

Appendix: The ODD Protocol

1 Purpose

The purpose of the model is to investigate the role of flood protection measures in risk reduction, the working of the existing public-private flood insurance partnership in the UK and the proposed new insurance scheme Flood Re and how these schemes can be used to incentivize risk management.

2 Entities, state variables and scales

The model consists of 6 agents; persons, houses, an insurer, a bank, a developer and a local government, that behave within the environment of the model.

Environment

Variable name	Brief description
Percentage of houses for sale at the start	The percentage of houses for which home sellers will be created at the start
Mortgage interest	The annual interest that is charged over a mortgage of a person
Mortgage term	The number of years (ticks) in which the person pays off his mortgage
Average flat value	The initial average value (in pounds) for the house type flat
Average terraced value	The initial average value (in pounds) for the house type terraced
Average semi -detached value	The initial average value (in pounds) for the house type semi-detached
Average detached value	The initial average value (in pounds) for the house type detached
Owner warning time	The number of years (ticks) a homeowner will pay more than he can afford on his house before putting his house up for sale
Number of trade actions	The number of times a homebuyer or home seller sets a price within a trade round
Housing ratio increase	The percentage with which the housing ratio of a person is increased compared to the calculated mortgage ratio of that person
Land value percentage	The percentage of a house value that initially can be seen as the land value. The rest is the building value of the house
Immigration percentage	The percentage of new homebuyers that enter the market every year
Percentage of movers	The annual percentage of persons that decide to sell their house because they want to move to a different house
Flood risk consider probability	the probability that a person will consider flood risk when buying a house
No selling decrease value percentage	The percentage with which the asking price of a house will be decreased at the end of a year when no buyer was found for it
Inflation percentage	The percentage with which a person's income will be increased every year to account for inflation
Percentage of proactive PLPM investors	The percentage of persons that will be labelled a proactive PLPM investor
Percentage of reactive PLPM investors	The percentage of persons that will be labelled a reactive PLPM investor
PLPM investment flood protection benefit	The amount with which the flood protection of a house increase when the owner has invested in PLPMs for it
Flood protection budget	The annual amount of money (pounds) the local government gets from the national government to invest in flood protection
Cost of flood defences	The cost of building flood defences for a single house

Flood defence investment flood protection benefit	The amount with which the flood protection of a house increase when the local government builds flood defences for it
Flood Re Assets	The amount of assets in the FloodRe system
Flood Re Levy	The levy that is taken from all flood insurance premiums to pay for the Flood Re system
Land value	Assigned to every patch in the model. It indicates the value a piece of land (patch) has on the market

Agents

Persons

Variable name	Brief description
Homeowner?	True if the person owns a house he does not want to sell
Home seller?	True if the person owns a house that he wants to sell
Homebuyer?	True if the person does not own a house but wants to buy one
Income	The amount of money a person earns annually
Housing ratio	The percentage of a person's income that he can afford to spent on his house
Mortgage ratio	The percentage of a person's income that he can afford to spent on mortgage payments
Number of incomes as down payment	The number of incomes a person can pay as a down payment when buying a house
Percentage sell price	The percentage with which a person will increases the house value of his house when he puts it up for sale
Would sell house for profit?	True if a person would consider selling his house for profit (10% of persons would)
Profit percentage	The percentage a person's house need to be worth extra compared to what he bought it for, before he decides to sell it for profit
Maximum house price	The maximum price a homebuyer can spent on buying a new house
Seller ask price	The price a home seller asks for his house
Annual fee	The annual fee a person needs to pay for the house he owns
Flood risk consideration status?	True is the person considers flood risk when buying a house

Houses

Variable name	Brief description
House type	The type the house is (flats, terraced, semi-detached or detached)
House value	The value of the house
Initial house value	The initial value of a house (at model start or when build)
Building value	The value of the building part of a house (The house value is equal to the building value + the land value of the patch the house is on)
Build year	The year the house was built
Flood damage history list	A list of all the years the house has previously been damaged by a flood
Person owned?	True if the house is owned by a person that does not want to sell it (homeowner)
Person on market?	True if the house is owned by a homeowner that does want to sell it (home seller)

