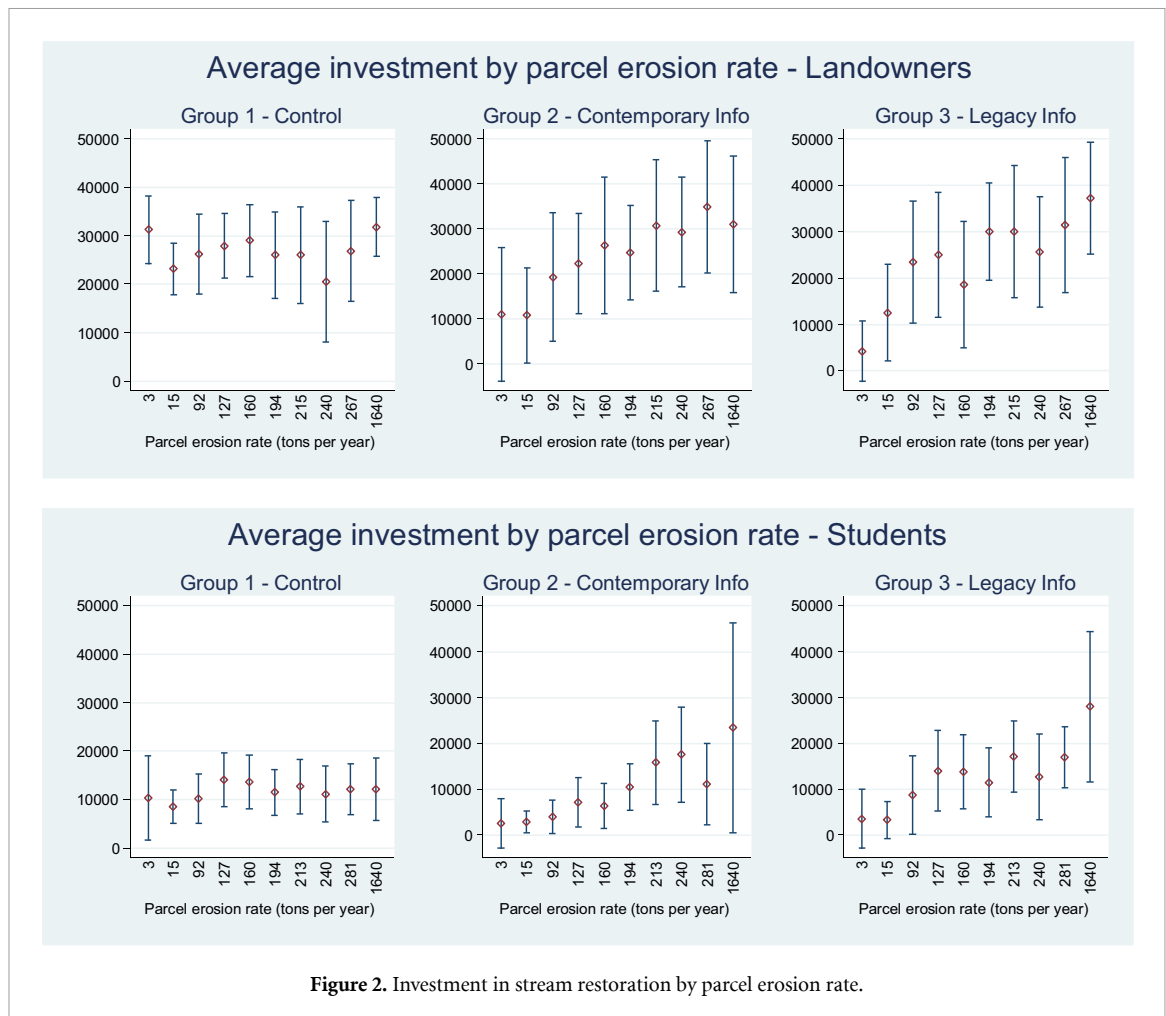
Variable	Mean	St. dev.	Min	Max
Landowners ( <i>N</i> = 31)				
Investment in conservation per round of experiment (% of budget)	50.3%	32.8%	0%	100%
Acres owned	353	882	3	5000
Farmer (1 = yes)	0.84	0.37	0	1
Female (1 = yes)	0.06	0.24	0	1
Age	54	13	30	80
Years living on property	29	17	0	65
Income from farming (if a Farmer)				
Less than \$100 000 (1 = yes)	0.15	0.36	0	1
\$100 00 to \$249 999	0.08	0.27	0	1
\$250 000 to \$999 999	0.15	0.36	0	1
\$1 million or more	0.23	0.42	0	1
No response to income category	0.38	0.48	0	1
Share income from farming (if a Farmer)	0.66	0.37	0.002	1
Education (1 = highest level attained)				
Eighth grade	0.13	0.34	0	1
Twelfth grade	0.39	0.49	0	1
Technical or Comm. College	0.10	0.29	0	1
College	0.32	0.47	0	1
Masters or doctorate	0.06	0.24	0	1
Students ( <i>N</i> = 46)				
Investment in conservation per round of experiment (% of budget)	28.7%	27.4%	0%	100%
Female (1 = yes)	0.65	0.48	0	1
Age	21	3	19	35
US origin (1 = yes)	0.87	0.33	0	1
Major area of study				
Economics (1 = yes)	0.06	0.24	0	1
Finance (1 = yes)	0.12	0.32	0	1
Business (1 = yes)	0.15	0.36	0	1
Agriculture or environment (1 = yes)	0.05	0.22	0	1
Other areas of study (1 = yes)	0.62	0.48	0	1
Class year				
Freshman (1 = yes)	0.38	0.48	0	1
Sophomore (1 = yes)	0.22	0.41	0	1
Junior (1 = yes)	0.22	0.41	0	1
Senior (1 = yes)	0.10	0.30	0	1
Graduate program (1 = yes)	0.08	0.27	0	1

