Annual Meeting, April 15, 2016

NEWRnet

Delaware • Rhode Island • Vermont

North East Water Resources Network

Delaware EPSCoR

Rhode Island EPSCoR

Vermont EPSCoR

How water quality monitoring with sensors and policy regimes impact human behavior: Findings from experiments, games, and agent-based modeling with implications for watershed governance

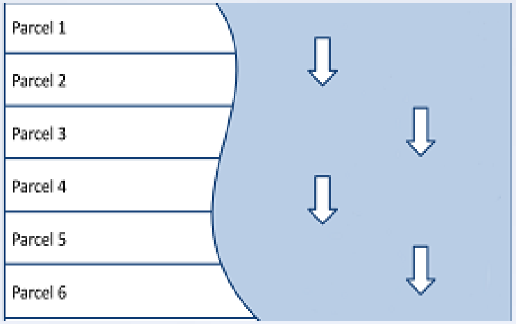
Drs. Kent Messer (UD), Emi Uchida (URI),

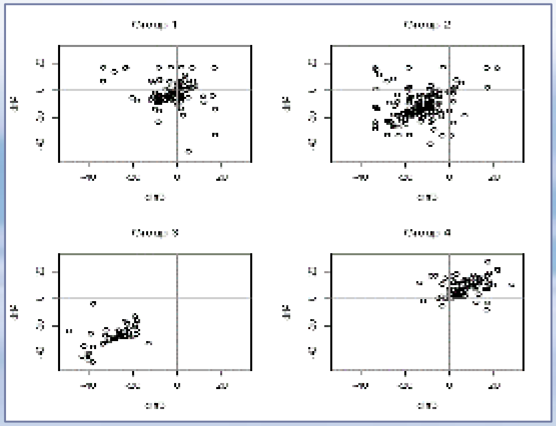
Asim Zia (UVM), and Scott Merrill (UVM)

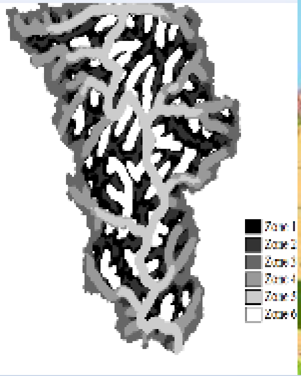
Grad Students: Linda Grand (UD) and Haoran Miao (UVM)

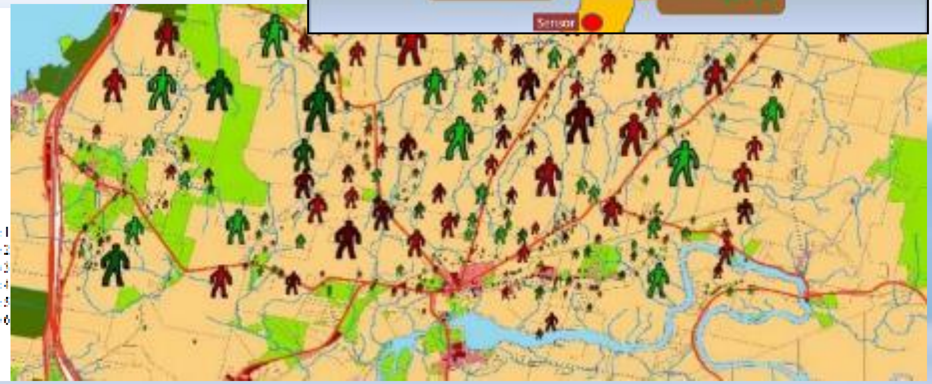
Roadmap of Presentation

1. Multidisciplinary Research (K. Messer - UD)
   - Research Example (H. Maio - URI)
2. Field Experiments (E. Uchida – URI)
   - Research Example (L. Grand – UD)
3. Experimental games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)



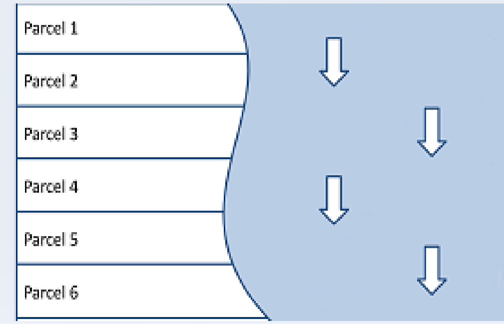


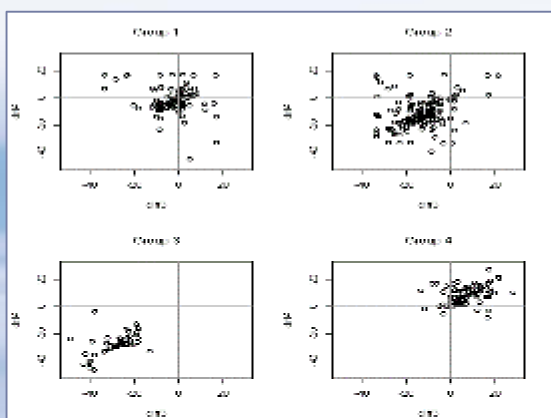


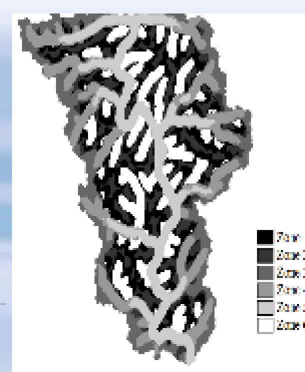


Roadmap of Presentation

1. Multidisciplinary Research (K. Messer - UD)
   - Research Example (H. Maio - URI)
2. Field Experiments (E. Uchida – URI)
   - Research Example (L. Grand – UD)
3. Experimental games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)







Goals of Our Talk

1. We have strong collaborations across the three EPSCoR states.
   - Active involvement of faculty, postdocs, and graduate and undergraduate students.

2. Our research linking water quality sensors, human behavior and policy is going great and its being well-received with our disciplines and in interdisciplinary contexts.
   - NEWRnet research has led to other major extramural awards.

3. We are engaged in exciting field experiments involving non-student participants.

4. We have linked agent-based models and economic experiments.

5. Our results are meaningful to policy makers, resource managers, and stakeholders.

Social Dimensions

- **Experimental Economics**
  - *Experimental Economics Projects*
  - *Multidisciplinary Projects*
- **Agent-Based Models**
  - *Missisiquoi watershed (VM)*
  - ABMs in Delaware & Rhode Island watersheds
- Graduate Course in Experimental Economics
- Field Studies Involving Farmers and Homeowners
- Outreach to Policy-Makers and Stakeholders


Rhode Island EPSCoR
Who we are…
University of Rhode Island
NEWRnet


Delaware EPSCoR
Who we are…
University of Delaware
NEWRnet
Go Ape!
CONGRATS!


Who we are…
The University of Vermont's
Experimental Economics Group
Asim Zia
Co-Director
Chris Koliba
Co-Director
Scott Merrill
Managing Director
Steven Exler
Information
Specialist
Carol Adair
Biogeochemistry
specialist
SEGS Lab
Social
Ecological
Gaming &
Simulation
Courtney
Hammond
Wagner
Graduate
Student
Linyuan Shang
Graduate Student
Ahmed Hamed
Post-Doc
VERMONT
EPSCoR

Overview of Research Accomplishments

- 27 Research Projects, involving 29 different researchers have been started related to NEWRnet themes.
  - 3 accepted (*Water Resource Research, Agricultural and Resource Economic Review)*
  - Collaborations with several assistant professors (Shanshan Ding, Todd Guilfoos, Scott Merrill. Leah Palm-Forster, Soni M. Pradhanang) and recent PhD graduates (Jacob Fooks, Maik Kecinski, Tongzhe Li)

- Grant Proposals Building on Cross-State & Multidisciplinary Collaborations
  - **USDA Center for Behavioral and Experimental Agri-Environmental Policy Research (CBEAR)**, Messer (co-Director), Uchida, Fooks, Kecinski, Li, and Palm-Forster (CBEAR Fellows) $1,290,000.
  - **NSF EPSCoR Track II grant on "Future of Dams"** jointly with collaborators in RI, NH and Maine. Gold (Co-PI), Uchida (Co-PI) and Guilfoos (Senior Researcher) $6,000,000.
  - **USDA-NIFA Agriculture and Food Research Initiative**. 2015-2019 A human behavioral approach to reducing the impact of livestock pest or disease incursions of socio-economic importance. PI J Smith, Co-PIs Merrill, Zia, and Koliba, et al.. $7,400,000.
  - **USDA AFRI – Water Quality Economics Workshop**, Guilfoos (PI), Messer and Uchida (co-PIs) $47,882.
  - **USDA Agricultural and Food Research Initiative**. Messer (Co-PI) expands the AgVISE project throughout the Delmarva Peninsula and also the Southeast of the United States $500,000.
  - **NSF's Coupled Nature Human Systems program** to study ecosystem services from mangrove forests, which include protecting the quality of drinking water Uchida (lead-PI), Guilfoos (co-PI) and Gold (Senior Researcher) $500,000.
  - **USDA Center of Excellence at the Nexus of Sustainable Water Reuse, Food Crop Production, and Health.** Messer and Kecinski (co-PI), Li (Senior Researcher). $10,000,000.

Value of Multidisciplinary Collaborations

- Soni M. Pradhanang (Assistant Professor of Hydrology and Water Quality)
  - "The impact of information on behavior under an ambient-based policy for regulating nonpoint source pollution" (Maio, et al. *WRR forthcoming)*
- Shanshan Ding (Assistant Professor of Statistics)
  - Spatial effects of sensor information in inducing cooperative behaviors for managing non-point source pollution: Evidence from a decision game in an idealized watershed. Asim et al. *in review at Ecology and Society*
- Matthew Miller (Manager of Wilmington's Drinking Water Plant)
  - "Contextual Messaging and Voluntary Contributions to Support Water Quality Improvements and Drinking Water Infrastructure" (Ellis et al., ARER *forthcoming)*
- Dan Leathers (Professor of Meteorology; Delaware State Climatologist)
  - "Visualization and Collective Identity in Nonpoint Source Pollution Settings" Butler et al., *in development)*
- Andrew Schroth, Kent Messer, Jacob Fooks
  - "Antecedent watershed conditions and optimal policy"

Stakeholder Engagement

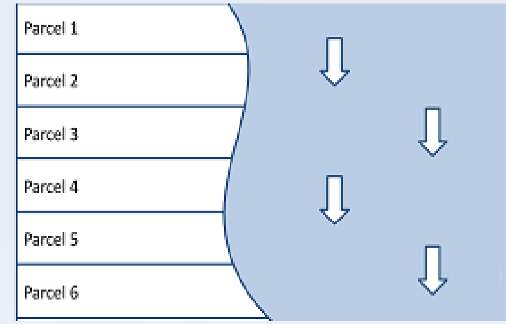
- Examples of State level engagement
  - Dan Leathers is the Delaware State Climatologist
  - Vermont Governor's Climate Cabinet
  - Rhode Island Nursey and Landscape Association
  - Lake Champlain Basin program
  - Delaware Inland Bays
  - SeaScape project
  - Vermont initiative on building a "culture of clean water"

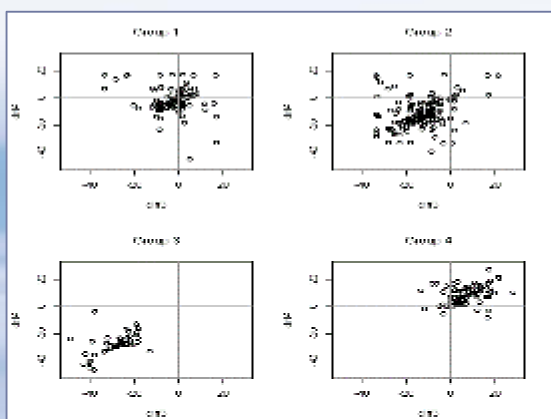
- Examples of National level engagement
  - USDA Natural Resource Conservation Service
  - USDA Farm Service Agency
  - National Association of State Conservation Agencies
  - National Association of Conservation Districts

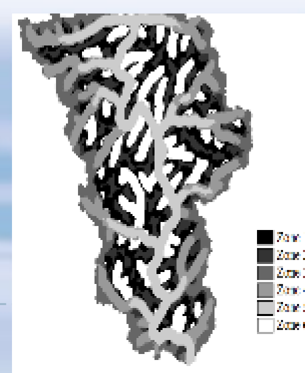
- Tri-state stakeholder meeting in the Fall of 2016.

