SUPPLEMENTAL MATERIALS

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Characterizing Heterogeneous Behavior of Non-Point-Source Polluters in a Spatial Game under Alternate Sensing and Incentive Designs

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SUPPLEMENTAL INFORMATION 1: HYPOTHESES, AND MIXED EFFECTS MULTINOMIAL LOGISTIC MODEL (MMLM) SELECTION

S1.1. Formal Hypotheses

Hypothesis 1: Incentives in the form of taxes and subsidies induce cooperative behavior among agents.

$$(\boldsymbol{H_{0:}\,\beta_{policy} = 1,\ H_{a:}\,\beta_{policy} > 1.})$$

Here we use β with subscripts to represent the coefficients of the corresponding variables in the cooperative group in the MMNL model, after exponential transformation.

Hypothesis 2: The number of water quality sensors as well as their sensing frequency increases cooperative behavior

$$(\boldsymbol{H_{0:}\,\beta_{two\,sensor} = 1,\ H_{a:}\,\beta_{two\,sensor} > 1;\ H_{0:}\,\beta_{high\,freq} = 1,\ H_{a:}\,\beta_{high\,freq} > 1..})$$

Here we use β with subscripts to represent the coefficients of the corresponding variables in the cooperative group in the MMNL model, after exponential transformation.

Hypothesis 3. The spatial locations of the agents relative to the spatial locations of the sensors, i.e. upstream, mid-stream, or downstream, affects the induction of cooperative behavior.

$$(\boldsymbol{H_{0:}\,\beta_{parcel*policy} = 1,\ H_{a:}\,\beta_{parcel*policy} < 1;\ H_{0:}\,\beta_{parcel*two\,sensor} = 1,}$$

$$\boldsymbol{H_{a:}\,\beta_{parcel*two\,sensor} < 1;\ H_{0:}\,\beta_{parcel*high\,freq} = 1,\ H_{a:}\,\beta_{parcel*high\,freq} < 1.})$$

Here we use β with subscripts to represent the coefficients of the corresponding variables in the cooperative group in the MMNL model, after exponential transformation.

S1.2: Mixed Effects Multinomial Logistic Model (MMLM) selection

Table S1 below shows Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) scores to enable MMLM selection by following the decision rule of selecting a model that minimizes AIC and/or BIC: Full factorial model number 4 appears best fit with both AIC and BIC minimization criteria (Figure S1).

Table S1. BIC and AIC scores for MMLM selection

Model #	Random effects by intercept type	Random effects by Subject type	Interactions	Minus 2 Log Likelihood	AIC	BIC
1	intercept	period(session)	No	7036.77	7096.77	7144.28
2	intercept	session	No	6992.31	7052.31	7046.06
3	intercept	period(session)	Yes	6402.33	6558.33	6681.85
4	**intercept**	**session**	**Yes**	**6351.01**	**6507.01**	**6490.77**
5	No random effects	No random effects	Yes	6425.06	6575.06	7031.31
6	No random effects	No random effects	No	7057.95	7111.95	7276.20

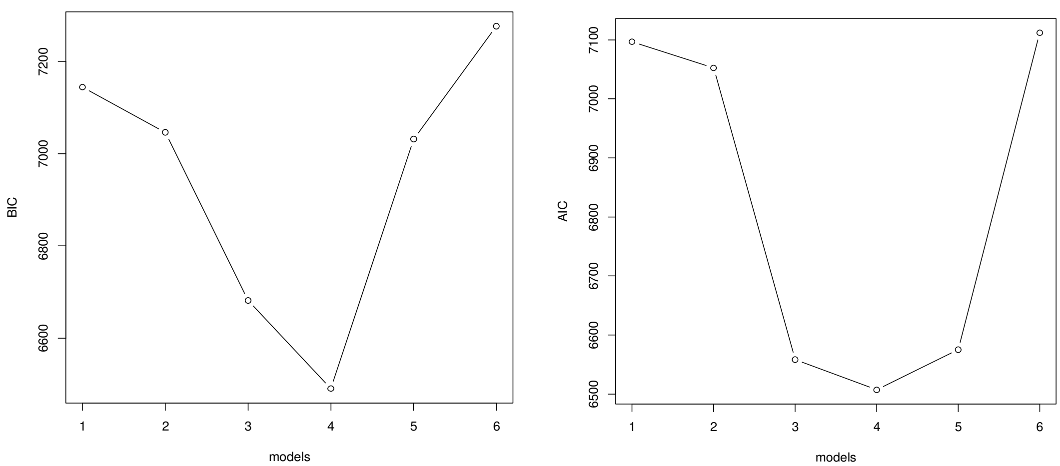

Figure S1: AIC and BIC plots for six candidate models.

