To Green or Not to Green: Simulating Incentive-based Dynamics 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
Evolution in Stormwater Management

Traditional Stormwater Management

Collect → Convey → Detain

Green Stormwater Infrastructure

Infiltrate → Retain

Stormwater as a Resource and an Opportunity
Rise in Retrofits

• 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
  • 8,000 - 15,000 impervious acres to be retrofitted – MS4

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

Generally

• Approximately 75% of impervious cover constructed prior to Federal regulations overseeing urban stormwater runoff

• Considering that new development <1% of existing development – more retrofits expected in the future for other programs
Public vs. Private Retrofits

Public ROW is limited

• Approximately 60% of lands are privately owned
• Most public lands are located in Western Region
  • MT ~ 63% privately owned – about average – similar to NY and WA
• States like MD, MA, and OH have private land ownership of 90% or above
• Most public ROW is transportation related

• Private land can be key to stormwater retrofit programs
Rise of Incentives

GSI Incentive Programs

• Philadelphia, PA
  • Credit/rebate of up to 80% provided for onsite retention
  • Aggressive grant/subsidy program (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. (DOEE)
Do Incentives Work for GI?

- Short answer is...not really (for most traditional programs)
- Longer answer is...maybe (or they could)
- Focus has been on programs / funding / financing
  - What about behavior, methods, and messaging?
- How best to measure behavior?
  - Agent-based modeling is one option
Community-Based Social Marketing

• Focuses on sustainable behavioral change
• Information-based efforts only go so far...
  • Advertisement is good for getting people to choose one brand over another – but not changing behavior
  • Requires direct contact with community members
• Consider the USDA Ag Extension Service Program
  • “State extension specialists work in close social and spatial contact with agricultural researchers...and this closeness facilitates their linking research-based knowledge to farmer problems.” (Rogers, 2003)
(How) Do Incentives Work for GI?

- Washington, D.C. Department of Energy and the Environment (DOEE)
  - RiverSmart Homes Incentive Program
    - Targets residential properties
    - Offers subsidies for adoption of GI on-site
    - Through 2014, total of 3,737 installations ~ 2.5% of all residential parcels
    - 63% rain barrels, 17% native plantings, 14% rain gardens
    - Clustering of adoption is evident
Clustering of GI Adoption

- DOEE RiverSmart Homes Incentive Program

Figure 2. Density of all GI installations through the RiverSmart Homes program from 2009 to 2014, overlaid on total population per census tract.
Clustering of GI Adoption

Lim, 2017
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

*That which is not good for the beehive cannot be good for the bees.*

Marcus Aurelius
Initial Modeling

Model:
- GSI adoption at parcel level
- Spatial dynamics
  - Connected GSI
  - Pockets of high adoption
- Investor dynamics
  - Population
  - “Peer pressure”
  - Aggressiveness
  - Competition
Initial Modeling

Brown and Ferreira, 2013
GSI Investment Model

• Model developed using Netlogo
  • Investment of GSI retrofits on urban parcels

• Representation space:
  • Environment = parcels (ability to “green”)
    • Physical = parcel size, landuse type, etc.
  • Behavior = opinion, innovation, etc.
• Agents = Public outreach specialists
Research Phases

Phase 1 - Generalized Model Development

Phase 2 – Model Testing & Refining

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

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

**Agents**
- Public outreach agents
- Potential/Actual Investors

**Phase 1 – Generalized ABM Architecture**
Elements of Model

• GSI adoption on private parcels
  • Decision-making (Theory of Planned Behavior)
  • Opinion dissemination (Relative Agreement Algorithm)
• Social Network dynamics (Small-World Theory)
• Innovation impacts (Diffusion of Innovation)
• Public Outreach Impacts (Power of Information)
• Neighboring Influences (Fixed-Window Theory)
“Inspired” by the DOEE SRC trading program

- “Sectors” mirror DC Wards
- Demographic/census data for DC
  - Income
  - Age
  - % with undergrad and grad degrees
- Landuse types and distribution based upon Wards
- Parcel size associated with landuse type from DC
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:
  - $A \propto \sum_{i}^{n} (b_i e_i) = \text{Attitude}$
  - $SN \propto \sum_{i}^{n} (n_i m_i) = \text{Social Norm}$
  - $PBC \propto \sum_{i}^{n} (c_i p_i) = \text{Perceived Behavior Control}$
- $BI \propto (A) + (SN) + (PBC)$
- $BI = W_1(A) + W_2(SN) + W_3(PBC)$
  - $W_1, W_2, W_3$ 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**
Opinion Dissemination