Roadmap of Presentation

1. Multidisciplinary Research (K. Messer - UD)
    - Research Example (H. Miao - URI)
2. Experimental Games (E. Uchida – URI)
    - Research Example (L. Grand – UD)
3. Experimental games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)







The impact of information on decision making

Haoran Miao, Ph.D. Candidate
Department of Environmental and Natural Resource Economics
University of Rhode Island

The impact of information on behavior under an ambient-base policy for regulating nonpoint source pollution

Haoran Miao[1], Jacob Fooks[2], Todd Guilfoos[1],
Kent Messer[3], Soni M. Pradhanang[4],
Jordan Suter[5], Simona Trandafir[1], Emi Uchida[1]

[1] Department of Environmental and Natural Resource Economics, University of Rhode Island
[2] USDA Economics Research Service
[3] Department of Applied Economics and Statistics, University of Delaware
[4] Department of Geosciences, University of Rhode Island
[5] Department of Agricultural and Resource Economics, Colorado State University

Motivation

- Nonpoint source (NPS) pollution
  - Information gap between environmental regulators and polluters
- A potential solution: Ambient based policy (Segerson 1988)
- Information problems still exist even targeting ambient pollution level
  - Ambient pollution is not perfectly measured
  - Spatial heterogeneity of polluters and diffused nature of NPS pollution add more complexity
- Recent sensing technology can provide more accurate information
  - Increased temporal and spatial monitoring

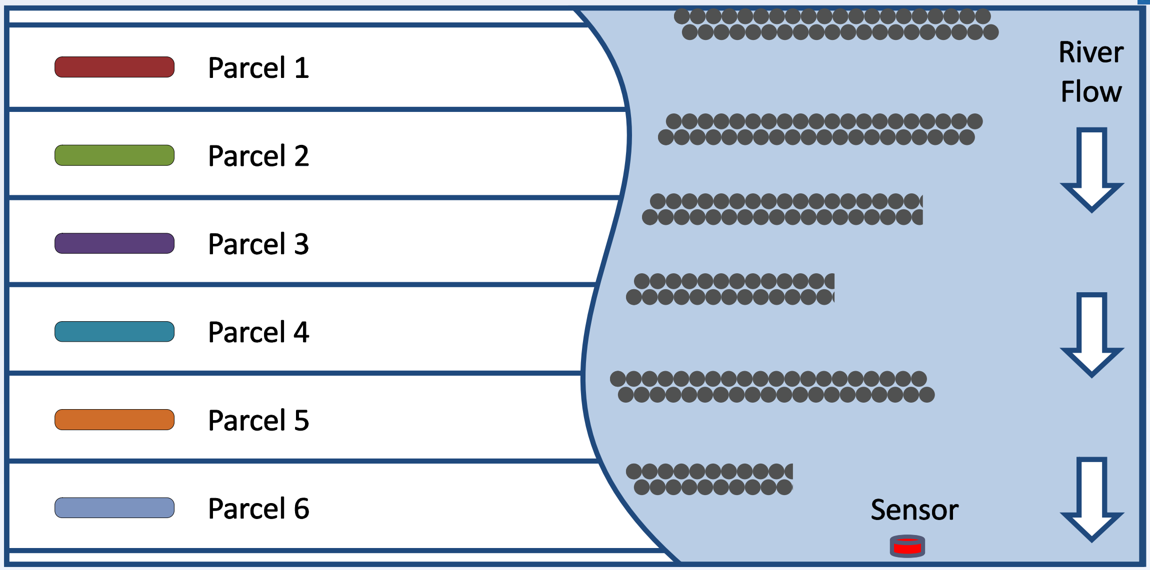
Research Question and Methods

- Research Question
  - How does increased temporal and spatial monitoring affect NPS polluter' behavior and social efficiency outcomes under ambient tax/subsidy?

- Methods
  - Utilize laboratory experiment with college students
  - Simulate pollution dynamics (Total N) over space and time with QUAL2K* model

    ** River and Stream Water Quality Model (Chapra et al., 2008) released by USEPA*

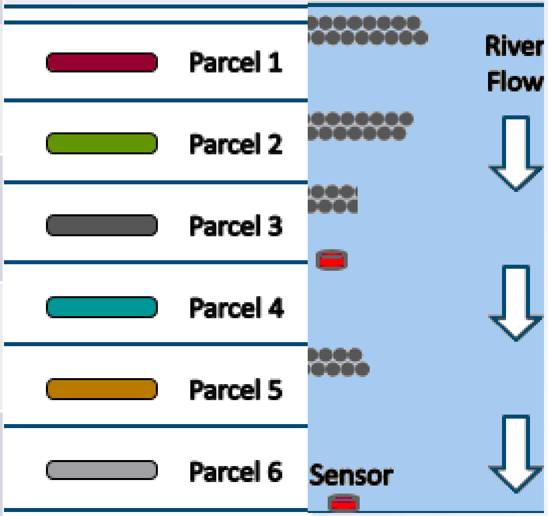
Experiment



- A public goods game (Segerson 1988 & Spraggon 2002)
  - Six firms operate on six different parcels (Emission level 0 - 50)
  - Damage happens just downstream of parcel 6
  - They face ambient tax/subsidy policy
  - Tax/subsidy is based on measured maximum pollution concentration and a threshold exogenously determined by the regulator
  - 108 college students as subjects

Treatments

Treatment	Label	Number of sensors	Frequency of sensing	Ambient tax/subsidy
A	No Sensor	0	No Sensing	No
B	One Sensor, Low Frequency	1	Low	Yes
C	One Sensor, High Frequency	1	High	Yes
D	One Sensor, Continuous	1	Continuous	Yes
E	Two Sensors, Low Frequency	2	Low	Yes
F	Two Sensors, High Frequency	2	High	Yes
G	Two Sensors, Continuous	2	Continuous	Yes



Selected hypotheses

	H1: overall emission	H2: Individual emission	H3: Individual emission		H4: Social efficiency
Tax/subsidy	↓		Upstream	Downstream	
# of sensors		No effect			
Increased frequency			↓	↑	↑

- H1: Tax/subsidy will reduce overall emissions compared to “no policy”.
- H2: More number of sensors has no effect on individual emission.
- H3: More frequent sensing reduces emissions on parcels farther away from the sensor compared to those closer to the sensor.
- H4: Continuous sensing leads to highest social welfare.

Results

	H1: overall emission	H2: Individual emission	H3: Individual emission		H4: Social efficiency
Tax/subsidy	↓ √		Upstream	Downstream	
# of sensors		No effect √			
Increased sensing			↓ √	↑ √	↑ √

Conclusion

- Increased temporal monitoring induces polluters to allocate emission reductions more efficiently.
- Increased temporal monitoring increases social welfare.
- Social welfare increases over time: Are subjects learning with more informatoin?
- What happens if group size increases?

Learning in imperfect information environment: nonpoint source pollution settings

Haoran Miao[1], Todd Guilfoos[1], Emi Uchida[1], Christopher Koliba[2], Asim Zia[2]

1 Department of Environmental and Natural Resource Economics, University of Rhode Island
2 Community Development and Applied Economics Department, University of Vermont

Research Question and Methods

- Research Question
  - Does more accurate information about pollution allow polluters learn to reach efficient behavior over time? Does group size affect efficiency?

- Methods
  - Agent-based modeling （ABM）
  - Laboratory experiment + Experience Weighted Attraction (EWA) learning model (Camerer 1999)

Learning model

- Why use learning model?
  - Static Nash equilibrium (NE) does not predict human behavior well in repeated games (Feltovich 2000)

Study 1 results	Low Frequency	High Frequency	Continuous sensing
Portion of subjects playing Nash Equilibrium	19%	38%	25%

- Experience Weighted Attraction Learning
  - Reinforcement learning
    - Adjust strategies according to what they earned in previous rounds
  - Belief based learning
    - Adjust strategies based on beliefs about what other players would do

Preliminary results & next steps

- ABM details
  - Watershed with many groups of 6 firms each
  - Agent make decisions
    - Apply parameters that characterize different patterns of learning from lab experiment
  - Policy intervention: more frequent sensing

- Simulation results (20 groups, 60 rounds)

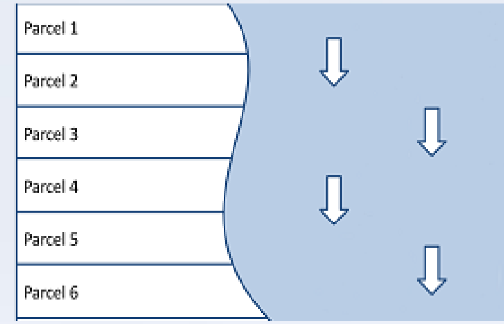
	Low Frequency	High Frequency	Continuous sensing
Portion playing NE (Actual data)	19%	38%	25%
Portion playing NE (simulated data)	22%	33%	25%

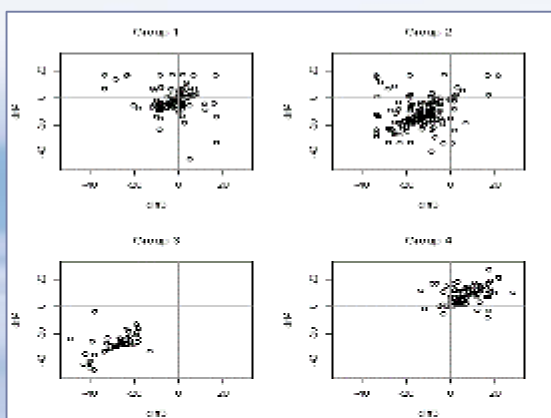
- Next steps
  - Increase group size
  - Introduce uncertainty in learning parameters

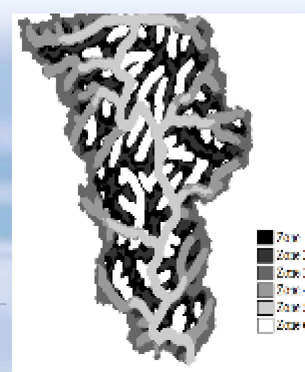
Roadmap of Presentation

NEWRnet
Delaware • Rhode Island • Vermont
North East Water Resources Network

1. Multidisciplinary Research (K. Messer - UD)
   - Research Example (H. Maio - URI)
2. Field Experiments (E. Uchida – URI)
   - Research Example (L. Grand – UD)
3. Experimental Games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)







Field Experiments

- Field experiments involve the land use choices by homeowners and farmers. More expensive and difficult, but have higher external validity, especially when talking to policy makers.

1. Effect of information, social nudges and financial incentives on residential lawn care decisions.

2. Agricultural Value Innovation Stewardship Enhancement (AgVISE) project
   - Evaluated how Delaware farmers made decisions regarding enrollment in cost-share programs for nutrient management

AgVISE

3. Homeowner Value Innovation Stewardship Enhancement (HomeVISE) project
   - Builds upon successful AgVISE and looks at nutrient management practices that can be implemented at the house or apartment level.
   - Ongoing in watersheds in northern Delaware.
   - Lead by Tongzhe Li (postdoc).

HomeVISE

Effect of information, social nudges and financial incentives on residential lawn care decisions: A field experiment

Emi Uchida, Associate Professor
Department of Environmental and Natural Resource Economics
University of Rhode Island

Residential lawns as a source of water pollution

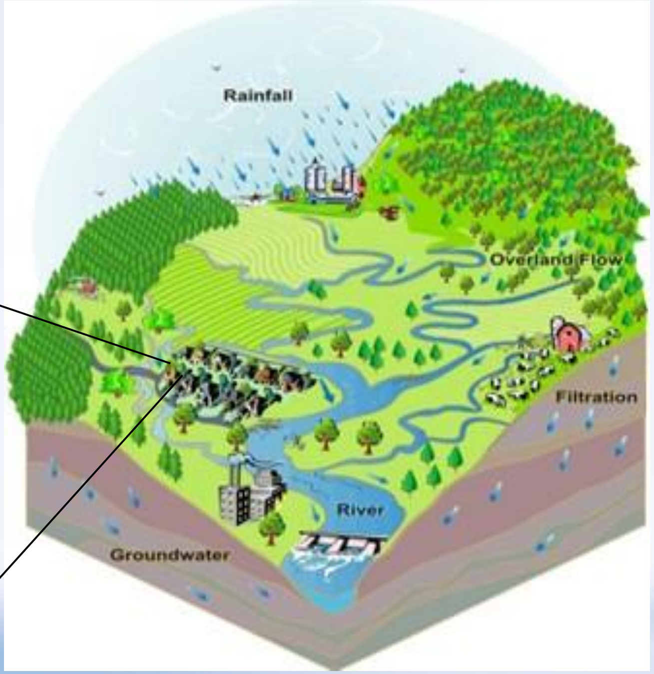


Image source: www.nirpc.org

Examples of BMPs for lawn care

- Mow high
- Leave the clippings
- Don’t fertilize early
- Avoid fertilizers from impervious surfaces
- Plant perennials on the boundaries with roads

www.gardening.cornell.edu

Testing behavioral change in lawn care decisions: Bringing insights from behavioral economics to change residents' lawn care decisions

Good information can lead to better decisions.

- Make salient the linkage between lawn care decisions and water quality

People care about others' behavior. People also want to do the right thing.

- Normative appeals spur non-monetary motivation such as moral costs (e.g., Levitt and List, 2007)
- Social normative messages: "Many residents in Rhode Island have already contracted with Green-certified lawn care professionals."

Financial incentives (sometimes) work, but it can crowd out intrinsic motivation to 'do the right thing.'

- Tension between financial vs. intrinsic motivation has been found in other contexts (e.g., Alpizar and Martinsson 2010; Lacetera et al. 2012; Pellerano et al. 2015 et al.)
- But no crowd out effect when the incentive is large enough (Gneezy 2011)

Goal of this research

To test and measure causal impact of

(a) better information;

(b) social nudges;

(c) financial information

on lawn care decisions.

Empirical issues in measuring causal impact

1. Many factors other than a program can influence changes over time
2. Selection matters: If voluntary, those who sign up for or are selected for a program can be different from those who are not
3. Researchers need to be able to observe outcomes
   - Lawn care practices (and lawns) are difficult to monitor.

RI's Green Certification in Lawn Care

- Requires completion of an extensive list of BMPs covering a range of activities that focus on water conservation and efficient turf management.

- Only 3 companies are certified as of today.

Empirical method to measure causal impact: Randomized evaluation

Residents in southern New England

- Has a lawn
- Does not have a contract with a green certified professional

Basic information only
(1500 subjects)

Basic information
+ Social nudging message
(750 subjects)

Basic information
+ Social nudging message
+ Financial incentive (Low, Med,High)
(750 subjects)

Data collection plan

Summer / Fall 2016: Design survey, collaborating with local schools to recruit subjects.