Results from all eight rounds were used to calculate total payments. Landowner participants earned \$88.59 and generated \$75.84 in charitable donations, on average, and the experiment session took approximately 90 min. Student participants earned \$25.52 and generated \$7.36 in charitable donations, on average, and their sessions took about 60 min. Given the known challenges of recruiting rural landowners to participate in field experiments, the different conversion rates are in large part due to the need to compensate for the different opportunity costs of time experienced by the two groups (Rosch *et al* 2020, Weigel *et al* 2020). The primary results cited below will be expressed in terms of the share of participant budgets, since Project Bucks are not a cardinal measure of interest.

## 2.1. Data description

Table 2 describes the data gathered from the experiment and survey. The top panel shows data from the landowner session and the bottom panel shows data from the student sessions. On average, landowner investment in stream restoration per round was just over 50% of their budget, compared with an average student investment of about 29% of the budget each round.

Landowner participants tended to be male farmers in their mid-fifties who, on average, earned 66% of their income from their farms. In terms of education, 39% of these participants had finished high school or equivalent, 32% had a college education, and 6% had a master's degree or doctorate. On average, the participants received between \$100 000 and \$500 000 in annual income from their farms, although 17% chose



not to disclose annual income. Among students, most participants were female undergraduates of US origin<sup>11</sup>. About 60% of all participants were freshman or sophomores, with a small share of graduate students. In terms of major, a combined 33% studied economics, business or finance, with the majority in other fields.

The survey also collected information on participant values and beliefs. Most landowners (68%) stated that they felt responsible for mitigating pollution problems on their land even if they did not cause the problem. Only 4 of the 31 participating landowners disagreed. Participants also stated their beliefs on the severity of various sources of water pollution in the Chesapeake Bay. On average, both