SUPPLEMENTAL INFORMATION 2: GAME DESIGN AND CALCULATION OF NASH EQUILIBRIA

S2.1: Description of the game and method

A total of 108 undergraduate subjects from University of Delaware voluntarily participated in six experimental sessions. Each session had eighteen subjects. In the beginning of each session of the experiment, we gave subjects the first part of the above instruction. They had about 15 minutes to read it and ask questions. They experienced three practice rounds before we gave them further instructions to get familiar with computer interface and the calculator mentioned in the instruction. In the part, the subjects understood what the decision number, their private income, tax/subsidy and social benefit were.

After three practice rounds, we gave the subjects the instruction for one treatment and gave them one oral presentation to emphasize how their production decisions affect water quality, tax or subsidy, and their profit. After we reviewed the numerical answers in the instruction with the subjects and the subjects said they had no more question about the interface and instruction, we proceeded to the first treatment. All the subjects were randomly grouped and given a random parcel number. Group member and parcel number stayed the same across one treatment. During the experiment, the subjects saw a calculator on the left side of the interface. On the right side of the interface, they saw a figure indicating their locations and number of sensors which is similar to Figure 1. There were also a sentence telling the subjects which parcel they were. They entered their production decision for six rounds and they were also able to see their previous rounds results including production decisions, water quality, tax or subsidy, income and profit on the right side of the interface. The principal measured the ambient water quality depending on the measurement method in each treatment once all decisions were made in one group. Tax or subsidy were decided based on the measurement and equation (2). Then each subject was shown his/her private income, tax or subsidy and total profit after each round.

We gave the subjects new instructions and another oral presentation about the second treatment after the first treatment ended. All the subjects were regrouped and randomly assigned a parcel number in the new treatment. Before the new treatment started we asked the subjects to try out the calculator for a couple of minutes to figure out the new payoff structures because their locations and tax/subsidy rules might change due to new treatments. Making sure the subjects reviewed the examples in the instruction and had no questions, we proceeded to the new treatment. All the rest of treatments followed the same procedure.

We systematically varied the treatment order in each session. The orders are presented in Table S2.

Table S2. Treatment orders

Session Number	Treatment order
1	Control, C, B, A, F, E, D
2	A, B, C, D, E, F, Control
3	C, B, A, F, E, D, Control
4	D, E, F, Control, A, B, C
5	Control, A, B, C, D, E, F

S2.2: Calculation of Nash equilibria

Due to complexity of the realistic physical nutrient transport model presented in the introduction, it is impossible to solve for the social optimum and Nash equilibria analytically and therefore we rely on numerical techniques to solve for both the social optimum and the Nash equilibria.

We find the social optimum by maximizing TB in equation 4. We searched 5000^6 combinations of production level [each parcel are assumed to have 5000 choices (0.01, 0.02, 0.03, …, 49.99, 50.00)] using Python programming and the optimal production level for six parcels based on linear damage are presented at the bottom of Table 2.

Similarly, we are able to use Python interacted with the nutrient model to calculate the Nash equilibria. Before the calculation, one initial point of production combination is randomly chosen. Starting from this initial point, an algorithm is designed such that production level in random parcel *i* is changed to maximize expected payoff of the participant at parcel *i* based on known production at five other parcels. The production array keeps updating until no single participant can increase his/her expected payoff by deviating from existing array unilaterally. Results are also presented in Table 2.

S2.3 Transport Model

The nutrient transport dynamics are developed based on the QUAL2E/QUAL2K model (Chapra et al., 2008) and parameters are drawn from existing studies for the mid-Atlantic US, specifically from Skippack Creek in Pennsylvania (EPA, 2005) and the Pocomoke River in Delaware (DNREC, 2005). Organic nitrogen (N), ammonium (NH4), nitrogen dioxide (NO2), nitrate (NO3), organic phosphorus (P), inorganic P, and algae are included in the model. We focus on total N, which is the sum of nitrogen species mentioned above. In this model, a stream, which is adjacent to k homogenous parcels, is divided into $k+1$ sections called "reaches," labeled R_i, $i = 0, 1, 2, \ldots, k$. R_0 is the "headwater". R_k is the state of the river downstream from the last parcel. We model six parcels, (k = 6), to match the number of subjects in groups in the experiment. Water flows from the headwater reach to the downstream reaches at a constant rate and stream channel characteristics (length, width, area and slope) are also constant across reaches.