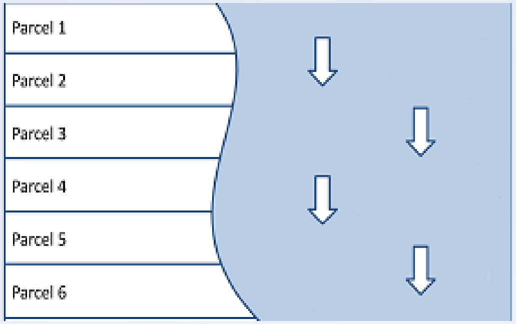
December 2016: Roll out invitation to participate in online survey

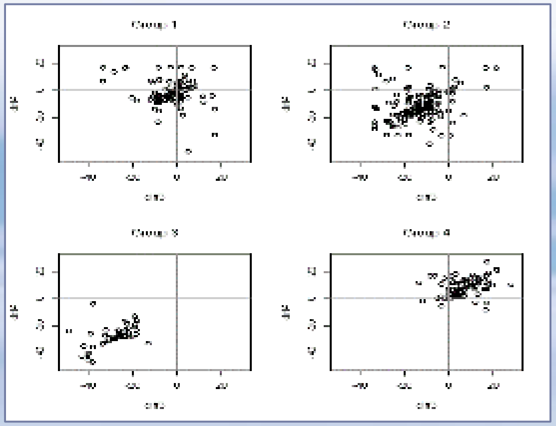
January – March 2017: Send out reminders

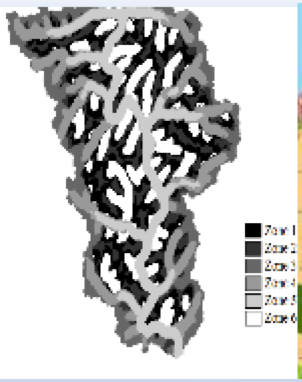
April 2017: Evaluate program outcomes

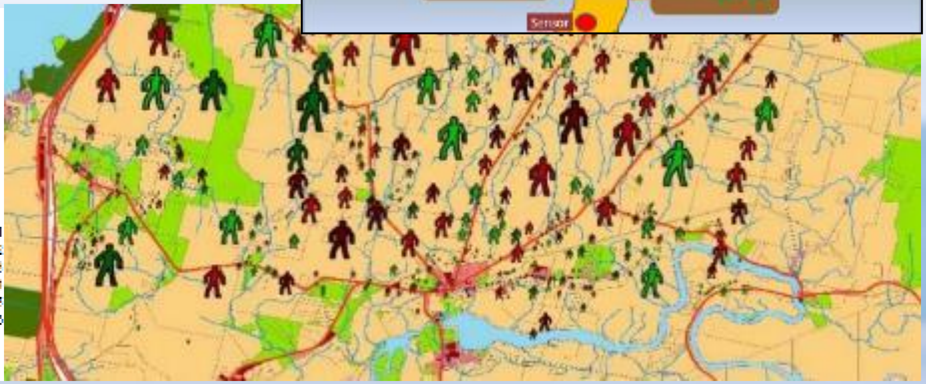
Roadmap of Presentation

1. Multidisciplinary Research (K. Messer - UD)
   - Research Example (H. Maio - URI)
2. Field Experiments (E. Uchida – URI)
   - Research Example (L. Grand – UD)
3. Experimental Games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)









Testing Policies to Reduce Non-Point Source Pollution under Climate Variability

Linda Grand, Jacob Fooks, Kent Messer

Delaware EPSCoR

Improving Delaware's environment and economy through research and education

Vermont EPSCoR

Rhode Island EPSCoR

NEWRnet

Delaware • Rhode Island • Vermont

North East Water Resources Network

NSF

Background

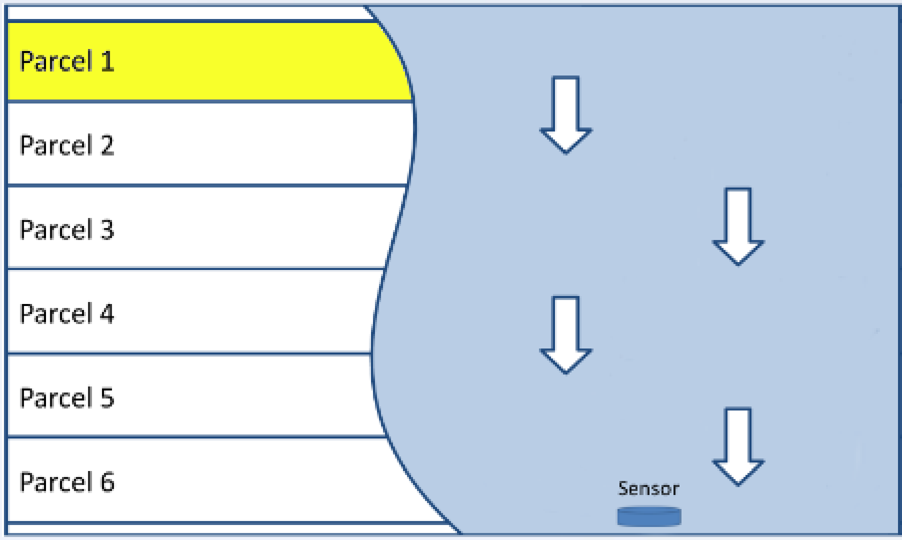
- MS Agriculture & Resource Economics- University of Delaware
- Interested in Water Research
  - Involved in NEWRnet Experimental Economic Class
- Applying research in California
  - Interning this summer at Public Policy Institute of California.
  - Seeing how the drought impacts drinking water utilities

Background

- Climate change will impact drinking water utilities
  - Quantity and timing of annual runoff, seawater intrusion, changes in temperature, increased sea levels
  - **Increased extreme events**
- Drinking water utilities may adapt by protecting upstream water sources subject to non-point source pollution
  - How can these efforts change the behavior of upstream users?
  - Does behavior change based on the structure of payments?

The Experiment

- Participants choose production => revenue and pollution.
- Participants may receive an additional subsidy:
  - **Ambient**
    - Based on total downstream **damage** of all 6 Parcels observed by a sensor
  - **Targeted**
    - Based off individual **production**
- Damages depend, in part, on weather.
  - Different distributions of weather variability across treatments:
  - (1) None, (2) Standard, (3) High, (4) Very High



Miao, H, J Fooks, T Guilfoos, K Messer; S Pradhanang, J Suter; S Trandafir, and E Uchida "The impact of information on behavior under an ambient-based policy for regulating nonpoint source pollution" *Water Resources Research* (2016).

"Visualization and Collective Identity in Nonpoint Source Pollution Settings" J. Butler, J Fooks, and K Messer. *Write-up in process.*

"Spatial Attribution in Nonpoint Source Pollution Policy" J Fooks, K Messer,and J Suter .

The lower the production the better

Results

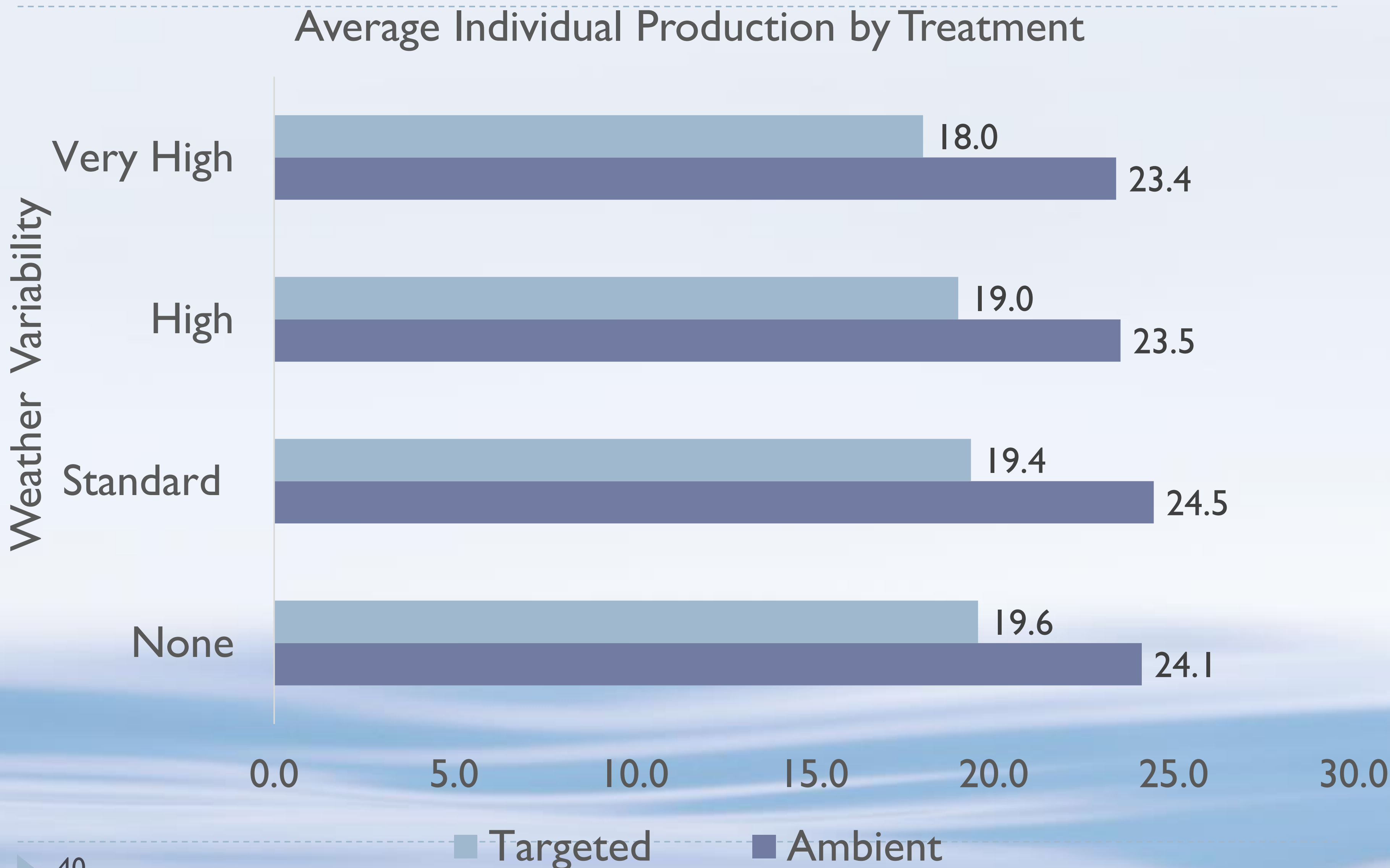


Table 1 Random Effects Regression on Individual Production

Dependent Variable Log(Production)	**Model 1**	
Number of Participants	96	
Number of Observations	3774	
Ambient	**.124*** **	**(0.048)**
Standard Weather Variation	-0.018	(0.039)
High Weather Variation	-0.041	(0.032)
Very High Weather Variation	**-0.089****	**(0.039)**
Ambient* Standard Weather Variation	0.027	(0.053)
Ambient*High Weather Variation	0.019	(0.052)
Ambient*Very High Weather Variation	**0.070***	**(0.040)**
Treatment Round	0.006	(0.005)
R^2	0.0227	
*p<0.10% level **p<0.0 5% level *** p<0.01 Standard Errors in parenthesis		

Policy Implications

- With higher weather variation uncertainty, ambient subsidies become less effective.
  - Ambient pollution policies requires a level of cooperation. With higher uncertainty this cooperation breaks down.
- The ability to use real time sensing at a micro level will help us achieve better policies.
- Our research suggests that drinking water utilities may prefer to implement targeted policies based on observable production inputs.
  - Better sensors will make this possible.

Conclusions

- Drinking water utilities can subsidize upstream users to improve water quality. There are different ways that they can do this.

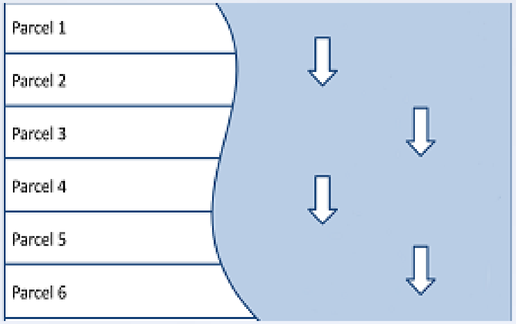
- The effectiveness of the subsidies may change based on both the structure of the subsidies and climate conditions.

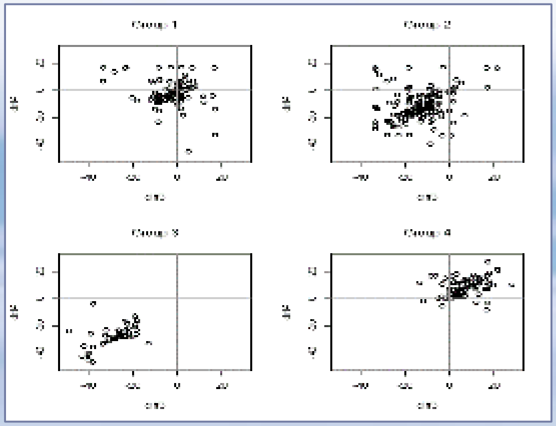
- As the likelihood of extreme events increases, ambient subsidies which target downstream damage become less effective relative to individual subsidies targeting "input" practices.

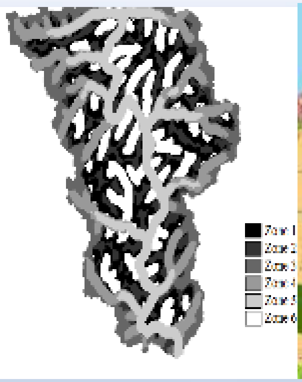
- As we create better sensors we will be able to implement better targeted policies that focus on individual behavior.