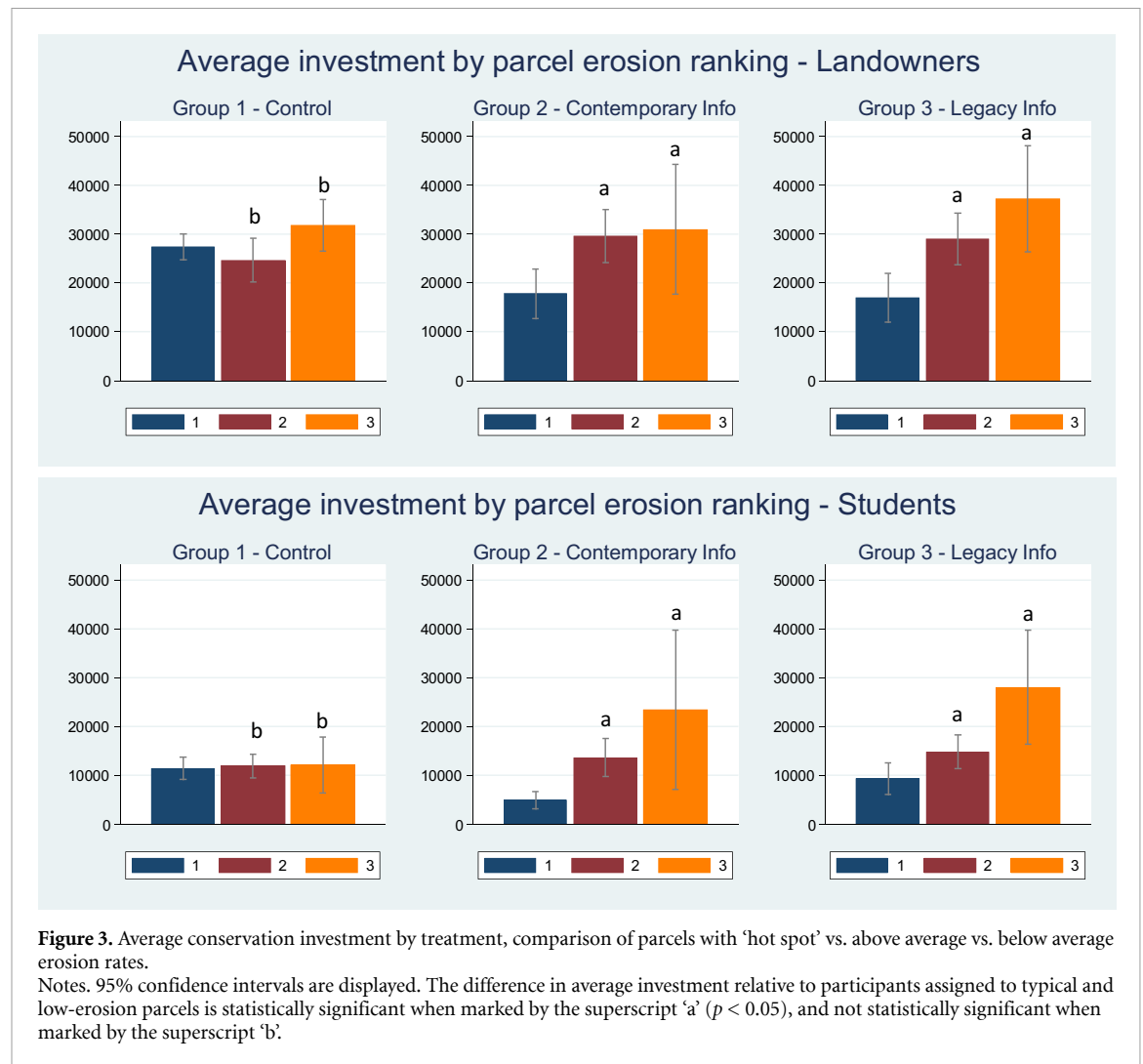
landowners and students believed that agriculture and wastewater treatment plants are larger contributors to water pollution in the Chesapeake Bay than legacy sources such as pollution released following dam removals, streambank sediment runoff, or leaky backyard septic tanks. This is broadly in line with public messaging from the Chesapeake Bay Program that agriculture is the largest source of nutrient and sediment pollution in the region, and combined sewage overflows from wastewater remain a major contributor to nutrient runoff<sup>12</sup>.

### 3. Results and discussion

Figure 2 presents the raw data on average investments in stream restoration in terms of Project Bucks for each land parcel for landowners and students, including 95% confidence intervals. For groups 2 and 3, there is a clear correlation between parcel erosion rates and investment decisions. Both landowners and students invested more when erosion rates were high and decreased their investments as erosion rates diminished (with students generally

<sup>11</sup> We note that the share of female participants is significantly higher in the laboratory experiment compared to the framed field experiment. Research on the role of gender in public good provision has found mixed results (Eckel *et al* 2008, Croson *et al* 2009), and we did not design our study to specifically contribute to this literature. We acknowledge that gender may have had an impact on contributions, but it is more likely that the different subject pools affected contributions to a greater extent, given that the experiment's framing is much more closely aligned with the experience of rural landowners. This illustrates the importance of conducting field experiments with populations of interest for environmental policy and behavioral interventions (Rosch *et al* 2020).