Total N concentration at a given reach in the stream can be monitored using sensing technology over the sensing window. Emissions from parcels move down stream in discrete time steps, $t = 0, 1, 2, \ldots$ Within the sensing window, a sensor may make an observation at any of these time steps. We assume that once production decisions are made, the resulting emissions from each firm enter the river simultaneously at time step $t = 1$. Besides the loadings from firms on parcels 1 through 6, there are constant but relatively large background nutrient loads that enter each across all reaches at constant rates. When firms emit nutrient loading (nitrite), concentration at each reach may have a peak early on in the sensing window and then decrease to a level lower, depending on the location of the parcel and level of the emissions in stream. The marginal damage of an increase in emissions at a given parcel is determined by the effect on the maximum concentration over the sensing window.

Relatively low emissions levels impact the maximum concentration for firms further away from the sensor while only relatively high emissions levels impact the maximum for the downstream firms. Two features of the calibrated QUAL2K model cause this outcome. Firstly, emissions from upstream firms mix with a large amount of accumulated background nutrient loading later in the sensing window. As a consequence, even relatively low emissions from upstream firms can induce a maximum concentration higher than the steady state concentrations. Secondly, emissions from the downstream firms pass through the sensor early in the sensing window when the background nutrient level has not accumulated. Therefore, when emissions from upstream firms are relatively low, relative high emissions of downstream firms only induce a peak early in the sensing window. Thus, the marginal impact of emissions from upstream firms on the maximum concentration is generally greater than that of emissions from downstream firms. Additional details of the nutrient model can be found in Miao et al. (2016).

SUPPLEMENTAL INFORMATION 3: EXPERIMENT INSTRUCTIONS

Welcome to an experiment about the economics of decision making. In the course of the experiment, you will have several opportunities to earn 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. At the end of the experiment, your earnings will be converted at a rate of $1 US dollar for $90 experimental dollars. Please read these instructions carefully and do not communicate with any other participants during the experiment.

Production and Byproduct

In today's experiment, you will participate in a number of parts. Each part will have six 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 your cumulative **profit**, which will be used to calculate your cash earnings at the end of the experiment.

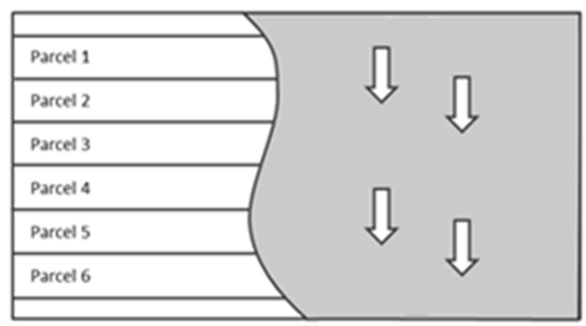

Figure S3: Map depicting land parcels 1-6.

Throughout the experiment, you will be in a group of six people. You and everyone else in your group will be playing the role of one of six business owners who operate on parcels of land along a river. The parcels are labeled Parcel 1 through 6, as displayed on the map to the right. Parcel 1 is the furthest upstream and Parcel 6 is the furthest downstream. The actual parcel that you operate on will be indicated to you on your computer screen.

Each business owner produces output that creates **income,** and also **byproduct** that goes into the river. In general, the higher the output that is produced, the more byproduct that is generated. Some **concentration** of this byproduct is harmless to individuals downstream. However, if the concentration is too large, the byproduct has negative effects on others downstream.