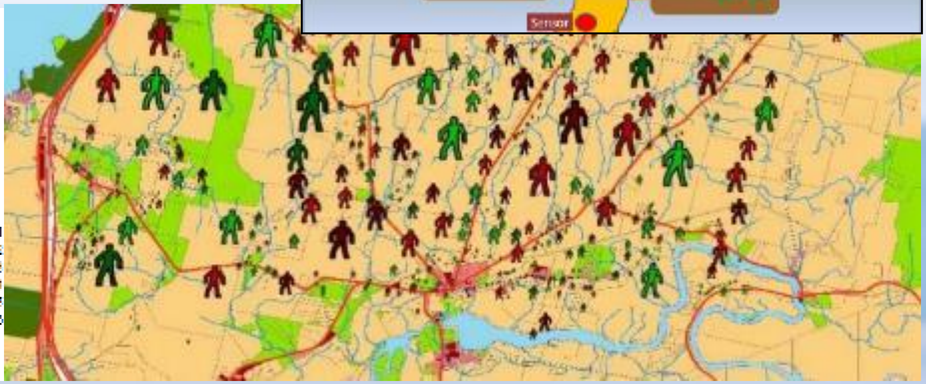
Roadmap of Presentation

1. Multidisciplinary Research (K. Messer - UD)
   - Research Example (H. Maio - URI)
2. Field Experiments (E. Uchida – URI)
   - Research Example (L. Grand – UD)
3. Experimental games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)

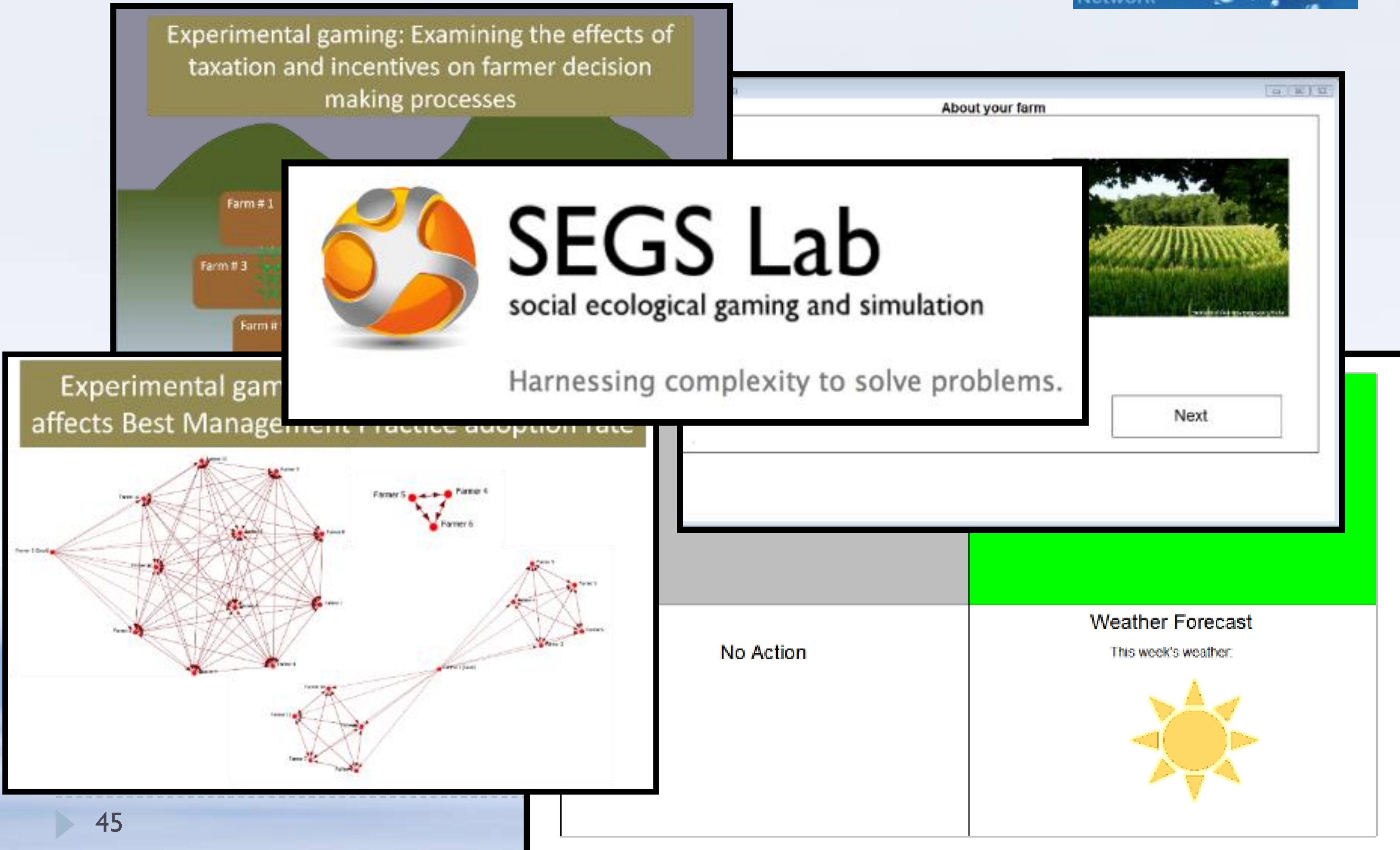






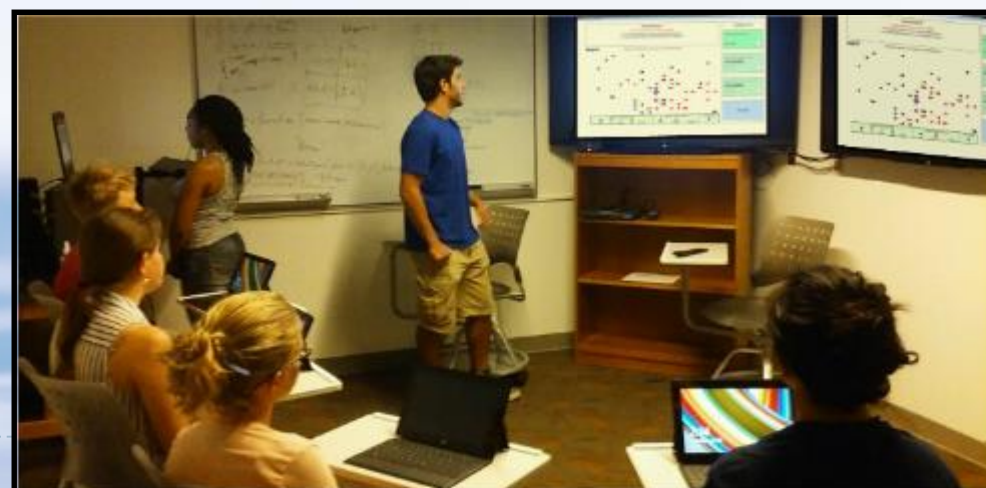


UVM's Experimental Games: Current
Scott Merrill - UVM

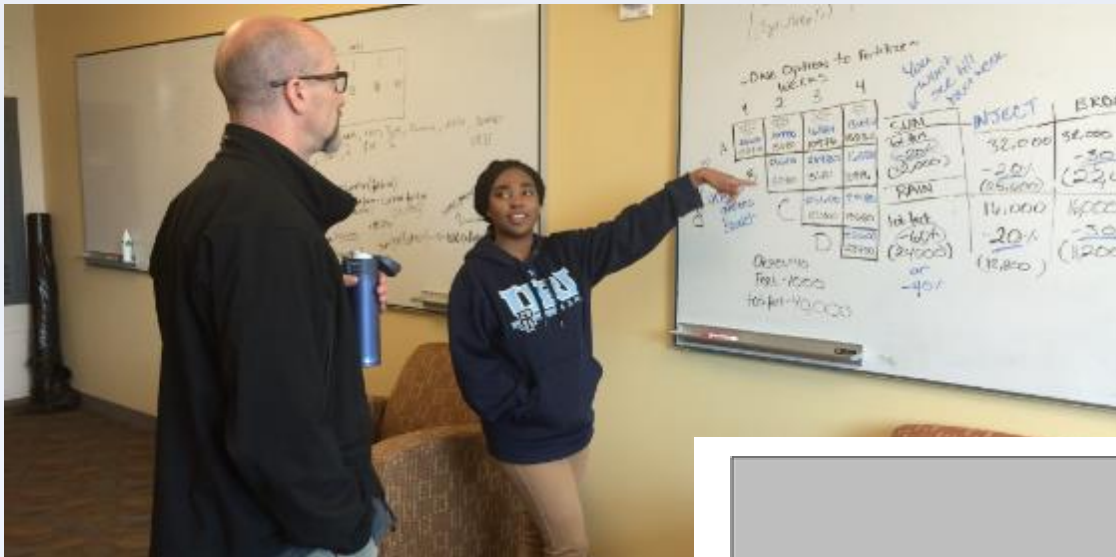


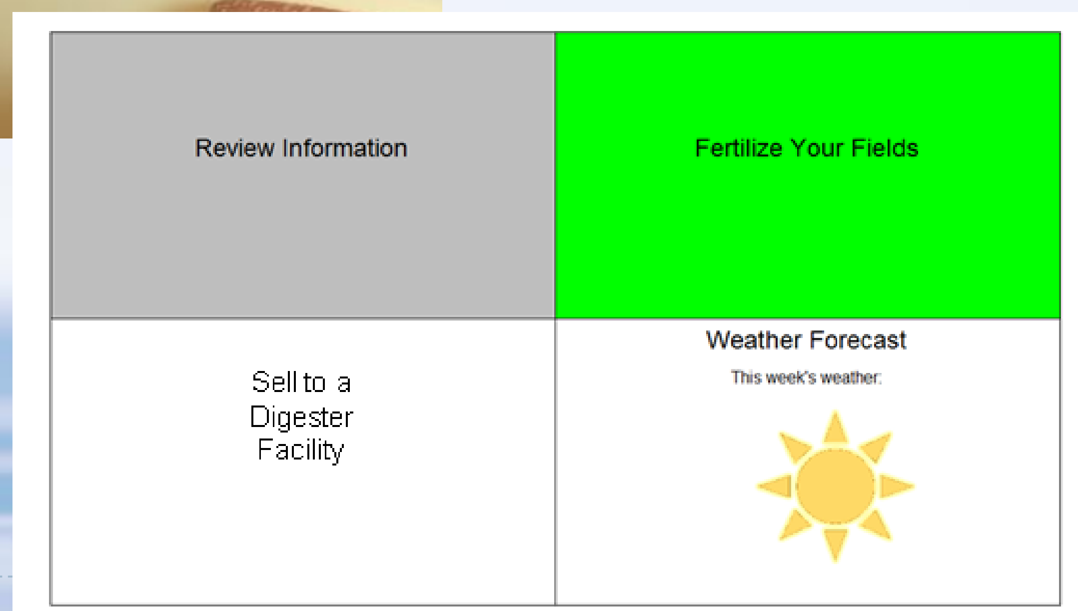
Research studies

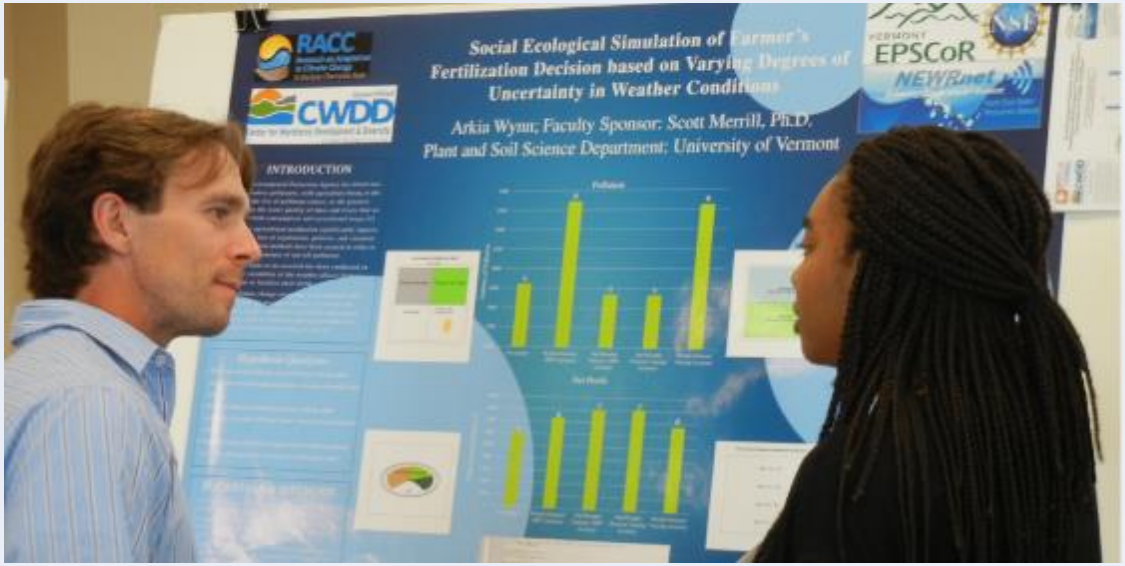
- Store, spread or sell (A manure management conflict)
- Benefits and buffer strip adoption
- Size matters: Innovation diffusion in a clustered social network experiment



Store, spread or sell

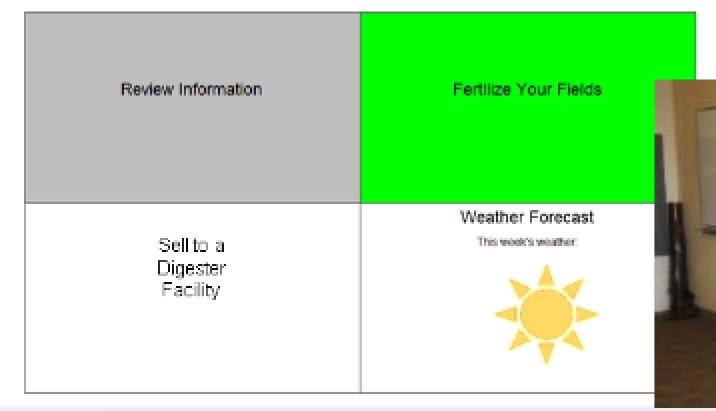






Hypotheses

- Using a risk aversion framework:
  - Uncertainty in weather forecasts will affect manure management decisions
  - Uncertainty in manure sell price will affect manure management decisions