Bank owned?	True if the house is owned by the bank
In construction?	True during the time the house is constructed by the developer
Developer owned?	True if the house is owned by the developer
Council tax band	The council tax band the house is assigned to
Property tax fee	The annual fee that has to be paid on property taxes for the house
Annual fee list	A list of fees the owner of a house has to pay on an annual basis
Fee duration list	A list of remaining time of each fees set in the annual fee list
Mortgage fee	The annual fee that has to be paid over the mortgage a person took for buying a house
Ageing repair fee	The annual fee that has to be spend on repairing a house from ageing
House value at buy	The house value of a house when it is bought
Flood damage list	A list with flood repair fees for every given flood return period
Flood status?	True if the house is flooded this year (tick)
Flood repair fee	The fee that has to be spend on repairing a house after flood damage (taken from the flood damage list)
Flood risk	An evaluation of the flood risk a house is in
Flood insurance status?	True if the house is insured against flooding
Flood insurance premium	The annual fee that has to be paid to insure the house against floods
Flood insurance excess percentage	The percentage of flood damage that is not covered by insurance and needs to be paid by the owner of the house
Flood insurance excess	The amount of flood damage to a house that is not covered by flood insurance
Flood protection level	The level (a value between 0 and 1) with which the damage done to a house by a flood is lowered because protection measures have been taken for this house
Re-insured to Flood Re status?	True if the house is re-insured in Flood Re
Flood Re insurer cost	The amount of money (pounds) the insurer has to pay to the FloodRe system for re-insuring this house

Insurer

Variable name	Brief description
Insurer assets	The amount of assets the insurer has
Initial flood insurance excess	The initial flood insurance excess a person has to pay on his insurance
Flood excess increase because of flooding	The amount with which a person's excess will increase when his house is hit by a flood
Expected average annual loss	The losses the insurer expects to make in the current tick from compensating flood damages.
Current loss ratio	The current loss ratio (total compensation pay outs / total premium incomes) of the insurer
Maximum acceptable loss ratio	A fraction describing the maximum loss ratio that the insurer is prepared to accept
Base flood insurance premium	The base flood insurance premium that every house has to pay

Bank

Variable name	Brief description
Bank assets	The amount of assets the bank has

Developer

Variable name	Brief description
Developer assets	The amount of assets the developer has
Proposed land	The patch of land the developer is proposing to build a house on
Proposed house type	The house type the developer is proposing to build
Proposed house value	The value of the house the developer is proposing to build
Proposed land value	The land value under the house the developer is proposing to build on
Proposed building value	The building value of the house the developer is proposing to build
Proposed council tax band	The council tax band of the house the developer is proposing to build
Proposed property tax fee	The property tax fee of the house the developer is proposing to build
Proposed flood damage list	The flood damage list of the house the developer is proposing to build
Proposed flood risk	The flood risk of the house the developer is proposing to build
Income cost ratio for development	The ratio of income vs cost the developer wants to reach by building a house
Development approval status?	The status of the approval of the development plan the developer send to the local government (true if the proposal is approved)
Build time	The time it takes the developer to build a house
Proposed Flood Re insurer cost	The proposed Flood Re insurer cost of the house the developer is proposing to build

Local government

Variable name	Brief description
Local government assets	The amount of assets the local government has
Percentage of land sales used for flood defences	The percentage of land sale income that goes towards the flood protection budget
Percentage of property taxes used for flood defences	The percentage of property tax income that goes towards the flood protection budget
Maximum fraction of value at risk	The maximum fraction of house values that can be at risk before the local government starts acting (building flood defences)
Number of projects in flood defence portfolio	The number of project the local government will look at before deciding on projects to build
Minimum houses in flood defence project	The minimum number of houses that should be in a flood defence project
Flood defence portfolio	The portfolio with flood defence project to choose from
Wanted benefit-cost ratio	The benefit cost ratio a local government want to get from a flood defence project
Maximum flood risk	The flood risk that the local government will accept as the maximum risk a house can be in to approve a development proposal
Development approval ratio	The maximum ratio between the value of flood risk a house adds to that of the total municipality and the profit the local government will gain, for the local government to approve a development proposal
Development proposal status?	The status of a development proposal sent to the local government (true if evaluation is requested)

One time step represents a year to allow the consequences of a flood as well as the reaction of the housing market to be investigated. Simulations were run for 30 years. Flood events were simulated using flood event time series data generated using an urban spatial weather generator.