<sup>12</sup> For example, see [www.chesapeakestat.com/](http://www.chesapeakestat.com/).



contributing less than landowners across all parcel erosion rates).

Figure 3 aggregates the data in figure 2 to illustrate the difference in restoration investments between low/typical-erosion parcels, high-erosion parcels, and erosion hot spots. We define low/typical-erosion parcels (high-erosion parcels) as those that are below (above) the median erosion level among these parcels—that is, below (above) 160 tons  $\text{yr}^{-1}$ . The parcel generating 1640 tons of sediment per year is defined as an erosion hot spot, and is excluded from the group of high-erosion parcels. This parcel is representative of severe legacy sediment erosion sites in the study region (Walter *et al* 2017).

When landowners in groups 2 and 3 were assigned to high-erosion parcels, investments increased by 68% and 82%, respectively, compared to investment levels with low-erosion parcels ( $p < 0.01$  for both groups 2 and 3). In contrast, there is no significant difference in investment levels by erosion rate for the control group, which did not have access to precise parcel-level information on erosion rates. A similar pattern was observed in the student sessions; however,

relative to the landowner investments, students invested a significantly smaller share of their budget per round, on average ( $p < 0.01$ ).

When landowners with the contemporary source information (group 2) are assigned the erosion hot spot parcel, average investments increase 74% relative to when they are assigned the low-erosion parcels ( $p < 0.05$ ), which is nearly identical to the 68% increase among landowners in this group assigned to high-erosion parcels described in the preceding paragraph. However, landowners who received legacy source information (group 3) markedly increased their investments when assigned to an erosion hot spot caused by legacy sources, with a 120% increase relative to those at low-erosion parcels ( $p < 0.01$ ). Again, similar patterns are observed among students.

### 3.1. Random effects regression on landowner willingness to invest

In this section, we describe the experimental results in more detail by using regression analysis to control for individual landowner and student characteristics and experimental round effects. This allows us to better



**Table 3.** Random effects regression model of the effect of contemporary and legacy erosion information on investment in stream restoration practices.

	Landowners	Students	Combined
<b>Group 2</b>			
Contemporary erosion information group (1 = yes)	−11 498.7** (4516.6)	−6109.3** (2472.7)	−7866.6*** (2408.9)
High-erosion parcel × Contemporary erosion info. group	15 667.1*** (4352.1)	8351.1*** (2537.8)	11 159.7*** (2243.4)
Erosion hot spot × Contemporary erosion info. group	16 944.3*** (6283.1)	17 904.6** (7542.7)	16 985.0*** (4472.4)
<b>Group 3</b>			
Legacy erosion information group (1 = yes)	−10 381.1* (5417.6)	497.7 (3737.6)	−6086.0** (2594.9)
High-erosion parcel × Legacy erosion info. group	14 392.2*** (4921.2)	5025.6*** (1645.8)	8867.8*** (2278.2)
Erosion hot spot × Legacy erosion info. group	20 141.7*** (6279.3)	18 740.1*** (4568.1)	19 013.8*** (3853.1)
High-erosion parcel (1 = yes)	−2122.1 (2707.1)	343.7 (819.9)	−452.8 (1022.1)
Erosion hot spot (1 = yes)	1363.6 (2597.2)	1375.7 (1260.2)	1407.9 (1204.4)
Student (1 = yes)	—	—	−13 537.6*** (2303.7)
Individual random effects	Yes	Yes	Yes
Controls for observable landowner or student characteristics	Yes	Yes	No
Controls for values and beliefs	Yes	Yes	No
Constant	−23 372.1 (34 384.2)	21 106.1 (19 532.3)	25 975.6*** (1884.4)
Observations	248	368	616
Number of individuals	31	46	77

Robust standard errors in parentheses.

\*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ .

identify the causal effect of information provision on stream restoration investments.

Table 3 shows the results of three generalized least squares regressions modeling the effect of legacy pollution information on investments in stream restoration. The regressions include individual random effects to control for unobservable differences between participants, such as personality traits that influence investment decisions<sup>13</sup>. To identify the effect of information about the quantity of erosion from contemporary or legacy sources, the regressions include an interaction term between relative parcel erosion rates—‘high-erosion’ or ‘hot spot’, as defined above—and the participant’s treatment group.