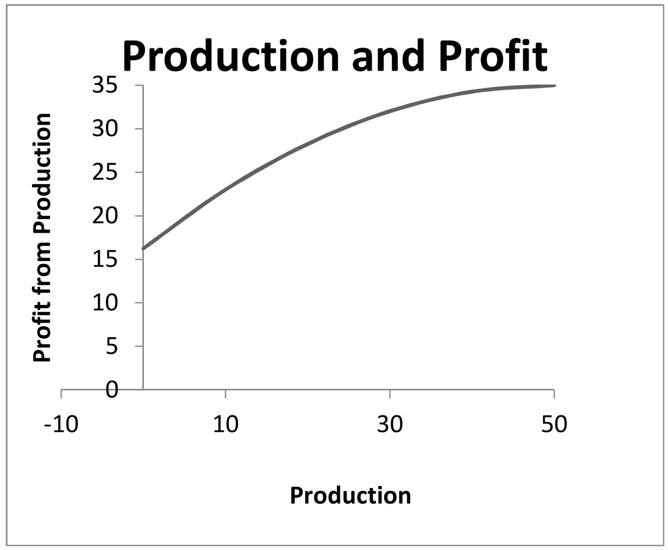

Figure S4: Experiment production and profit curve.

In each round, you must choose your **production** level**,** between 0 and 50 units. The amount of **profit** that you earn increases the more you produce between $16.25 and $35.00, as shown in Graph 1. In some parts of today's experiment, your profit may 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 **concentration** of the byproduct is in the river relative to a **target**. The concentration is an average of measurements that can occur at any time during a round. The actual measured concentration in a particular round could be above or below the average. 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 no tax/subsidy. As concentration increases beyond the target, the tax gets larger. At the end of the experiment, your earnings will be the sum of the profits you earned from all of the rounds.

In some parts of the experiment, how your production influences the measured concentration (and hence the group's tax/subsidy) may depend on which parcel you operate. The byproduct from all of the parcels enters the river simultaneously and then flows downstream, spreading out and mixing together. The longer distance the byproduct flows (i.e., upstream parcels with lower numbers), the more it will spread and mix. The concentration will be initially high as the byproduct flows from a parcel, but as the byproduct moves further downstream, it dilutes and hence the concentration decreases. At the same time, however, the byproduct also spreads out over a longer stretch of the river.

In the parts where there is a tax/subsidy, there will be either **one** or **two sensors** which take a measurement of the concentration of the byproduct in the river as it flows past. If there is only one sensor it will be located just downstream from Parcel 6. If there are two sensors, one will be located just downstream of Parcel 6, and one will be located between Parcel 3 and Parcel 4, as shown in the figure to the right.

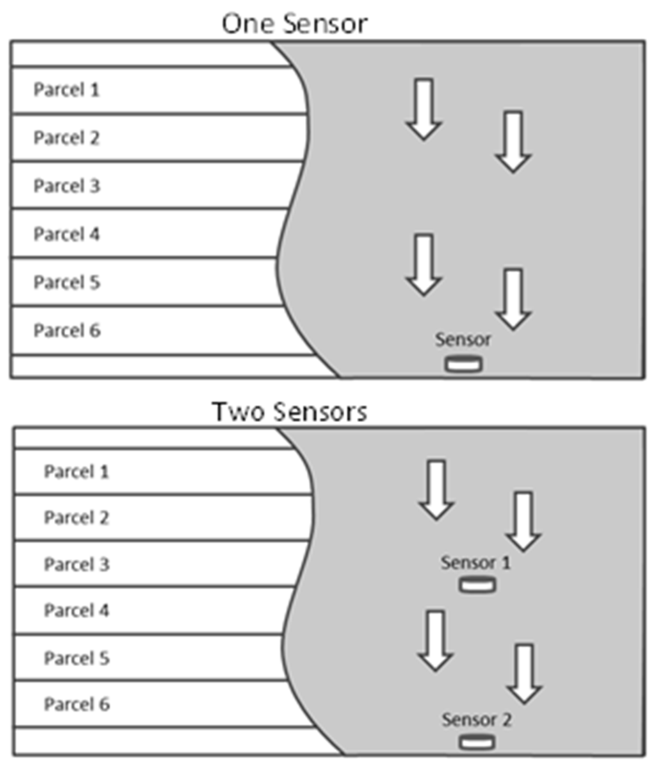

Figure S5: Maps depicting sensor placement for one and two sensors, respectively.

Within each round, the concentration of the byproduct fluctuates when it flows past the sensor(s) because byproduct from the six parcels mixes and dilutes as it flows downstream. This means that the higher the sensing frequency, the more accurate the measurement will be. Depending on the part of today's experiment, the sensor(s) will take measurements at three different rates during each round: (1) **low sensing frequency**; (2) **high sensing frequency**; and (3) **continuously**. When the sensor measurement is not continuous, the measured concentration is likely to have high variability. The more frequently measurements are taken, the more accurate the measurement will be.