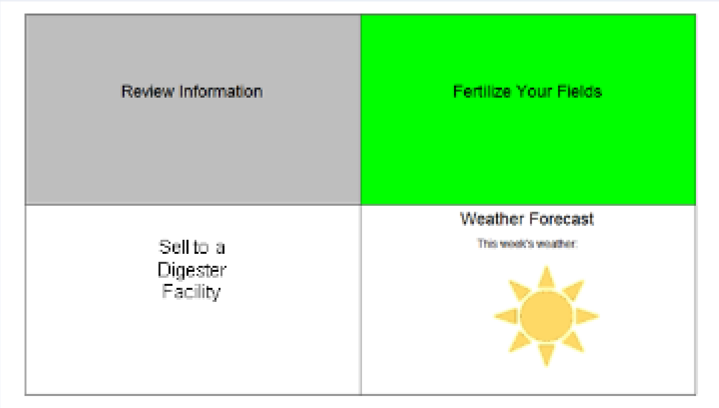
Manure storage conflict

- Sell manure to a Digester facility or put manure on your fields under sub-optimal weather conditions which could result in nutrient loss and degradation of water quality

Project authors in no order: Merrill, Wynn, Uchida, Guilfoos, Trandafir, Miao, Koliba, and Zia

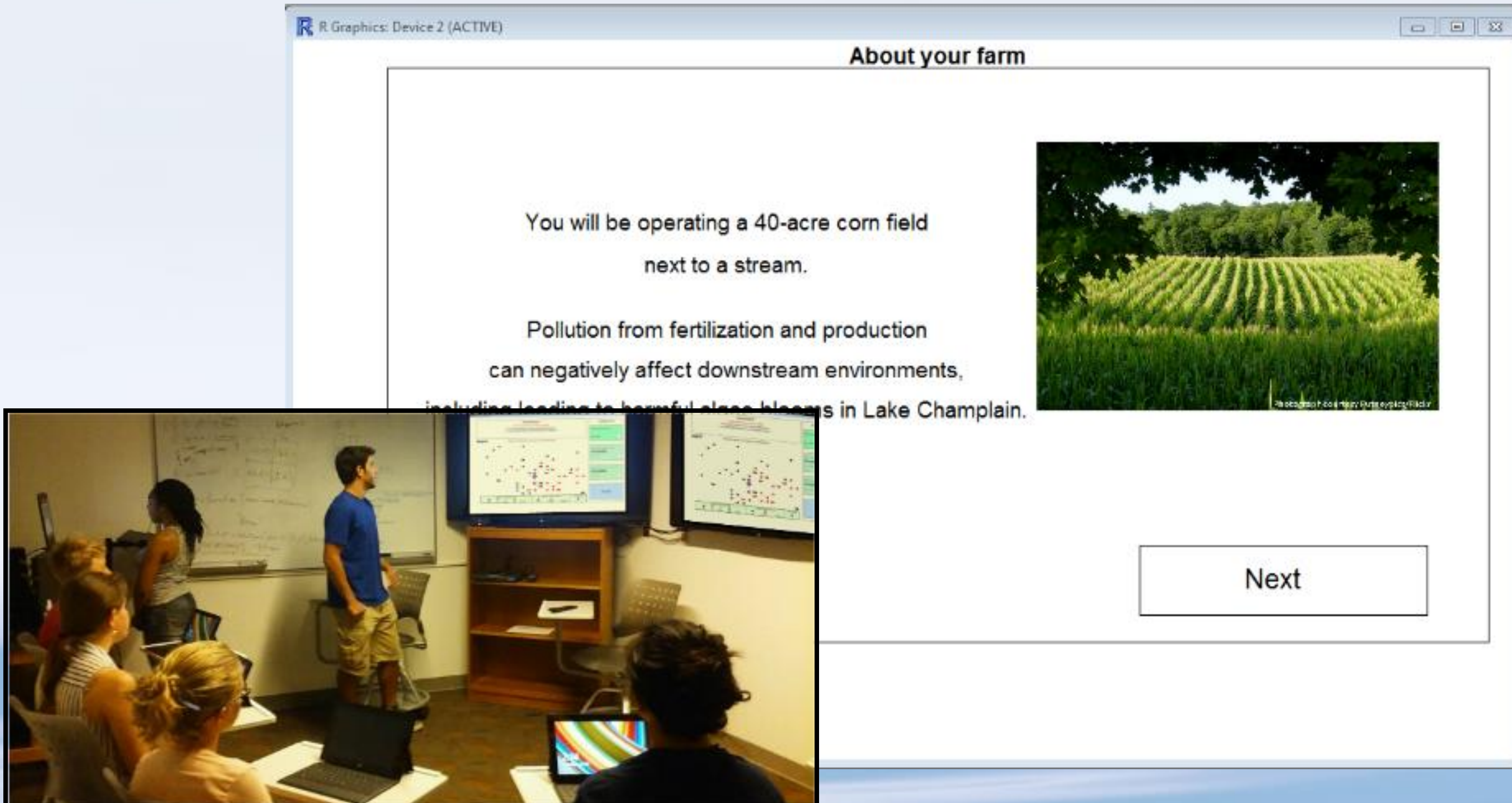
Implications:

1. Can interventions aimed at alternative methods of managing the manure storage conflict result in reduced broadcast applications of manure?

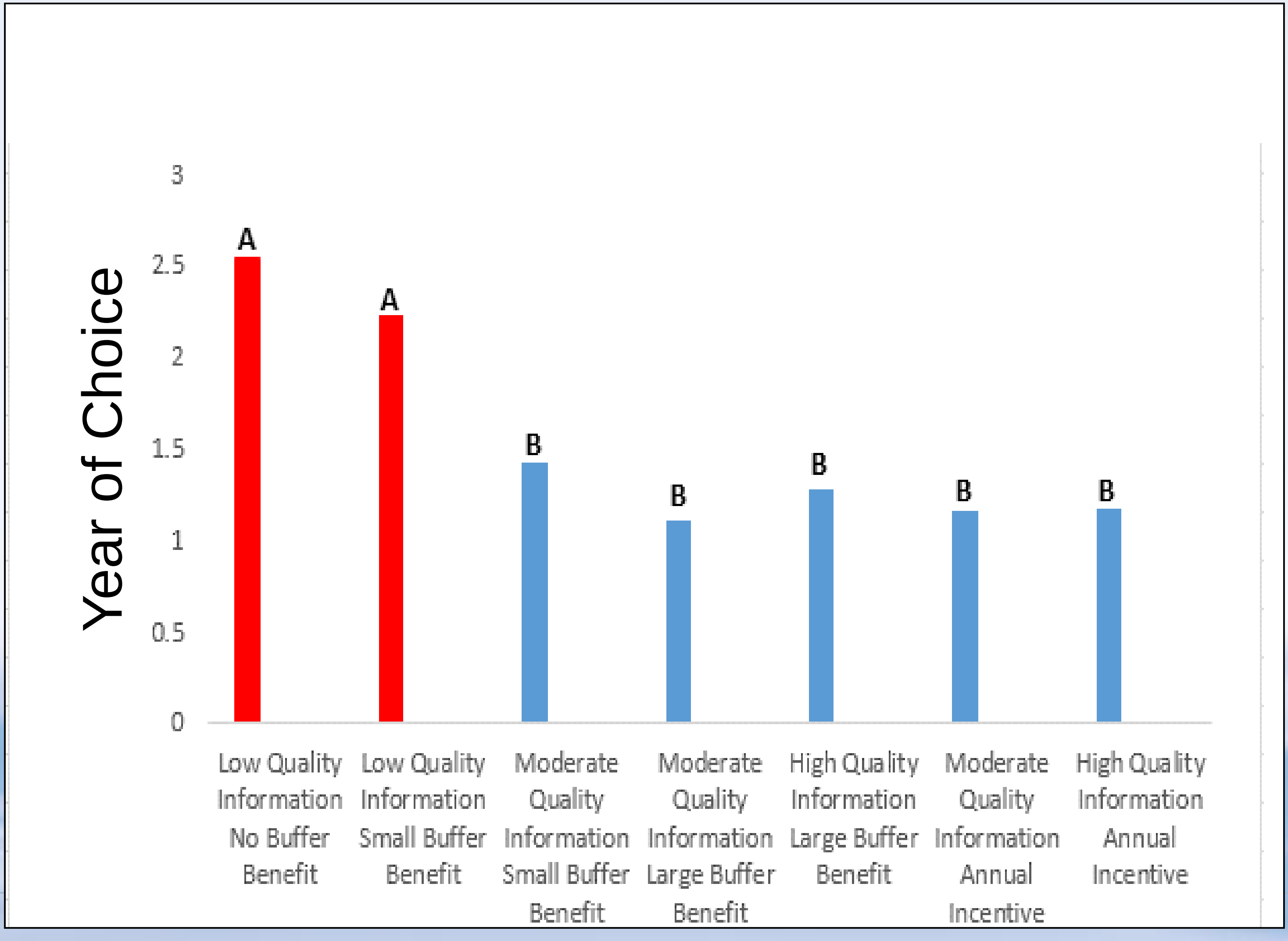


2. Do individuals behave differently when risk and uncertainty are associated with stochastic events (e.g., weather events)? ABM parameterization.

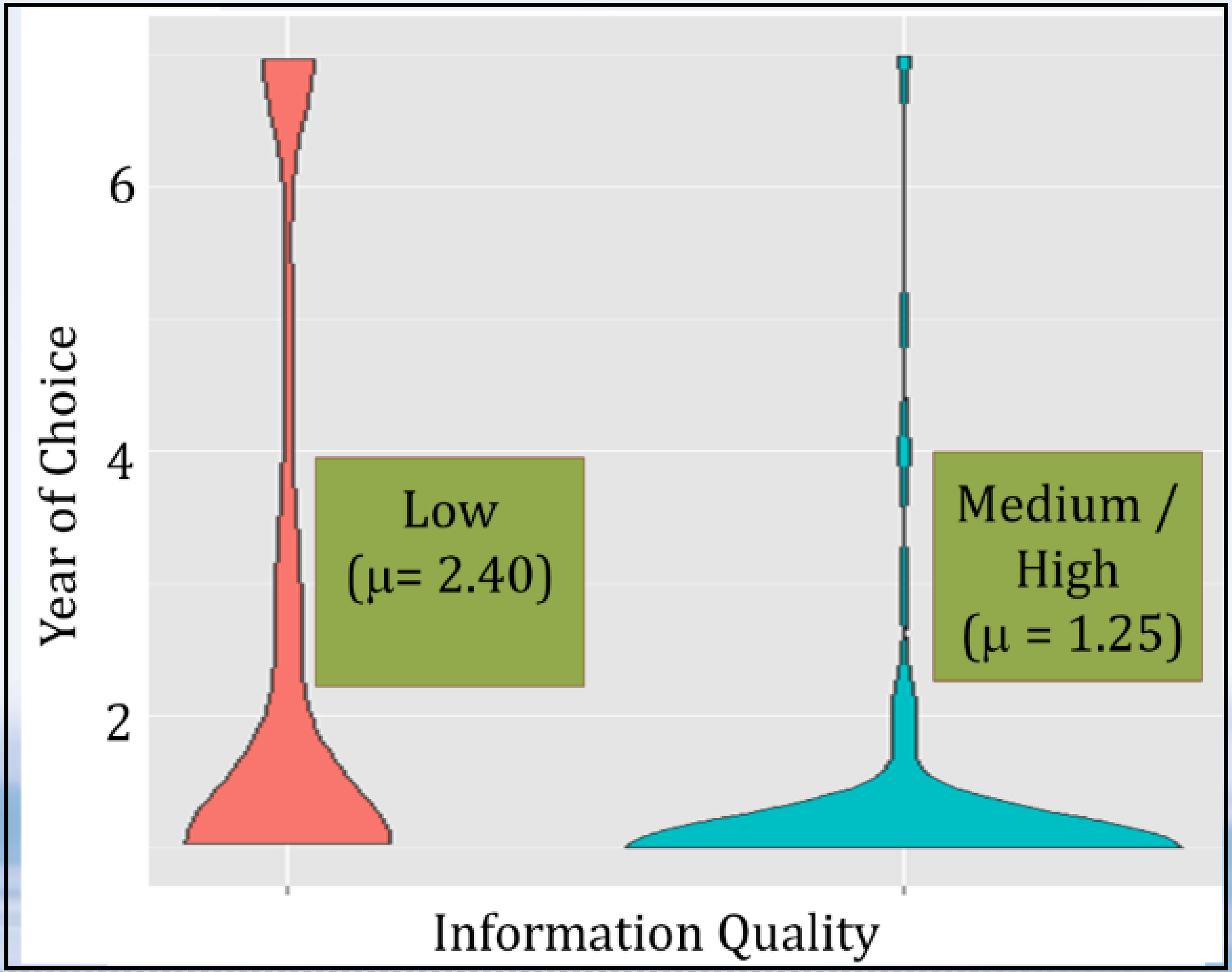
An examination of the effect of information: Does awareness of the effects of buffer strips influence adoption rates?



