**Urban Water security**

**OVERVIEW**

**Purpose and patterns**

This model is inspired by water governance problems in cities around the world. Investments need to be made to reduce the damage from extreme events (droughts, floods, polluted water) at different spatial scales and severity. Individuals can contribute to private infrastructure. Public authorities invest in public infrastructure and they need to make decisions about where they invest their limited resources.

The overall purpose of the stylized theoretical model is to understand how assumptions of decisions making by households and public authorities impact the spatial vulnerability of the urban system. Questions to explore are: what leads to inequality of vulnerabilities? Will different disturbance regimes require different governance priorities to derive sustainable and fair outcomes?

This is a stylized model based on experience in developing a model on water governance for Mexico City (Baeza et al. (2019), Bojórquez-Tapia et al. (2019), Shelton et al. (2018)) and aims to capture the spatial vulnerabilities in a city as a consequence of decisions made by different levels of society (Eakin et al. 2017). The model is also an example of implementing a coupled infrastructure system capturing different types of infrastructure (Anderies et al., 2016). Public infrastructure providers and resource users make decisions on the creation and maintenance of infrastructure.

**Entities, state variables and scales**

Agents representing residents are located in one of M neighborhoods. Each resident agent has a certain income Y, private infrastructure, a memory of past damage from events, and the level of damage from events experienced in the current time step.

A neighborhood consists of a patch with a maximum number of residents that can occupy the neighborhood. The cost of living in the neighborhood relates to the mean income of resident agents in the neighborhood. The figure below shows the default setting of 49 neighborhoods and a maximum of 36 residents in each neighborhood. The neighborhood also has a public infrastructure.

Background pattern

Description automatically generated

The public authority that makes decisions on where to invest in public infrastructure, is operating at the observer level. This agent has a budget and a priority criterium on how to rank neighborhoods for investments. The priority criterium can change based on the outcomes of voting from residents.

The model will move forward in time tick by tick, not representing a specific time unit. Every 50 ticks the governmental autority change of priorities of the investments in public infrastructure. The agents keep track of 10 ticks of historical data that could impact decisions they make.

**Process overview and scheduling**

Each tick the information is updated in the following order:

1. Events: random events at the individual, neighborhood, and city-wide level causes damage.
2. The residents make decisions about whether to invest in their private infrastructure.
3. The public authority ranks neighborhoods in order of importance and invests in public infrastructure until the budget runs out.
4. Update metrics and visualization.

**DETAILS**

**Initialization**

We assume initial levels of 1 for the private and public infrastructure. The income of the residents is drawn from a log normal distribution exp(n(0,)), then ranked from highest to lowest income, and subsequently put into neighborhoods of similar income levels. Hence we have differences in income between neighborhoods if . The intensity of past events is assumed to be 0.1 for the different types of events. However, we assume that the damage levels in the working memory of the agents are 0 at the start of the simulation.

**Input data**

Parameters used in the model

|  |  |  |
| --- | --- | --- |
| Parameter | description | value |
|  | Maximum level of the damage for an event at the resident level | 1 |
|  | Parameter that defines the shape of damage function | 4 |
|  | Parameter of exponential distribution for events | 0.5 |
| , | Parameters of Cobb Douglass function | 0.4, 0.4 |
|  | Decay rate of private infrastructure | 0.15 |
|  | Decay rate of public infrastructure | 0.15 |
| budget | Budget of public authority to invest in public infrastructure | 5 |

**Submodels**

*Events*

Each tick we check whether there are events happen at the individual, neighborhood and city level, and if so with what level of intensity. The damage caused by an external event depends on the intensity of the events, based on a general damage function (Prahl et al., 2012).

Where is the relative damage of the property of agent i in neighborhood j to event type z. The parameter is the maximum value of the damage for event type z. The default model has event types: individual, neighborhood and city level. The parameter defines the shape of the damage function. The variable defines the intensity of the event and is an outcome from an exponential distribution. The variable is the infrastructure level for the property of agent i in neighborhood j that protect the property from damage.



Figure: we vary the value of

The value the intensity of events is a sum of events that happen at the city level, the neighborhood level and the household level. For simplicities sake we draw three numbers from the same exponential distribution function with mean (1 / ).

The infrastructure reducing property loss is a combination of private and public investments. For simplicities sake, we assume that they are two somewhat complementary stocks that generate via a Cobb-Douglas function a total infrastructure level

We implicitly assume that both private and public infrastructure is needed to have functional infrastructure. A neighborhood can have a water well, but if the household has not a bucket, private infrastructure, the household cannot obtain water. A neighborhood can have a drainage system to absorb rainfall events, but if the household has not created ways for rainfall water to move to the streets, it still can experience water damage.

The level of public and private infrastructure declines each tick with a decay rate or and increases if agents have invested in the infrastructure.

The total damage that an agent experience relates to the cost of living in the neighborhood. We multiply the damage level with the Price of living in neighborhood j.

*Investments in private infrastructure*

Agents make each time step a decision to invest in private infrastructure. They use records of the events of the last 10 timesteps to calculate what the expected benefit of increasing the private infrastructure with one unit. If this higher than the expected costs the agent will invest in the private infrastructure.

*Investments in public infrastructure*

The investments in the public infrastructure is defined by a governmental authority who has a budget B and has to make decisions which neighborhoods to invest. How does the water authority make it’s allocation decisions? We assume that the water authority ranks the neighborhood according to one of the following criteria:

* Neighborhoods with a lower level of infrastructure will get higher priority.
* Neighborhoods with a higher total damage in the last 10 time-steps get a higher priority
* Neighborhoods with a higher relative damage to income get a higher priority

**Some results**

Below we show some initial results with 100 runs for a series of parameter values. We vary the budget from 4, 8 to 12. We vary the mean intensity of the event distribution from 0.2 to 1.

If we only consider the mean intensity 0.2, we see that if the budget is allocated according to relative damage, this leads to lowest inequality of damage. If the budget is allocated according to level of infrastructure available, we see the lowest level of damage. There is no clear pattern of private infrastructure. More budget lead to a lower level of damage, but a higher level of damage inequality (?)







If we look at different values of mean intensity, we see that more intense events lead to lower inequality (all be impacted a lot), more damage and more private infrastructure.







Better analysis can be done, including looking at differences between average income neighborhoods.

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