A calculator is provided on your computer that will allow you to determine the average tax/subsidy, and profit for any set of production decisions for the six parcels. This will be available to you throughout the experiment so that you can try out different strategies without it affecting your earnings. You can enter production decisions for each parcel by typing it directly into the column labeled "Production" or you can also change production by using the slider for each parcel.

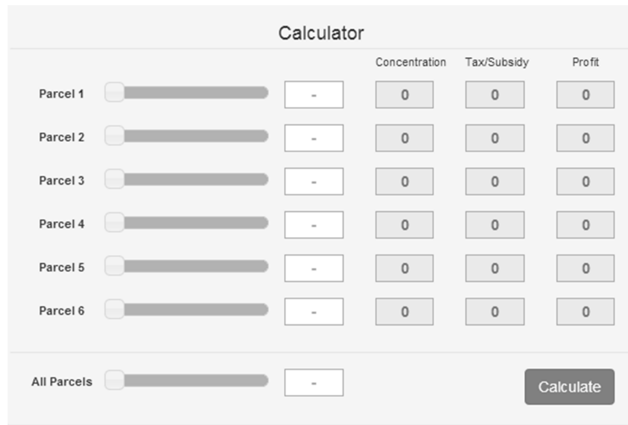

Figure S6: Calculator provided during the experiment to compute the average tax/subsidy and profit for each parcel.

Prior to each part of today's experiment, an explanation of how the tax/subsidy will be determined will be provided as well as the number of sensors and the frequency with which sensing will occur. In each part of the experiment, you will be provided with several examples that you can try on the calculator. These examples will let you understand how the change in sensing affects your profit. The calculator will automatically adjust based on the part of the experiment.

In summary, in each round:

1. You begin with no production or byproduct from your parcel, and zero byproduct concentration in the river.
2. You choose your level of production for your business on your parcel.

3. Your level of production determines your income and the amount of byproduct that goes into the river. In general, the more you produce, the higher your income and the byproduct you generate.
4. The concentration of the byproduct is measured by either one or two sensors. Measurements will occur within a round either at (1) a low frequency, (2) a high frequency, or (3) continuously.
5. If applicable, the same tax/subsidy will apply to all business owners in your group. The tax/subsidy will depend on everyone's production level in your group and the measured concentration level relative to a threshold.
6. How much the byproduct from your parcel contributes to the measured concentration (and hence the group's tax/subsidy) depends on how much you produce and how far upstream your parcel is from the sensor.
7. Your profit in each round is the sum of your income from production and the tax/subsidy.
8. At the end of today's experiment, your experimental earnings will be the sum of all of the profits you earned from all of the rounds. These experimental earnings will then be converted to US dollars at a rate of 1 experimental dollar for 90 US dollars.

We will begin with three practice rounds that will give you an opportunity to familiarize yourself with the software. These first three rounds will not result in any cash earning. In the practice rounds there is no tax/subsidy, and there are no sensors measuring the concentration of the byproduct. Therefore, your profit in each round is determined only by your production in that round.

To help you understand how your calculator works in this part of the experiment, please complete the table below. The administrator will review the information featured in these tables with you.

Table S3. Production and profit example with no tax/subsidy

Example	Parcels	Production for all Parcels	Tax/Subsidy for all Parcels ($)	Profit for all Parcels ($)
A	1-6	0	$0.00	$16.25
B	1-6	15	$0.00	$25.81
C	1-6	35	$0.00	$33.31
D	1-6	50	$0.00	$35.00

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S4. Production and profit example with no tax/subsidy, specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
E	1	$0.00	$16.25	$23.00
F	2	$0.00	$16.25	$23.00
G	3	$0.00	$16.25	$23.00
H	4	$0.00	$16.25	$23.00
I	5	$0.00	$16.25	$23.00
J	6	$0.00	$16.25	$23.00

Table S5. Production and profit example with no tax/subsidy, specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
K	1	$0.00	$35.00	$23.00
L	2	$0.00	$35.00	$23.00
M	3	$0.00	$35.00	$23.00
N	4	$0.00	$35.00	$23.00
O	5	$0.00	$35.00	$23.00
P	6	$0.00	$35.00	$23.00

Experiment Instructions – No Tax/Subsidy

In this part of today's experiment, there is no tax/subsidy, and there are no sensors measuring the concentration of the byproduct. Therefore, your profit in each round is determined only by your production in that round.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S6. Production and profit example with no tax/subsidy and no sensors

