To Green or Not to Green: Modeling Incentive-based Programs for Green Infrastructure Investment on Private Properties

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Simulation of Economic Incentive Frameworks for an Urban Stormwater Program Using an Agent-based Modeling Platform

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Overview

• Background/Motivation
• Initial Modeling
• Ongoing/Future Work
Background

- What’s the problem?
- What is green stormwater infrastructure?
- Where should we invest?
- Why incentivize?
“Only Major Growing Source of Water Pollution” – U.S. EPA

- 40-80% of sediment in Chesapeake Bay is from eroded urban streams
- 850 billion gallons of untreated wastewater/stormwater per year
- 300-900% increase in nuisance flooding in Eastern U.S. coastal cities over last 50 years
- 2014 had 8th worst dead zone in Chesapeake Bay – 1 mi³

Urban Stormwater Runoff

- Water Quality Impairments
- Flooding
- Combined Sewer Overflows
- Ecological Impacts
Traditional Stormwater Management

Collect → Convey → Detain

Green Stormwater Infrastructure

Infiltrate → Retain
Public vs. Private Retrofits

Public ROW is limited

- **Philadelphia, PA**
  - 10,000 impervious acres to be retrofitted - CSO

- **District of Columbia**
  - 415 impervious acres to be retrofitted – MS4
  - $100M of GI pledged in CSS areas - CSO

- **Prince George’s County, MD**
  - 15,000 impervious acres to be retrofitted – MS4

- **Montgomery County, MD**
  - 4,300 impervious acres to be retrofitted – MS4

*Considering that new development <1% of existing development – more retrofits expected in the future for other programs*
Rise of Incentives

GSI Incentive Programs

• Philadelphia, PA
  • Credit/rebate of up to 80% provided for onsite retention
  • Aggressive grant programs (based upon $/ac treated)
    • Promotes the aggregation of projects

• District of Columbia
  • Stormwater Retention Credit (SRC) trading program
  • Allows for 50% off-site mitigation for retention
  • Trading program established, run by Dept. of Env. (DDOE)
GSI Investment Dynamics

“Hand of God”
- Top-down
- Mandated
- Bureaucratic
- Piecemeal

Organic Growth
- Bottom-up
- Incentivized
- Efficient
- Aggregated
Initial Modeling

Taken From:

Agent-Based Modeling

- Framework consisting of **agents** in an **environment** (interaction rules)
- Explores complex **emergent** system behavior (macro vs. micro)
- Irrational, imperfect knowledge, heterogeneous population
- Spatially and temporally dynamic
Modeling: Greening Cities

“Real” Urban Development

Stylized Urban Development

Ideal Urban Development
Research Effort

GSI Investment Model

- Model developed using Netlogo
  - Investment of GSI retrofits on urban parcels
- Representation space:
  - Environment = parcels (ability to “green”)
  - Agents = Investors (Risk, Aggressiveness)
  - Behavior = synthetic data / assumptions
    - Investor risk, competition, growth
Results - Patterns

Initial Conditions: GC = 3, IR = 1, TU = 300, FT = 1, FN = 3, LoC = 4

Results: 329 invested parcels, 180 multiple investors, 115 active investors

Observations:
- High investment
- High connectivity
- Initial investors ~ invested parcels
- ~40% of invested parcels are occupied by investors
- ~55% of invested parcels have multiple investors
- Inefficient policies

Risk-averse, unaggressive investors
Results - Patterns

Initial Conditions: GC = 2, IR = 2, TU = 50, FT = 1, FN = 2, LoC = 1

Results: 199 invested parcels, 9 multiple investors, 16 active investors

Observations:
- High/moderate investment
- Moderate/well connected
- Invested parcels ~25% of total parcels
- ~8% of invested parcels are occupied by investors
- ~5% of invested parcels have multiple investors

Ideal policy conditions:
- Risky, aggressive investors
Ongoing/Future Work

- Use non-synthetic ("real") behavioral data
  - Risk, motivations, innovativeness, etc.
- Move from stylized to real-world setting
- Social influence on information dissemination
- Investigate various incentive-based programs
- Investigate water quality/quantity benefits
Phase 1 - Generalized Model Development

Phase 2 - Data Collection and Synthesis

Phase 3 - Applied Model Development and Analysis

Phase 4? – Tie to WQ Modeling
Phase 1 – Generalized ABM Architecture

Agent-Based Modeling

Agent Behavior
- Decision-making factors
- Risk tolerance
- Social network influence
- Influence on adoption by surrounding parcels

Environment
- Parcels
- Capacity for adoption
- GSI suitability

Finance Assumptions
- Discount rate
- Interest rate
- GSI practice costs

Program Framework
- Fee /credit
- Trading
- P3 or PACE

Agents
- Private property owners
- Investors
- Public outreach agents

Policies
- Fee / rebate levels
- Level of subsidization / rebate
- Scaling fees/rebates
- Transaction cost level
Social Influence

Relative Agreement Algorithm:

1. Agent $i$ with opinion $x_i$ and uncertainty $u_i$ influences agent $j$ with opinion $x_j$ and uncertainty $u_j$

2. Agreement is determined and opinion of agent $j$ is adjusted
Social Influence

Small World network dynamics

- If $P=0$, info only gained from immediate neighbor
- If $P=1$, info gained randomly from anyone
- “Realistic” or “typical” social networks have a $0.01 < P < 0.1$
Phase 2 – Data Collection

• Survey / interview [agent]
  • TPB, Innovativeness, Risk
  • Statistical analysis
  • Model parameter development
• GIS data [environment, agent]
• GSI cost data
Theory of Planned Behavior

- Factor is based upon the strength of belief \(b, n, c\) below) and the evaluation \(e, m, p\) below) of belief in each case
- Mathematical Form is:
  - \(A \propto \sum_i^n (b_i e_i) = \text{Attitude}\)
  - \(SN \propto \sum_i^n (n_i m_i) = \text{Social Norm}\)
  - \(PBC \propto \sum_i^n (c_i p_i) = \text{Perceived Behavior Control}\)
  - \(BI \propto (A) + (SN) + (PBC)\)
  - \(BI = W_1(A) + W_2(SN) + W_3(PBC)\)
    - \(W1, W2, W3\) determined through regression with \(BI\) as criterion
Theory of Planned Behavior

Attitude:
- “I think GSI is important to protect environment”
- “I think GSI can improve downstream waters”

Subject Norm:
- “If I installed GSI, my neighbors would support”
- “My neighbors/friends opinion of me is important”

Perceived Behavioral Control:
- “I could install GSI on my property”
- “The lack of technical knowledge is preventing me from installing GSI on my property”

Intention:
- “I want to install GI on my site”

Actual Control:
- “I can afford GI investment on my site”

Adoption
Phase 3 - Research Analysis

Applied Model

Agent-Based Modeling
- Policies (incentives, programmatic, framework)
- Modeling parameters (financial, behavioral)

Emergent Behavior
- Diffusion of innovation (rate)
- Level of investment (amount)
- Distribution of adoption (spatial)

Policy Recommendations
- Incentive level (rebate level, subsidization level)
- Programmatic (fee rates & schedule, level of outreach & education, framework)
Conclusions

- GSI retrofits on private property = needed, challenge
- Initial modeling has fleshed out concepts
  - Proof of concept
- Future work
  - Incentive programs
  - Decision-making dynamics
  - Social influence
  - Actual costs and spatial data
Questions?

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