The potential effects of providing landowners with information on legacy pollution sources can

be ascertained by comparing the investment behavior across groups 2 and 3. Here, the key question of interest is whether informing landowners that legacy pollution sources are a primary cause of streambank erosion—as opposed to their current practices—tends to reduce investment in mitigation efforts. Results summarized in table 3 indicate that the answer is no.

Among landowners, the increased investment for parcels with higher erosion rates is equally large among group 3 as in group 2, an increase of 29% versus 31% of landowner budgets (or 14 392 versus 15 667 Project Bucks, respectively). For students, the results are similar. Those assigned to high-erosion and hot spot parcels increased their monetary investments in stream restoration by similar levels regardless of whether they were informed that the cause of erosion problems was contemporary or historic. The primary result evident from comparisons across groups 2 and 3 is that legacy pollution information did not significantly reduce landowner or student investment. When people were informed that

<sup>13</sup> Hausman specification tests did not reject the null hypothesis that the random effects model is consistent ( $p = 0.4177$  among landowners;  $p = 0.3466$  among students). Empirical robustness checks comparing our results with fixed effects models showed nearly identical results.

streambank erosion problems are inherited from previous generations, they were still willing to address the issue.

In economic theory, the degree to which a sense of moral culpability affects willingness to pay for solutions to an environmental problem remains an open question. In two different contexts—endangered species protection and climate change—Bulte *et al* (2005) and Ellis *et al* (2016) find that people are willing to pay more to mitigate environmental problems when they feel a stronger sense of responsibility for its cause. Here, we find that landowners and students remain willing to invest in addressing legacy pollution problems even if presented with information that they themselves are not personally responsible for its cause.

Based on the language used for the legacy information treatment group, human responsibility for the source of pollution may still be an important factor contributing to willingness to invest—that is, the environmental problem is of human origin and not ‘naturally occurring’. However, in this context of a framed field experiment involving legacy NPS pollution, personal responsibility for the cause of pollution does not appear necessary to encourage investment.

A second key result evident from table 3 is that average investments of landowners in groups 2 and 3 decreased by 23% and 21% of their budget (11 4999 and 10 381 Project Bucks, respectively), in comparison to the control group. This result is driven by landowners in groups 2 and 3 who more frequently invested nothing in stream restoration when they were assigned low-erosion parcels<sup>14</sup>. In contrast, landowners in group 1 tended to invest some positive amount in stream restoration each round, if only because they were not aware they were on a relatively low-erosion parcel. This result suggests a potential downside to the provision of erosion information. Although parcel-specific erosion information encourages more investment by high-erosion landowners, it may decrease investment by landowners on low-erosion parcels. A similar double-edged effect of information provision has been found in different contexts, such as energy and water usage, and is known in psychological and economic literature as the ‘boomerang effect’ (Allcott 2011, Ferraro and Price 2013, Loewenstein *et al* 2014). We discuss the lack of a boomerang effect among students in group 3 in the following section.

### 3.2. Does legacy pollution information uniquely influence investment?

Potential differences in investment behavior are evident when comparing the contemporary and legacy information groups. These are worth noting briefly as

they raise important theoretical questions regarding the mechanisms by which legacy pollution information may uniquely affect environmental investments and provide fruitful avenues for future research.

First, landowners assigned to an erosion hot spot in the legacy source information treatment (group 3) invested more than landowners assigned to erosion hot spots in the contemporary source information treatment (group 2), an increase of 40% versus 34% of landowner budgets (or 20 142 versus 16 944 Project Bucks, respectively) compared to the control group. Given sample sizes available, this difference in the change of investment across groups 2 and 3 is not statistically significant. Yet it is reasonable to consider the psychological grounds that may exist for a larger response among landowners who receive legacy pollution information. For example, landowners who are told that their current management practices are primarily to blame for severe pollution loads (hot spots) may respond defensively, and accordingly information provision may backfire for some individuals by leading to less pro-environmental investment (Chang 2012). Similarly, survey evidence has shown that when farmers are encouraged to adopt a conservation practice based on arguments already considered and rejected, there is a negative framing effect that actually reduces interest in adopting the practice (Andrews *et al* 2013). In contrast, landowners may respond more cooperatively if they do not perceive themselves as being unfairly targeted or blamed for problems that are in fact inherited from previous generations.