Example	Parcels	Production for all Parcels	Tax/Subsidy for all Parcels ($)	Profit for all Parcels ($)
A	1-6	0	$0.00	$16.25
B	1-6	15	$0.00	$25.81
C	1-6	35	$0.00	$33.31
D	1-6	50	$0.00	$35.00

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S7. Production and profit example with no tax/subsidy and no sensors, specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
E	1	$0.00	$16.25	$23.00
F	2	$0.00	$16.25	$23.00
G	3	$0.00	$16.25	$23.00
H	4	$0.00	$16.25	$23.00
I	5	$0.00	$16.25	$23.00
J	6	$0.00	$16.25	$23.00

Table S8. Production and profit example with no tax/subsidy and no sensors, specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
K	1	$0.00	$35.00	$23.00
L	2	$0.00	$35.00	$23.00
M	3	$0.00	$35.00	$23.00
N	4	$0.00	$35.00	$23.00
O	5	$0.00	$35.00	$23.00
P	6	$0.00	$35.00	$23.00

Experiment Instructions – One Sensor, Low Frequency Measurements

In this part of the experiment, the concentration of the byproduct is measured by **one sensor** which takes **low frequency measurements**. In this setting, **every parcel has approximately the same influence** on determining the tax/subsidy. In general, the tax is lower (subsidy is higher) compared to when there are more frequent sensing.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S9. Production and profit example with tax/subsidies and one sensor, low frequency measurements

Example	Parcels	Production for all Parcels	Tax/Subsidy for all Parcels ($)	Profit for all Parcels ($)
A	1-6	0	37.42	53.67
B	1-6	15	14.97	40.78
C	1-6	35	-14.97	18.35
D	1-6	50	-37.42	-2.42

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S10. Production and profit example with tax/subsidies and one sensor, low frequency measurements; specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
E	1	24.93	41.18	47.93
F	2	24.94	41.19	47.94
G	3	24.95	41.20	47.95
H	4	24.95	41.20	47.95
I	5	24.95	41.20	47.95
J	6	24.95	41.20	47.95

Table S11. Production and profit example with tax/subsidies and one sensor, low frequency measurements; specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
K	1	12.54	47.54	35.54
L	2	12.48	47.48	35.48
M	3	12.46	47.46	35.46
N	4	12.45	47.45	35.45
O	5	12.45	47.45	35.45
P	6	12.45	47.45	35.45

Experiment Instructions – One Sensor, High Frequency Measurements

In this part of the experiment, the concentration of the byproduct is measured by **one sensor** which takes **high frequency measurements**. Based on this setting, **upstream parcels** farther away from the sensor tend to have a **bigger impact on the tax/subsidy** than the downstream parcels closer to the sensor. In general the tax is higher (subsidy is lower) than when the measurement is taken only once during each period.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S12. Production and profit example with tax/subsidies and one sensor, high frequency measurements

Example	Parcels	Production for all Parcels	Tax/Subsidy for all Parcels ($)	Profit for all Parcels ($)
A	1-6	0	8.01	24.26
B	1-6	15	3.25	29.06
C	1-6	35	-12.81	20.50
D	1-6	50	-44.05	-9.05

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S13. Production and profit example with tax/subsidies and one sensor, high frequency measurements; specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
E	1	6.20	22.45	29.20
F	2	5.73	21.98	28.73
G	3	5.36	21.61	28.36
H	4	5.10	21.35	28.10
I	5	4.94	21.19	27.94
J	6	4.86	21.11	27.86

Table S14. Production and profit example with tax/subsidies and one sensor, high frequency measurements; specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
K	1	-1.52	33.48	21.48
L	2	1.27	36.27	24.27
M	3	2.75	37.75	25.75
N	4	3.78	38.78	26.78
O	5	4.42	39.42	27.42
P	6	4.50	39.50	27.50

Experiment Instructions – One Sensor, Continuous Measurements

In this part of the experiment, the concentration of the byproduct is measured by **one sensor** which takes a measurement **continuously throughout each round**. Based on this setting, **upstream parcels** farther away from the sensor tend to have a **bigger impact on the tax/subsidy** than the downstream parcels closer to the sensor. In general the tax is higher (subsidy is lower) than when the measurement is not taken continuously in each period.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S15. Production and profit example with tax/subsidies and one sensor, continuous measurements