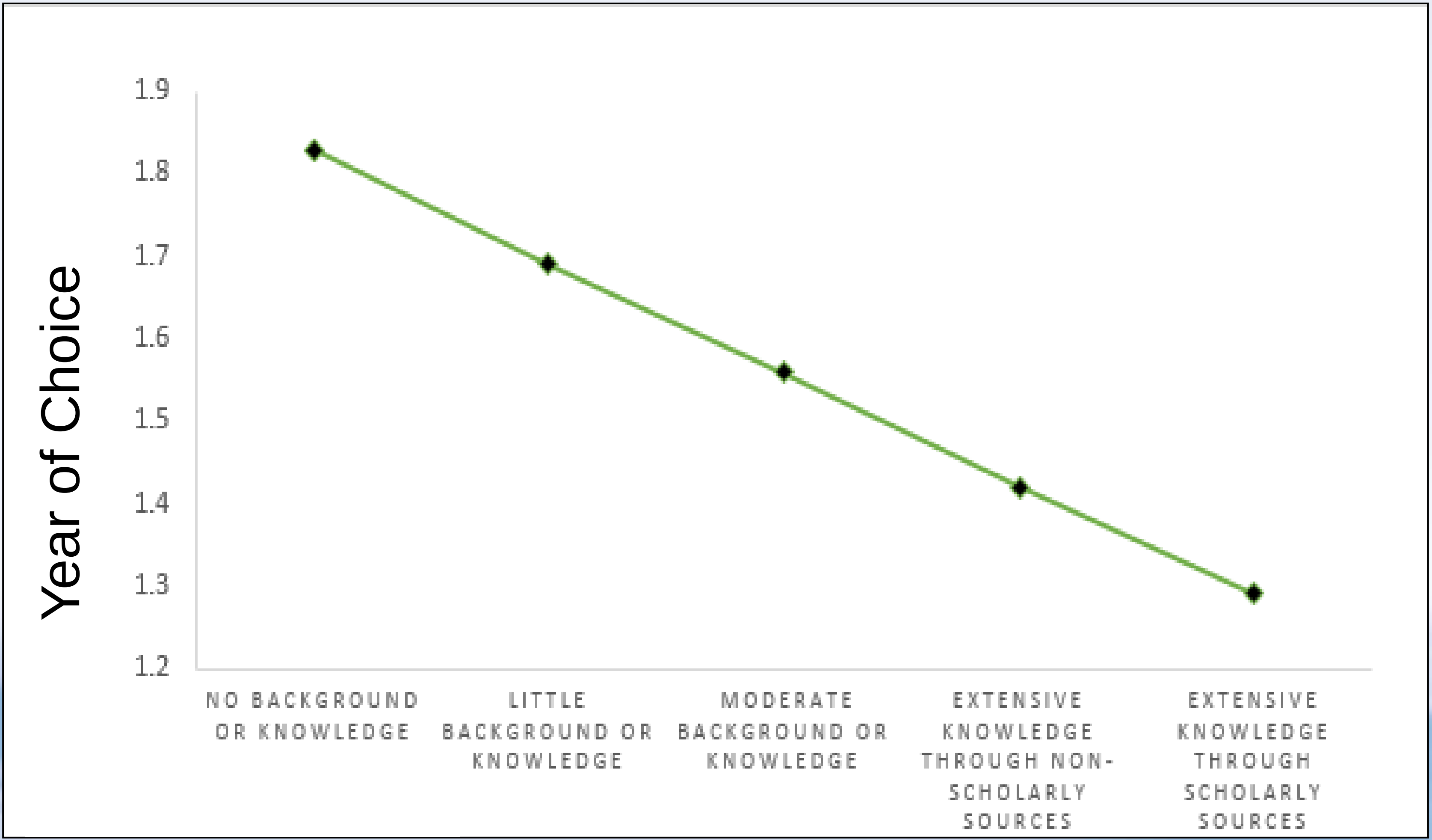
Results and implications:



Results and implications:

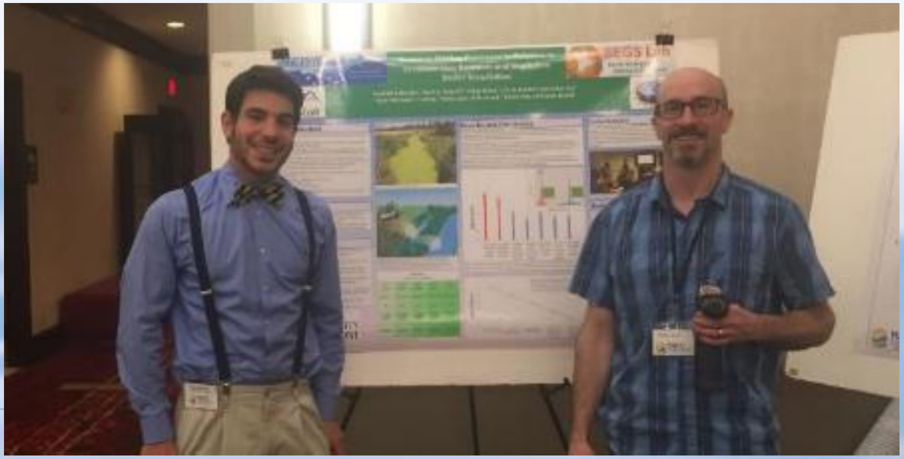


Results and implications:



Future directions of this project

- Multiplayer functionality – ABM parameterization
- Collaboration with University of Rhode Island to run experiments in multiple states



Influence of peer network configurations on adopting novel management tactics

NEWRnet
Delaware • Rhode Island • Vermont
North East Water Resources Network

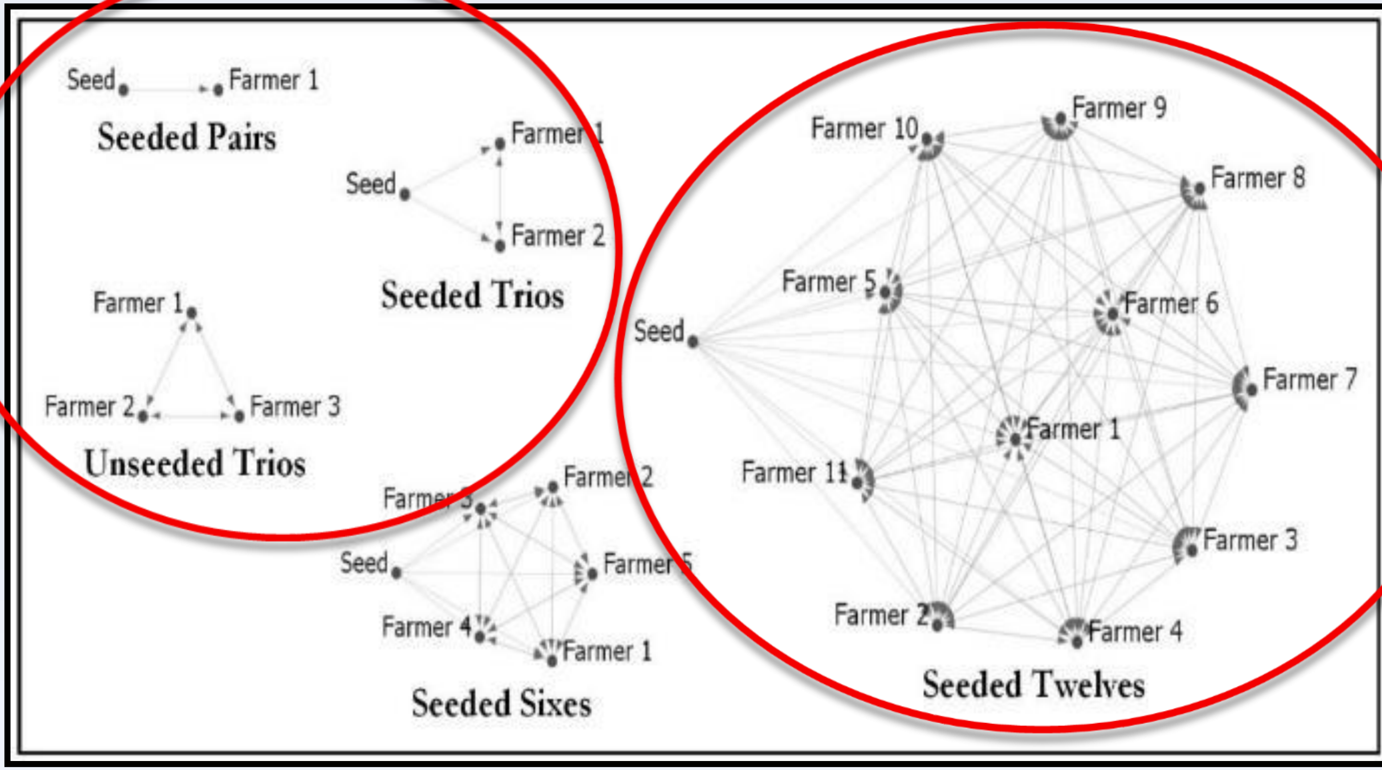
Hypothesis:

The decision to adopt a novel best management tactic will be impacted by the size of one's peer network

http://blog.martinbelan.com/wp-content/uploads/2012/10/20121008_Vermont_Bragg_Hill_Road_1096_00010.jpg

Novel collaborative efforts

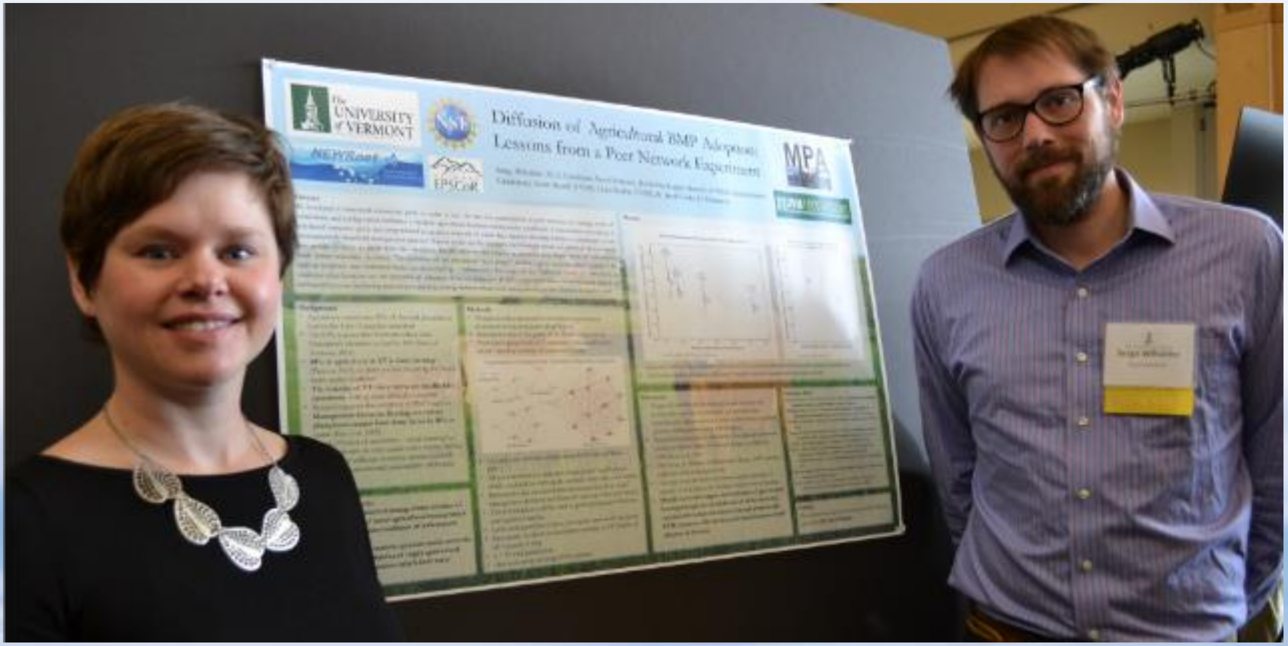
Experimental Economics: Gaming and Simulation course



- Study findings and implications:
  - As the social network size increased participants made better decisions about adopting new manure management practices

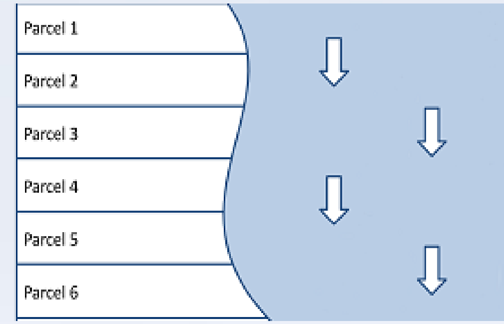
Size Matters: Innovation diffusion in a clustered social network experiment

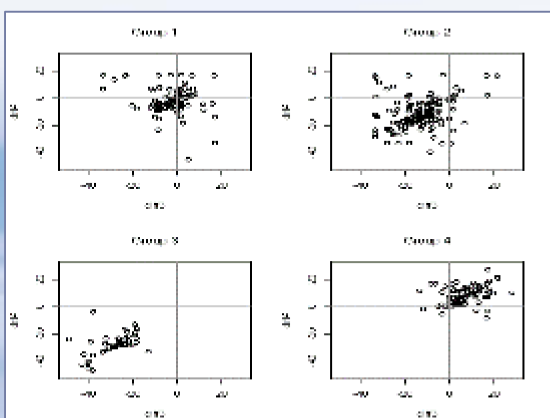
Wiltshire, Logan, Merrill, and Fooks. Size Matters: Innovation diffusion in a clustered social network experiment. Journal of Behavioral and Experimental Economics

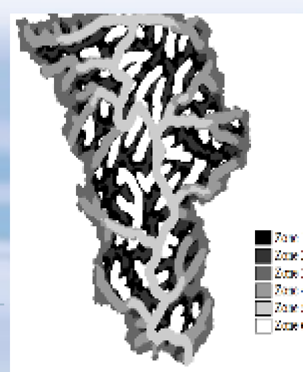


Roadmap of Presentation

1. Multidisciplinary Research (K. Messer - UD)
    - Research Example (H. Maio - URI)
2. Field Experiments (E. Uchida – URI)
    - Research Example (L. Grand – UD)
3. Experimental games (S. Merrill - UVM)
4. Agent-based Models (A. Zia - UVM)







Scaling from experimental games to agent based models

- Zia, Asim, Kent Messer, Shanshan Ding, Haoran Miao, Jordan Suter, Jacob Fooks, Todd Guilfoos, Simona Trandafir, Emi Uchida, Yushiou Tsai, Scott Merrill, Scott Turnbull, Christopher Koliba (In Review) **Spatial effects of sensor information in inducing cooperative behaviors for managing non-point source pollution: Evidence from a decision game in an idealized watershed**. *Ecology and Society*

- Zia, Asim, Yushiou Tsai, Scott Turnbull, Shanshan Ding, Haoran Miao, Christopher Koliba, Scott Merrill, Kent Messer, Jordan Suter, Jacob Fooks, Todd Guilfoos, Simona Trandafir, Emi Uchida (In Preparation) **Simulating the effects of alternate control strategies on heterogeneous farmer behaviors and water quality outcomes: an agent based modeling application in Mississquoi watershed of Lake Champlain Basin**. *Journal of Economic Dynamics and Control*

Longstanding debate in behavioral sciences on selfish versus cooperative behaviors

Results from previous experimental studies, mostly of voluntary mechanisms and conducted under controlled laboratory conditions, suggest that the behavior of human agents is neither perfectly **selfish** nor perfectly **cooperative** (Ledyard 1995, Gintis 2000, Messer et al. 2007).