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

\[ s_i = [x_i - u_i, x_i + u_i] \]

\[ s_j = [x_j - u_j, x_j + u_j] \]
Social Networks

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 $0.01 < P < 0.1$
Opinion Dissemination Regular Network
Innovation Impacts

Innovation Index

• Based upon demographic (census block) data
  • Washington, D.C. as source
• Age, degree of undergrad, grad degrees
• Younger, more education = more innovative
• More innovative = open, aware, risk-taker, etc.

Sector 1 (Ward 3)
- Upper income
- Low-Density Res (60%)
- Institutional (17%)
- Early Adopters
- Northwest Area

Sector 2 (Ward 5)
- Lower-middle income
  - Low/Med-Density Res (28%)
  - Low-Density Res (24%)
  - Institutional (18%)
  - Commercial (12%)
  - Late Majority
  - Northeast Area

Sector 3 (Ward 6)
- Middle income
- Low/Med Density Res (45%)
- Med-Density Res (13%)
- Early/Late Majority
- Capital Hill Area

Sector 4 (Ward 8)
- Lower income
  - Med-Density Res (39%)
  - Low/Med Density Res (26%)
  - Low-Density Res (15%)
  - Laggards
  - Southeast/Anacostia Area

Sector 5 (Ward 2)
- Upper-middle income
- Low/Med-Density Res (23%)
- Office (21%)
- Institutional (20%)
- Commercial (14%)
- Early Majority
- Downtown Area

Modeling Environment

Conceptual Environment
Public Outreach

Outreach Influence

• More engagement
  • Higher awareness
  • Higher opinion
• # of outreach agents can vary
• Random movement
  • One local move per time step
• Time Step 1 – Public Outreach
• Time Step 2 – Public Outreach
• Time Step 3 – Public Outreach
Neighboring Effect

Neighbor Influence

- “Moore Neighborhood”
- Consistent w PV adoption
- Lighter shade means better site for GSI
  - Fewer constraints
  - High innovation, high opinion
  - Favorable payback
- Time Step 1 – Innovator
- Time Step 2 – Early Adopter
- Time Step 3 – Early Majority
- Time Step 4 – Late Majority
- Total of 4 invested in neighborhood
Randomly Select Parcels

Does GSI exist onsite already?

Awareness

Contact made with public outreach agent?

# of GSI owners in my neighborhood > threshold

Is innovation > threshold?

Global Set-Up
Determine site characteristics:
- Sector
- Landuse
- Parcel size
- Constraints
- Stormwater fee
- GSI practice

- Potential credit generation
  Agent establishment:
  - Public outreach officials
  Municipal/development demand*

Property Owner Decision-Making Process

Monthly Cycle

Restart Decision-making Process

Yes

No

Input

Continue investing?

Yes

No

Input

Stay “green”

Lose the “green”

Does revenue > O&M cost?

Opinion

Is opinion > threshold?

High PBC
Payback < threshold
Constraints > threshold

Self-Invest?

Outsider Investor?

Payback < threshold
# of GSI owners in my neighborhood > threshold
Constraints > threshold

Interested Investor

Interested Investor

Interested Investor

Interested Investor

“Purgatory”?
Conceptual Model
Phase 2
Model Testing & Refining

• Sensitivity analysis of parameters
• Isolate/analyze aspects of model
• Compare with empirical studies (DOEE, etc.)
• Give model geospatial relevance
• Refine GSI cost data
Agent-Based Modeling Development

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

Observe Emergent Behavior

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

Describe Possible Policy Considerations

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

Phase 3 Research Analysis
Applied Model
Conclusions

- GSI retrofits on private property = needed, challenge
- Incentive programs for GSI don’t really change behavior
- GSI adoption on private property has strong spatial and clustering pattern
- Agent-based model has replicated clustering patterns
- Future work:
  - Refine behavioral parameters
  - Better understand community-based social marketing methods and their effects
Questions?

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