Example	Parcels	Production for all Parcels	Tax/Subsidy for all Parcels ($)	Profit for all Parcels ($)
A	1-6	0	0.99	17.24
B	1-6	15	0.53	26.34
C	1-6	35	-16.91	16.40
D	1-6	50	-54.85	-19.85

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S16. Production and profit example with tax/subsidies and one sensor, continuous measurements; specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
E	1	0.89	17.14	23.89
F	2	0.76	17.01	23.76
G	3	0.70	16.95	23.70
H	4	0.69	16.94	23.69
I	5	0.68	16.93	23.68
J	6	0.68	16.93	23.68

Table S17. Production and profit example with tax/subsidies and one sensor, continuous measurements; specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for all Parcels ($)	Profit for Specified Parcel ($)	Profit for All Other Parcels ($)
K	1	-2.85	32.15	20.15
L	2	0.38	35.38	23.38
M	3	0.59	35.59	23.59
N	4	0.66	35.66	23.66
O	5	0.68	35.68	23.68
P	6	0.68	35.68	23.68

Experiment Instructions – Two Sensors, Low Frequency Measurements

In this part of the experiment, the concentration of the byproduct is measured by **two sensors** which take **low frequency measurements**. Parcels 1 through 3 have their tax/subsidy based on Sensor 1's measurements, while parcels 4 through 6 have their tax/subsidy based on Sensor 2's measurements. In this setting, **every parcel has approximately the same influence within the block** on determining the tax/subsidy. The Block 1 parcels (Parcels 1 through 3) have an effect on the Block 2 parcels (Parcels 4 through 6), but not vice versa. In general, the tax is lower (subsidy is higher) compared to when there are more frequent sensing.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S18. Production and profit example with tax/subsidies and two sensors, low frequency measurements

Example	Production for all Parcels	Block 1 (Parcels 1-3)		Block 2 (Parcels 4-6)	
		Tax/Subsidy ($)	Profit ($)	Tax/Subsidy ($)	Profit ($)
A	0	18.75	35.00	37.42	53.67
B	15	7.50	33.31	14.97	40.78
C	35	-7.50	25.81	-14.97	18.35
D	50	-18.75	16.25	-37.42	-2.42

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S19. Production and profit example with tax/subsidies and two sensors, low frequency measurements; specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for Block 1/Block 2 ($)	Profit for Specified Parcel ($)	Profit for Other Parcels in Block 1/Block 2 ($)
E	1	13.75/24.93	30.00	36.75/47.93
F	2	13.75/24.94	30.00	36.75/47.94
G	3	13.75/24.95	30.00	36.75/47.95
H	4	11.25/24.95	41.20	34.25/47.95
I	5	11.25/24.95	41.20	34.25/47.95
J	6	11.25/24.95	41.20	34.25/47.95

Table S20. Production and profit example with tax/subsidies and two sensors, low frequency measurements; specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for Block 1/Block 2 ($)	Profit for Specified Parcel ($)	Profit for Other Parcels in Block 1/Block 2 ($)
K	1	1.25/12.54	36.25	24.25/35.54
L	2	1.25/12.48	36.25	24.25/35.48
M	3	1.25/12.46	36.25	24.25/35.46
N	4	11.25/12.45	47.45	34.25/35.45
O	5	11.25/12.45	47.45	34.25/35.45
P	6	11.25/12.45	47.45	34.25/35.45

<u>Experiment Instructions – Two Sensors, High Frequency Measurements</u>

In this part of the experiment, the concentration of the byproduct is measured by **two sensors** which take **high frequency measurements**. Parcels 1 through 3 have their tax/subsidy based on Sensor 1's measurements, while parcels 4 through 6 have their tax/subsidy based on Sensor 2's measurements. Based on this setting, **upstream parcels** farther away from the sensor tend to have a **bigger impact on the tax/subsidy** than the downstream parcels closer to the sensor. The Block 1 parcels (Parcels 1 through 3) have an effect on the Block 2 parcels (Parcels 4 through 6), but not vice versa. In general the tax is higher (subsidy is lower) than when the measurement is taken only once during each period.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S21. Production and profit example with tax/subsidies and two sensors, high frequency measurements