Based on GIS data an outline of the Borough of Camden, major parks and areas of opportunity for the developer to build houses in are outlined. Also based on GIS data 95,561 initial houses are positioned on a grid of 300 by 300 patches. Because of the size of the housing data set and the amount of available patches, a patch can have two houses of different house types assigned to it. Each flat consist of 15 houses that are placed on top of each other. Only one of these houses is assigned to be at the bottom level and will be at risk of surface water flooding.

3 Process overview and scheduling

Because of the size and complexity of the model the full process overview will not be given here. However, an extensive overview of all the behaviours in the model, their explanation and their pseudo code can be found in appendix D of Dubbelboer (2015). Besides this the model code is also published on OpenABM (<https://www.openabm.org/model/4647/version/1/view>).

To give an overview of the process and scheduling of the model, the order in which all actions within the model are performed is given here:

Setup

First the environment is set up. After this the insurer is set up because it provides information that houses need when they get set up. After houses are set up persons can be set up and directly move into houses. After this the three remaining agents are set up. This gives the following order of setup:

- Setup environment
- Setup insurer
- Setup houses
- Setup persons
- Setup bank
- Setup developer
- Setup local government

Go

The go procedure is a bit more complex than the setup and goes as follows:

- First the **flood event** action of the environment will be run. This is done first because it provides information on flooding in the current year that is used by all agents
- After this the **process house** action of houses will be run because in this action houses gather and compute data that is used by the persons in the model. Within the action of processing houses the following actions are run by each house individually
 - Calculate flood risk (house action)
 - Set flood insurance premium and excess (insurer action)
 - Calculate expected average annual loss (insurer action)
 - Decide on re-insuring in Flood Re (insurer action)
 - House flood repair (house action)
- After the houses are processed, the **process person** action of persons will be run. Within the action of processing persons the following actions are run by each person individually:

- Decide on house selling (person action)
 - Foreclose house or sell on market (person actions)
- Invest in PLPMs (person action)
- Correct income for inflation (person action)
- After the persons are processed the **process insurer** action of the insurer will be run. Within the action of processing the insurer the following actions are also run by the insurer:
 - Compensate policy holders (insurer action)
 - Calculate current loss ratio (insurer action)
 - Adjust insurer assets (insurer action)
- Now that the houses, persons and insurer have gathered and computed all needed data the **process market** action of the environment can be run. Within the action of processing the market the following actions are also run:
 - Developer market run (environment action)
 - Set maximum affordable house price (person action)
 - Disconnect seller from house if buyer is found (houses action)
 - House buyer enters house (person action)
 - Set flood insurance (person action)
 - Set mortgage fee (house action)
 - Update land values based on the made transaction (environment action)
 - Person market run (environment action)
 - *Same actions as in developer market run above*
 - Bank market run (environment action)
 - *Same actions as in developer market run above*
 - Update building value based on the total of all made transactions (environment action)
- Now that the market is run the **process bank** action of the bank can be run. This needs to be done after the market because the bank needs to process the houses it just bought on the market. Within the action of processing the bank the following actions are run:
 - Bank flood insurance set
 - Bank maintain house
- Now the local government and developer actions are run. The **process developer** action of the developer will first be run so that they can pass information on proposed developments to the local government. Within the action of processing the developer the following actions are also run:
 - Locate land for development (developer action)
 - Decide to create development proposal (developer action)
 - Evaluate development proposal (local government action)
 - Develop housing (developer action)
 - Finish house construction (developer action)
 - Developer flood insurance set (developer action)
 - Developer maintain houses (developer action)
- After the developer is processed the **process local government** action will be run. Within the action of processing the local government the following actions are also run:
 - Collect property taxes (local government action)
 - Collect flood protection Investment (local government action)

- Decide on building flood defences (local government action)
 - Build flood defences (local government action)

4 Design concepts

Basic principles: The model takes a microeconomic model of a US double auction market, adapts it to the UK situation and extends it to include a more elaborate insurance system and a larger focus on the role of housing developments and the local government in regards to flood risk management.

Emergence: This model was designed to explore the reaction of a housing market to flood risk and the uptake of flood protection measures under different circumstances. Transaction prices and person selling behaviour are modelled as emerging behaviour resulting from changes in agent characteristics and the surrounding environment. Behaviour of the local government to invest in flood protection emerges from changing patterns of flood risk in the model. Investing in PLPMs is less emerging as it is based on set states and flood events, but becomes more so when different insurance scheme policies are tested in the model. Lastly, decisions of the insurer to place a person in Flood Re is emergent, resulting from changing flood risk patterns that lead to changing insurance premiums and excesses for the policy holder.