Second, it is notable that the boomerang effect—i.e. the decreased investment among participants assigned to low-erosion parcels—is not present among students who are informed that erosion problems are the result of inherited legacies rather than current practices (group 3). Moreover, among landowners, this unintended effect is only marginally significant for those in group 3 ( $0.05 < p < 0.10$ ). Further study with greater statistical power is warranted. Theoretical or psychological explanations for the boomerang effect vary, including a desire for conformity, and cognitive resistance to perceived attempts to influence behavior (Schultz *et al* 2007, Fischer 2008, Byrne and Hart 2009). Yet in the context of legacy pollutants such as nonpoint nutrients and sediment, the behavioral genesis of the boomerang effect is less clear. When a person is asked to make contributions toward a public good, such as an initiative intended to reduce pollution caused by a contemporary source (e.g. littering), reciprocity motives may indicate that if you are personally adding little to the problem in comparison to others you are already doing your part, suggesting no further need to contribute (Croson 2007, Shang and Croson 2009, Fischbacher and Gächter 2010). However, in the context of legacy pollutants, information that your property is performing better than the norm is

<sup>14</sup> Since individual random effects are included in these regressions, the effect is not due to idiosyncratic differences between members of the groups.

not related to your own efforts or current behavior. Thus, a potential factor contributing to the psychological genesis of the boomerang effect is not present for this critical area of environmental concern.

These results are suggestive of potential avenues for future empirical research that may shed light on key theoretical questions in behavioral economics. Investigating the pathways by which information on legacy pollutant sources affect behavior has implications for both economic theory and NPS mitigation policy that are not yet well-understood.

## 4. Conclusions and policy implications

NPS water pollution is characterized as a ‘wicked’ problem, partly due to the complex temporal dynamics by which legacy nonpoint pollutants continue to contribute to water quality problems over time (Shortle and Horan 2017, Lintern *et al* 2020). With voluntary incentive programs as the primary policy tool utilized for combating NPS pollution, it is important that landowners and citizens understand more fully the quantities and causes of nutrient and sediment runoff from the landscape.

The results of this study indicate that landowners provided with information on the quantity of legacy sediment erosion from streambanks on their properties significantly increase their investment in mitigation efforts when their properties produce more runoff than typical parcels in the region. Using a framed field experiment, we find the increased investment at high-erosion and hot spot parcels occurs regardless of whether participants are informed they are personally responsible for the cause of this erosion. Given increasing recognition of the importance of legacy pollution as a source of water quality impairment, we recommend that landowners, citizens, and policymakers be informed of research on the critical contribution of legacy sources to pollution problems today. Our experimental results from both the field and laboratory indicate that this should not discourage investment or participation in NPS mitigation efforts.

Further, we find evidence of an unintended negative effect of information provision, in that landowners assigned to low-erosion parcels tended to invest less in stream restoration. This phenomenon has been identified as the boomerang effect in prior literature. Potential tools that have been suggested for minimizing this effect include combining pro-environmental messages with the descriptive information (Ayres *et al* 2012), ranking the lowest-erosion parcels to encourage an environmentally-beneficial competitiveness (Bhanot 2017), and possibly only providing detailed descriptive information to high-erosion landowners. Yet for the purpose of projecting potential policy effects, it is important to note that the increased investment among participants in the erosion information groups (groups 2 and 3) when

assigned to high-erosion and hot spot parcels is larger in absolute value than the decrease when assigned to low-erosion parcels, suggesting a net increase in willingness to invest due to the provision of erosion information.

Overall, these results demonstrate the potential benefits of informing landowners of legacy sediment and nutrient pollution that exists at varying levels of severity across the landscape. Improvements in the quality of aerial LiDAR data have made it possible to precisely locate and quantify stream bank erosion through DEM and point cloud differencing, which is particularly valuable for identifying legacy sediment erosion hot spots (Walter *et al* 2017, James *et al* 2019). State and local governments can use parcel-level maps like those produced for this study to both identify high-pollution areas and, once identified, as a tool for informing landowners of elevated pollutant loads on their properties (Fleming *et al* 2019). These findings suggest that informational outreach or ‘nudges’ to landowners, citizens, and policymakers based on the magnitude and location of legacy pollution sources could lead to greater investments in mitigation, as compared to the status quo of imprecise or even nonexistent parcel-level information on legacy sediment and nutrient runoff.

## Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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