After reviewing experimental research conducted to estimate cooperative and non-cooperative decision behaviors for provision of public goods under voluntary mechanisms, Ledyard (1995:172-173) noted that:

> "There appear to be three kinds of players: **dedicated Nash players** who act pretty much as predicted by game theory with possibly a small number of mistakes, a group of subjects who will respond to self interest as will Nash players if the incentives are high enough but who also make mistakes, and respond to decision costs, fairness, altruism, etc., and a group of subjects who behave in an inexplicable (irrational?) manner. Casual observation suggests that the proportions are 50 percent, 40 percent, 10 percent in many subject pools."

Hypotheses & Miao et al. Game Design

(1) Incentives in the form of taxes and subsidies induce cooperative behavior among agents in a river-system network.

(2) The number and frequency of water-quality sensors increases cooperative behavior.

(3) The spatial locations of the decision-makers relative to the spatial locations of the sensors affects the induction of cooperative behavior.

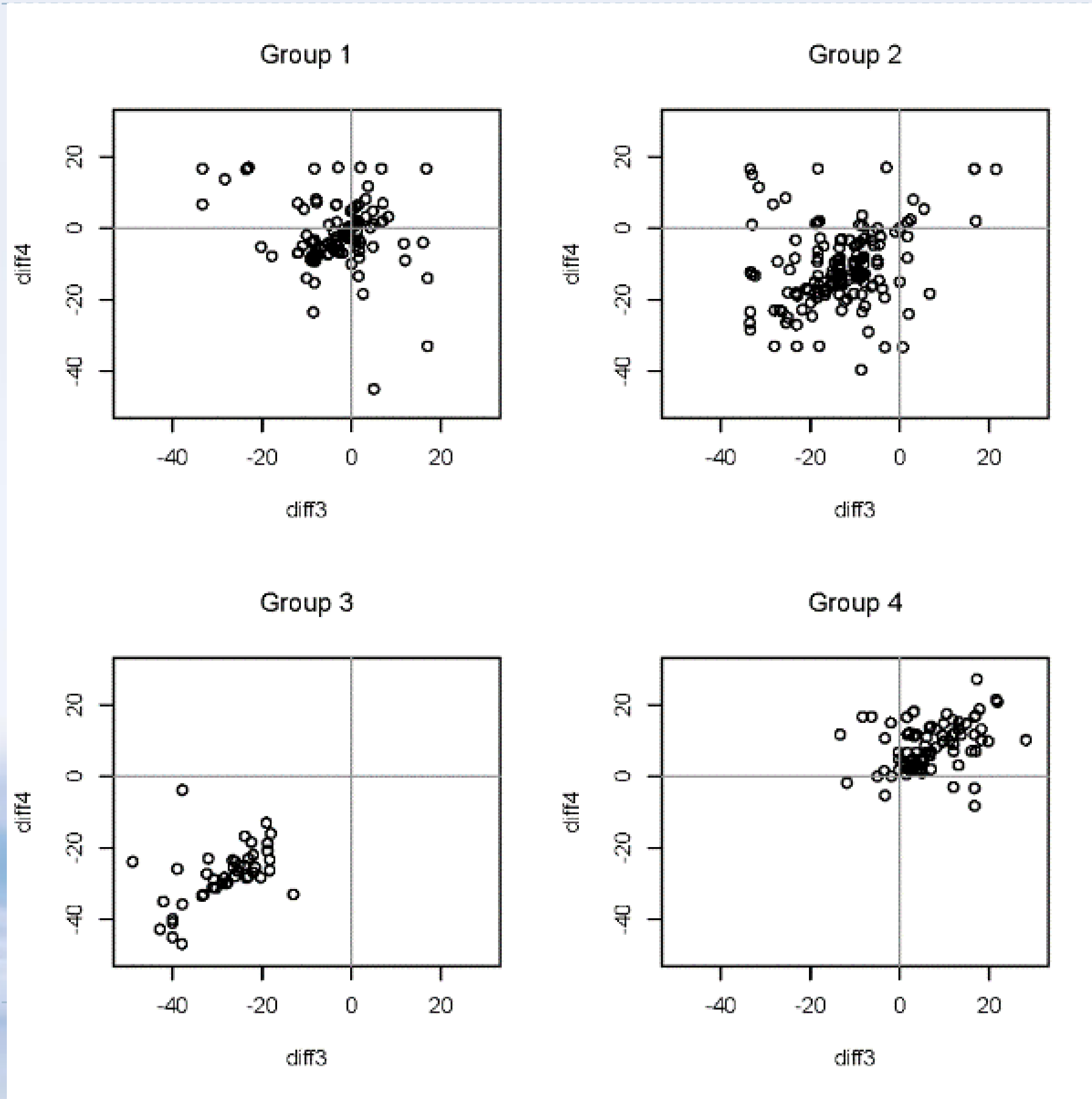
Table 1: *Theoretical predictive prodcution levels (Nash Equilibrium) of each parcel*

Treatment/Parcel	Parcel 1	Parcel 2	Parcel 3	Parcel 4	Parcel 5	Parcel 6
Status quo	50	50	50	50	50	50
Treatment A	33.5	33.4	33.3	33.3	33.3	33.3
Treatment B	21.8	22.8	28.5	36.5	44.6	48.8
Treatment C	Multiple Nash Equilibrium					
Treatment D	33.3	33.3	33.3	33.3	33.3	33.3
Treatment E	22	20.2	29	38.4	45	48.9
Treatment F	Multiple Nash Equilibrium					
Social optimum	20	24	30	33	44	49

Clustering analysis of gaming data reveals four types of behavioral strategies

Competitive/
selfish

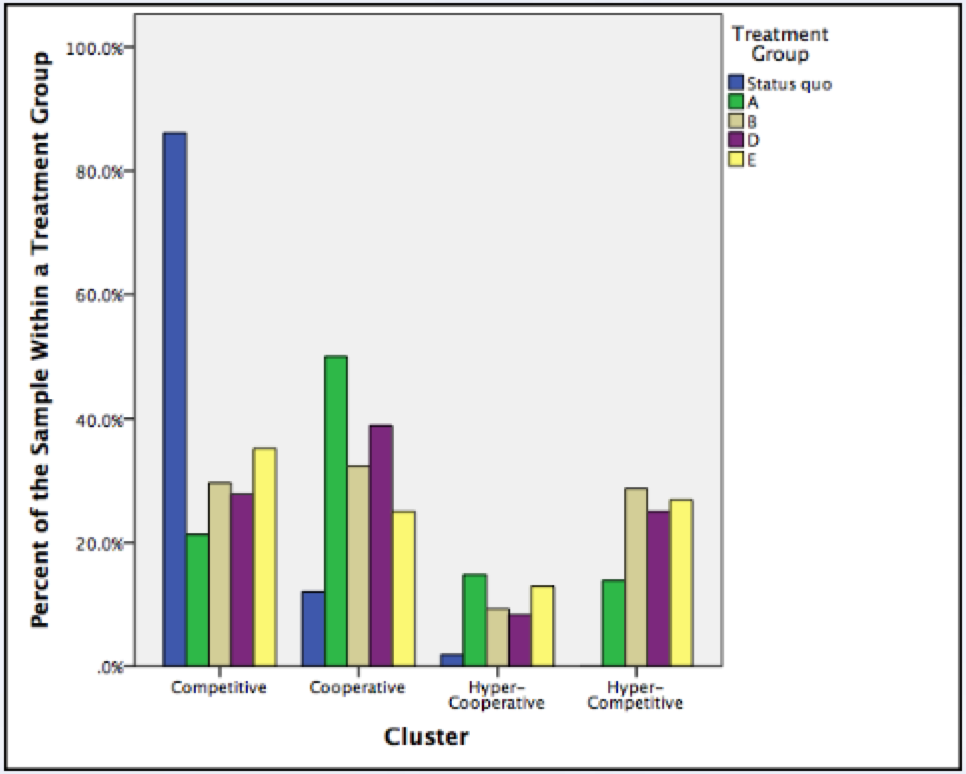
Cooperative



Hyper-
Cooperative

Hyper-
Competitive/
selfish

Sensors and incentives influence spatially sensitive behavioral strategies



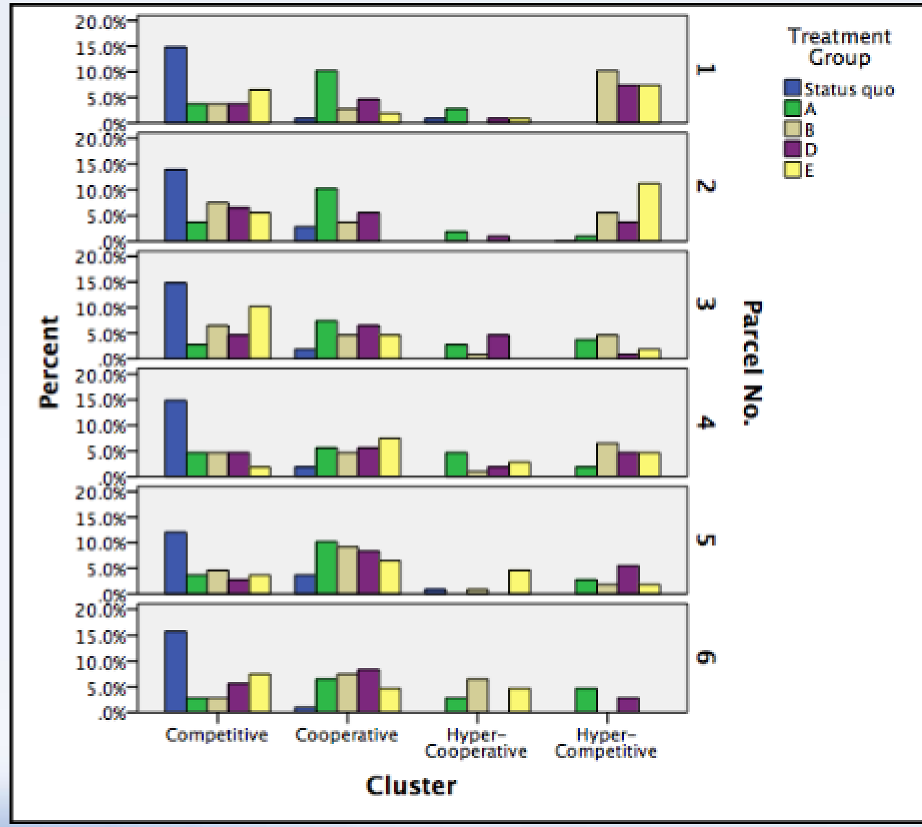


***Table 2:** Treatment table*

Treatment/Parcel	Sensor Number	Frequency of Sensing	Ambient Tax/Subsidy
Treatment A	One	One time	Yes
Treatment B	One	Four time	Yes
Treatment C	One	Continuous	Yes
Treatment D	Two	One time	Yes
Treatment E	Two	Four time	Yes
Treatment F	Two	Continuous	Yes

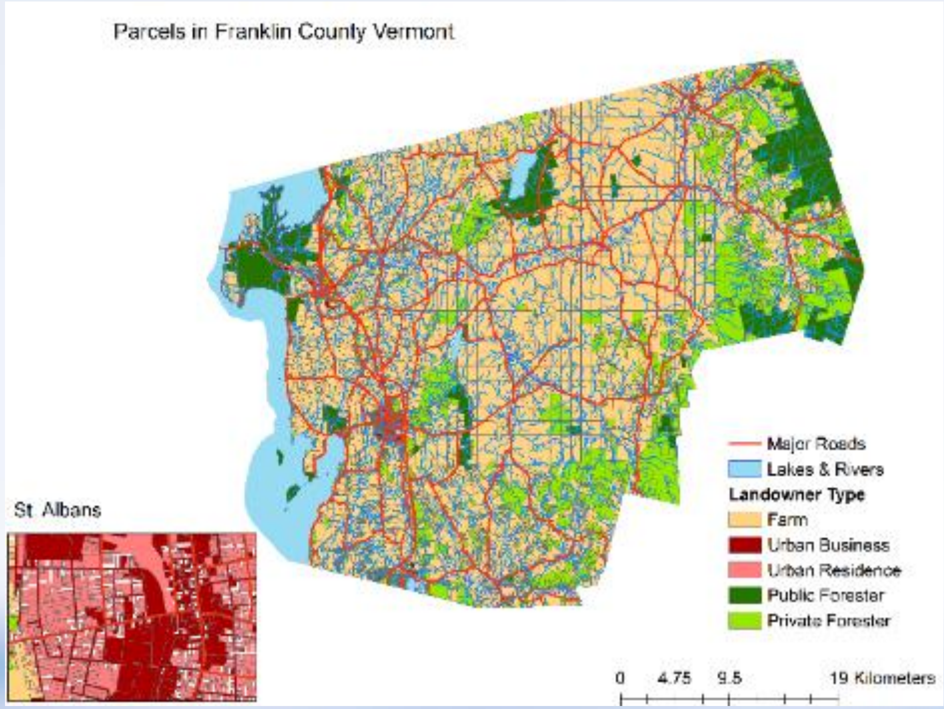
Multilevel multinomial logistic regression models predict induction of cooperative behaviors for different policy and sensor regimes

- Incentives in the form of taxes and subsidies generally induce cooperative behavior but the effect is conditional on the location of the agent’s property in the river network
  - Downstream agents display a slightly greater likelihood to behave selfishly/competitively despite the tax/subsidy incentives.
  - The number of sensors and frequency of sensing has the greatest effect in inducing cooperative behavior for upstream agents.