	Production for all	Block 1 (Parcels 1-3)		Block 2 (Parcels 4-6)	
Example	Parcels	Tax/Subsidy ($)	Profit ($)	Tax/Subsidy ($)	Profit ($)
A	0	4.29	20.54	8.01	24.26
B	15	3.70	3.25	3.25	29.06
C	35	-17.64	15.67	-12.81	20.50
D	50	-46.47	-11.47	-44.05	-9.05

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S22. Production and profit example with tax/subsidies and two sensors, high frequency measurements; specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for Block 1/Block 2($)	Profit for Specified Parcel ($)	Profit for Other Parcels in Block 1/Block 2($)
E	1	4.16/6.20	20.41	27.16/29.20
F	2	4.00/5.73	20.25	27.00/28.73
G	3	3.92/5.36	20.17	26.92/28.36
H	4	3.89/5.10	21.35	26.89/28.10
I	5	3.89/4.94	21.19	26.89/27.94
J	6	3.89/4.86	21.11	26.89/27.86

Table S23. Production and profit example with tax/subsidies and two sensors, high frequency measurements; specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for Block 1/Block 2 ($)	Profit for Specified Parcel ($)	Profit for Other Parcels in Block 1/Block 2 ($)
K	1	-4.62/-1.52	30.38	18.38/21.48
L	2	-0.89/1.27	34.11	22.11/24.27
M	3	-5.43/2.75	29.57	17.57/25.75
N	4	3.89/3.78	38.78	26.89/26.78
O	5	3.89/4.42	39.42	26.89/27.42
P	6	3.89/4.50	39.50	26.89/27.50

Experiment Instructions – Two Sensors, Continuous Measurements

In this part of the experiment, the concentration of the byproduct is measured by **two sensors** which takes a measurement **continuously throughout each round**. Parcels 1 through 3 have their tax/subsidy based on Sensor 1's measurements, while parcels 4 through 6 have their tax/subsidy based on Sensor 2's measurements. Based on this setting, **upstream parcels** farther away from the sensor tend to have a **bigger impact on the tax/subsidy** than the downstream parcels closer to the sensor. The Block 1 parcels (Parcels 1 through 3) have an effect on the Block 2 parcels (Parcels 4 through 6), but not vice versa. In general the tax is higher (subsidy is lower) than when the measurement is not taken continuously in each period.

To help you understand how the calculations works in this part of the experiment, please review the following tables. The administrator will review this information with you.

Table S24. Production and profit example with tax/subsidies and two sensors, continuous measurements

Example	Production for all Parcels	Block 1 (Parcels 1-3)		Block 2 (Parcels 4-6)	
		Tax/Subsidy ($)	Profit ($)	Tax/Subsidy ($)	Profit ($)
A	0	6.63	22.88	0.99	17.24
B	15	6.62	32.43	0.53	26.34
C	35	-27.20	6.11	-16.91	16.40
D	50	-72.47	-37.47	-54.85	-19.85

In the following examples, consider what happens when five of the six parcels produce 10 and the specified parcel produces 0 (examples E-J) or 50 (examples K-P).

Table S25. Production and profit example with tax/subsidies and two sensors, continuous measurements; specified parcel's production = 0, and all other parcels' production = 10

Specified Parcel's Production = 0; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for Block 1/Block 2 ($)	Profit for Specified Parcel ($)	Profit for Other Parcels in Block1/Block 2 ($)
E	1	6.63/0.89	22.88	29.63/23.89
F	2	6.62/0.76	22.87	29.62/23.76
G	3	6.62/0.70	22.87	29.62/23.70
H	4	6.62/0.69	16.94	29.62/23.69
I	5	6.62/0.68	16.93	29.62/23.68
J	6	6.62/0.68	16.93	29.62/23.68

Table S26. Production and profit example with tax/subsidies and two sensors, continuous measurements; specified parcel's production = 50, and all other parcels' production = 10

Specified Parcel's Production = 50; All Other Parcels' Production = 10				
Example	Specified Parcel	Tax/Subsidy for Block 1/Block 2 ($)	Profit for Specified Parcel ($)	Profit for Other Parcels in Block1/Block 2 ($)
K	1	-6.74/-2.85	28.26	16.26/20.15
L	2	-4.29/0.38	30.71	18.71/23.38
M	3	-63.10/0.59	-28.10	-40.10/23.59
N	4	6.62/0.66	35.66	29.62/23.66
O	5	6.62/0.68	35.68	29.62/23.68
P	6	6.62/0.68	35.68	29.62/23.68