Adaptation: Home owners who proactively invest in PLPMs will experience less loss from a flood event. Home owners who reactively invest only see benefits when a second flood occurs. Home buyers that consider flood risk will not buy houses that have recently been flooded, putting them in less flood risk. Insurers react to a flood event by increasing the flood insurance excess of people hit by the flood, better covering their flood risk in the future. Based on the flood risk within its municipality the local government build flood defences to protect homeowners, lowering any damage from future flood events.

Objectives: Homebuyers want to get the best affordable property. Home owners want to live in a house they can afford for as long as possible and want to feel safe. Home sellers want to sell their house for a price higher than the houses market value. The insurer wants to make profit while providing everyone with affordable flood insurance. The developer wants to make a profit by selling houses for a higher price than the building cost them. The local government wants to protect people living in their municipality by building flood defences, and wants to keep up with the high housing demand set by the national government.

Learning: When a flood event occurs some people will invest in PLPMs. After a flood event the local government also invests in flood defences in the affected area.

Predictions: People invest in PLPMs and the local government invests in flood defences because they predict that a flood event will again occur in the future. The insurer calculates flood insurance premiums and excesses by predicting the probabilities of flood events occurring in the future. The developer develops houses by predicting the future demand for housing.

Sensing: Agents within the FloodRe model save all information that has previously been provided to them and they make decisions based on this. Besides this, every agent maximizes his utility, being able to perfectly calculate the result of every action. Information is complete and certain and agents behave in a rational way.

Interaction: Persons, the bank and the developer interact with each other in the housing market when houses are sold and bought. People interact with the house they own to get information on its current state and value. When a person takes flood insurance he interacts with the insurer, after which the insurer interacts with the house to gather information on the basis of which the flood insurance premium and excess is set. The local government interacts with houses when it builds flood defences for them. The developer interacts with the local government when it wants a development proposal to be approved.

Stochasticity: Certain values of states are stochastically assigned to make it represent the variability within the real world.

Collectives: Houses are grouped into types, indicating whether the house is a flat, terraced, semi-detached or detached property. Based on market transactions the values of all houses of a certain type will be updated. Persons are grouped into homeowners, home seller and home buyers. Within the housing market the homebuyers and home sellers interact with each other.

Observation: Data is collected on an annual basis. Data gathered includes: House values; the number of houses put on sale and the reason for selling; flood risk; flood insurance premium and excess value; flood repair fees; the number of houses re-insured in Flood Re; the number of PLPM investments; and the number of houses for which flood defences are built. Average values are calculated based on the number of houses and people in the model. Data is analysed using the data analysis tool R.

5 Initialization

The initial set up environment consists of 95,561 houses that are placed on a grid according to GIS data. Every house gets a person assigned to them and a single insurer, bank, developer and local government are set up. This is the same in every simulation run.

The states the agents get assigned can however vary. Although most states are set the same every time for every agent, some states are stochastically assigned to allow the model to better represent the real world. This is done in places where limited information was available. For instance market values for each individual house are not known, just an average house value for each of the 4 house types in the study area. Because every house of the same house type does not have the same value every house gets a value assigned to it based on a normal distribution over this average.

A full overview of the description of the initialization of the model can be found in appendix D of Dubbelboer (2015) and the model code is also published on OpenABM (<https://www.openabm.org/model/4647/version/1/view>).

6 Input

The model uses data sets provided by the London Datastore; the Office for National Statistics; residential building data from Landmap (2014); derived data from the UK Buildings Residential Building Class Dataset¹; surface water flood depth maps from the DrainLondon project led by the Greater London Authority; and flood depth-damage functions for short (<12hr) duration floods (Penning-Rowsell et al. 2010). Besides this many sources are used for assigning specific values to states

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of agents. A full overview of all input data and their sources can be found in appendix L of Dubbelboer (2015).

7 Submodels

Because of the size and complexity of the model the full process overview will not be given here. However, an extensive overview of all the behaviours in the model, their explanation and their pseudo code can be found in appendix D of Dubbelboer (2015). The model code is also published on OpenABM (<https://www.openabm.org/model/4647/version/1/view>).

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