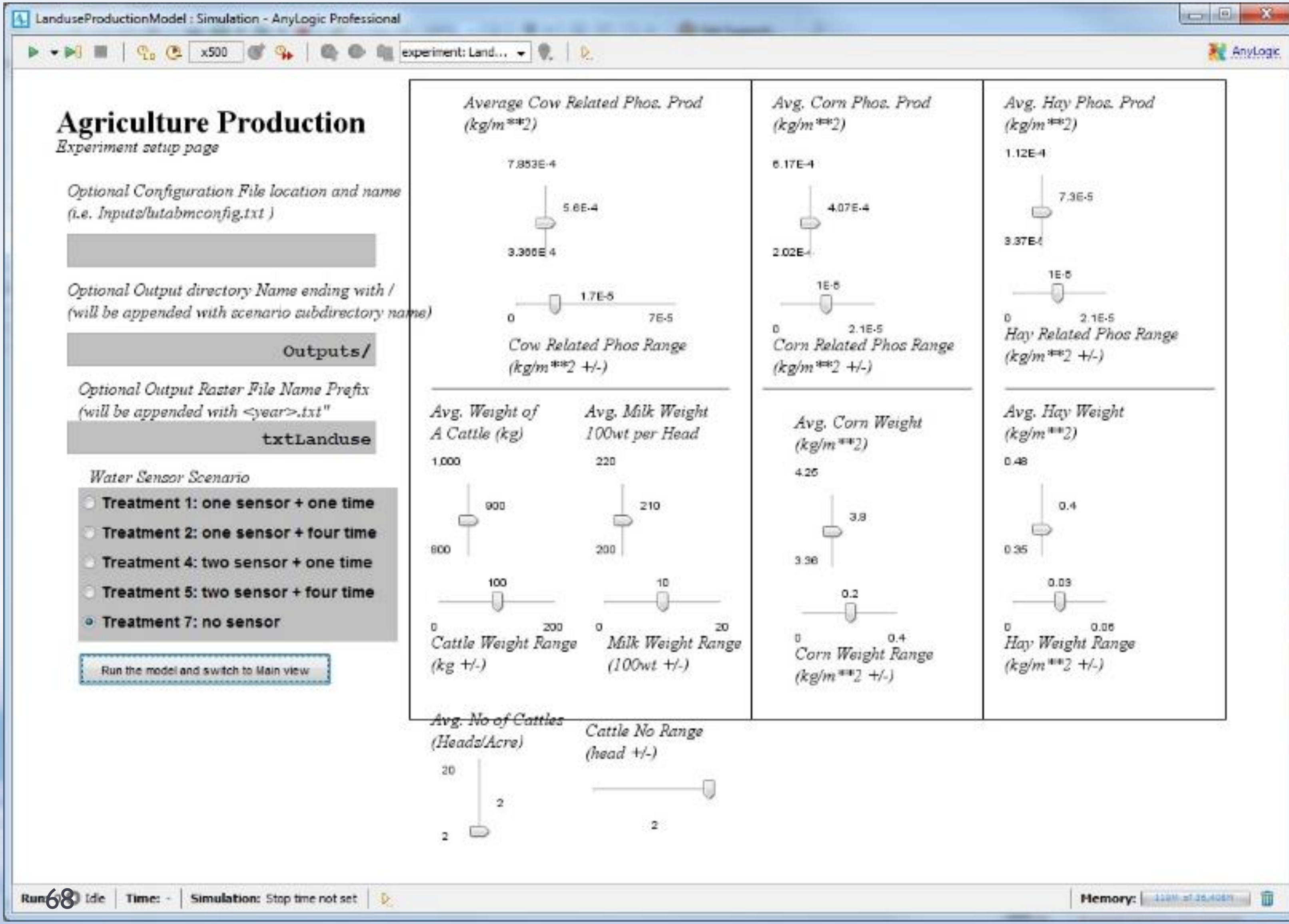
- There is an optimal number of sensors and frequency of sensing that can maximize the induction of cooperative behavior. Beyond that number and frequency, the addition of sensors and frequency of sensing diminish the likelihood of cooperation in maintaining water quality.

Scaling from Games to ABMs

- A base layer of Franklin county in Missisquoi Watershed is used to initialize the farmer populations, parcels and other spatial attributes
- Joint agricultural and P production functions are assigned to farmers by their behavioral & parcel types
- Behavioral types ascertained from gaming data under various treatments are assigned to farmers in the ABM



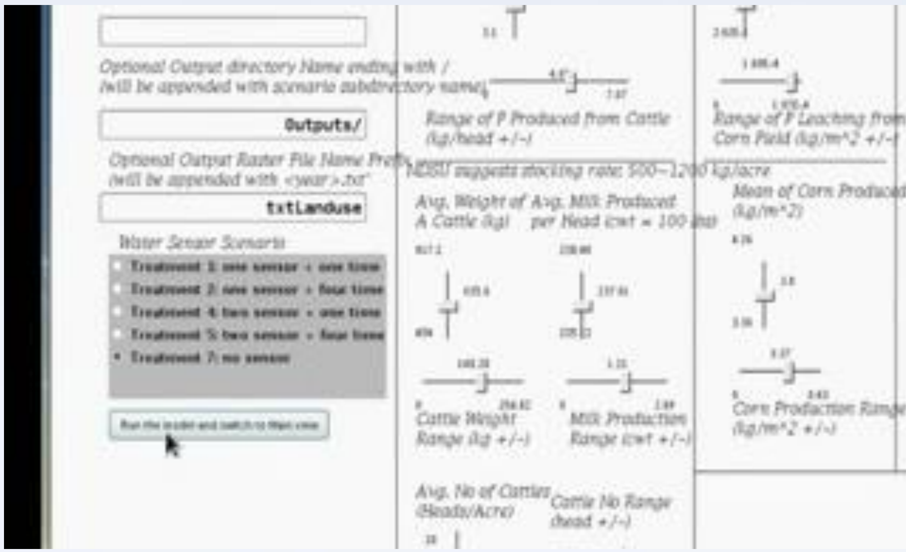
A simplified version of ABM interface for "management simulator" mode

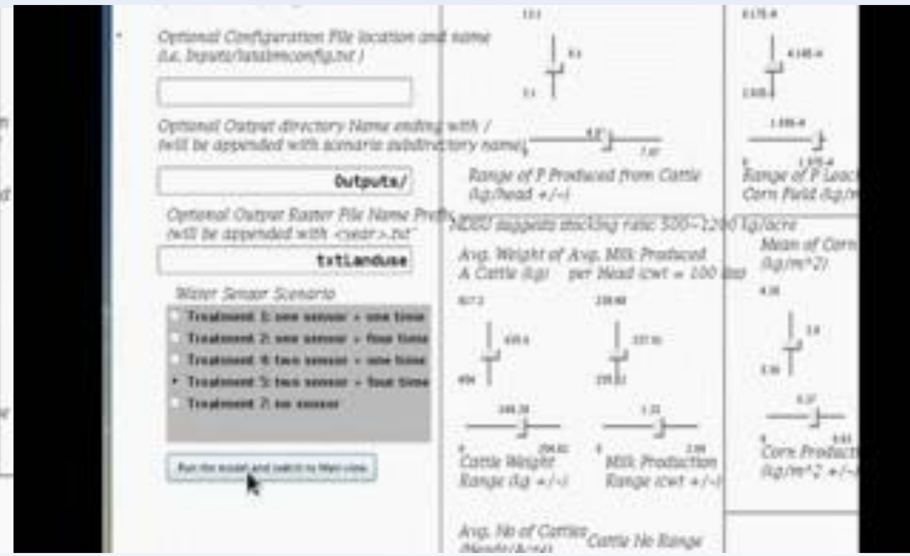


Farmer behavioral strategies can be tracked and aggregated at multiple scales

Control: No Sensor

Treatment 5: Two Sensors & 4 times





Farm Agents

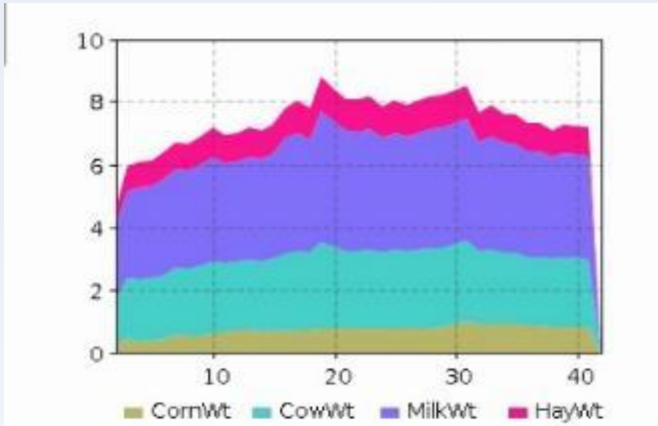
- **Scaled by Farm Area**
- **Colored by Behavior**

Behavior	Typical	Ultra
Cooperative	Dark Green	Bright Green
Competitive	Dark Red	Bright Red

Agricultural and P (and all other variables) in the ABM can be tracked and analyzed

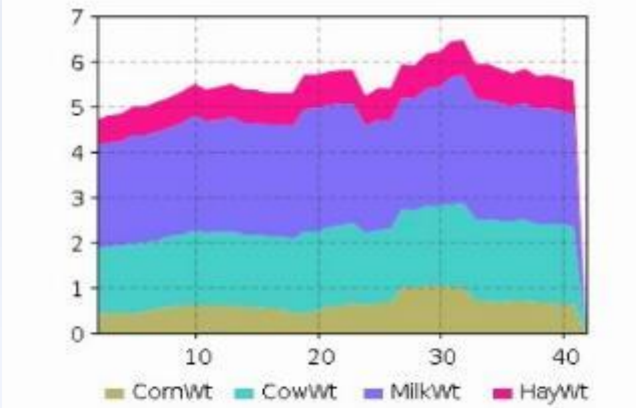
Control: No Sensor

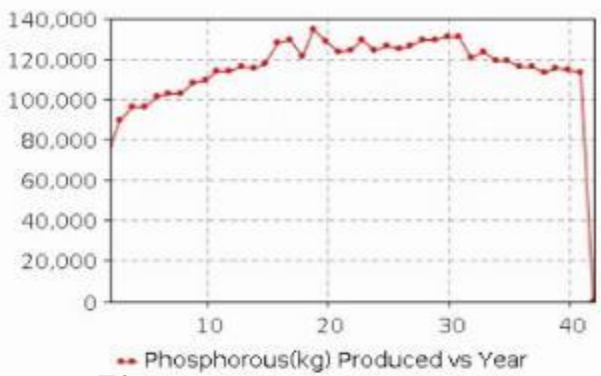
Treatment 5: Two Sensors & 4 times



Combined Production

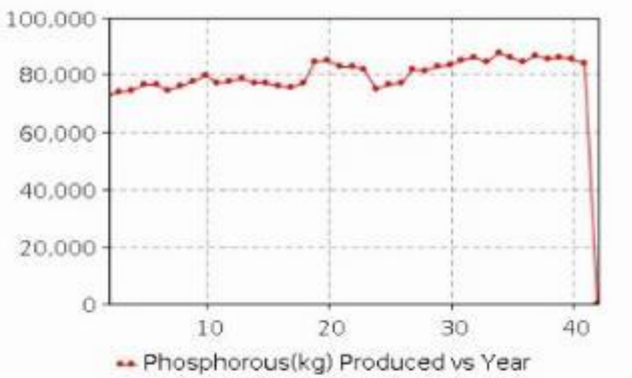
- Corn
- Cow
- Milk
- Hay





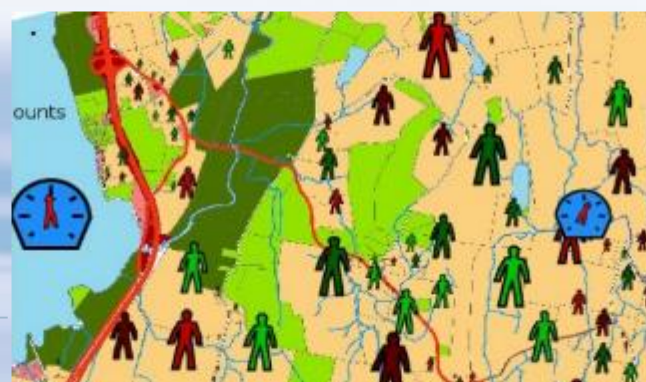
Phosphorus Produced

Note: Scale on Y-axis is dissimilar in all four graphs



Ongoing ABM development

- **Enable simulation of sensor placement across sub-watersheds**
  - Assign parcels to drainage basins
  - Sensors may be activated at outlet of each basin
  - Metrics for parcels sensed and area sensed per sensor
- **Calibrate ABM output to high-frequency P data under a variety of extreme event scenarios**
- **Estimate value of sensor information under different behavioral and extreme event scenarios**
- **Adapt ABM platform to watershed in DE & other gaming data**



How water quality monitoring with sensors and policy regimes impact human behavior: Findings from experiments, games, and agent-based modeling with implications for watershed governance

Thank you!

Questions?