Market-Led Urbanism and Geographic Crises: A Micro-Simulation Lens on Beirut

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Highlights and Assumptions

1. Challenges to using agent-based models (ABM) in urban studies
2. Integrating econometric modelling with ABMs
3. The importance of GIS and GPS data in simulations (geographic information system mapping) and OpenStreetMap.
4. Rent-Gap theory
5. Urban impact of refugee's influx into a city
6. In our ABM, agents represent households. Each household lives at a location in the city, which represents a residential dwelling. The agents seek to move if their income permits, if their current dwelling is too poor in maintenance, or if the cognitive dissonance with their neighbors is too great. Locations decline in maintenance level in time, and can be repaired or redeveloped.

Agent-based Models

An *agent* is “a representation of a decision-making entity in the real world, be it an individual or an organisation” Van Dam et al. (2013)

Agent-based modelling (ABM) is “a paradigm for simulating the actions and interactions of autonomous heterogeneous agents, which do not need to be perfectly rational or perfectly informed, in order to study the emergent system-level effects of collective agents’ behaviour within a certain environment, over time” (Chappin et al., 2019).

“Agent-based models are constructed to discover possible emergent properties from a bottom-up perspective. They attempt to replicate, in silico, certain concepts, actions, relations or mechanisms that are proposed to exist in the real-world, in order to see what happens.” Van Dam et al. (2013)

Literature

- Picascia (2015) and Picascia & Yorke-Smith (2017): rent-gap theory and gentrification using agent-based simulations applied to European cities.
- Ge (2013): Agent-based spatial model on U.S. housing market.
- Zhang & Li (2014): applied ABM on a buyer and seller search behavior in the housing market in Beijing.
- Collins & Frydenlund (2016): refugees
- Goren (2016): conflict in Mali
- Suleimenova, Bell, & Goren (2017): conflict in Africa
- Hebert, Perez, & Harati: conflict in Syria
- Hatton (2017): migration into Europe

Why Beirut?

- Limited affordable housing
- Complex political and socioeconomic systems
- Weak public institutions (regulations are rarely enforced)
- Unstable geo-political environment
- Exceptionally high number of refugees (nearly 50%!)
- Dire Economic and financial crisis (October 2019)
- Devastating explosion of the port of Beirut (August 2020)
- High dependency on imports
- Neo-liberal real estate market (high income inequality)

The Beirut metropolitan area and its quartiers

Housing price index

In the first stage we estimate the following structural model in which the demand and supply sides are given respectively by:

$$q_t = \alpha_0 + \alpha_1 y_t + \alpha_2 p_t + \alpha_3 r_t + u_t \quad (1)$$

$$q_t = \beta_0 + \beta_1 c_t + \beta_2 p_t + \beta_3 r_t + v_t \quad (2)$$

In equilibrium, by setting equations (1) and (2) equal, we obtain the reduced form equations for p_t^* and q_t as follows:

$$p_t^* = \lambda_0 + \lambda_1 y_t + \lambda_2 c_t + \lambda_3 r_t + \epsilon_t \quad (3)$$

$$q_t = \gamma_0 + \gamma_1 y_t + \gamma_2 c_t + \gamma_3 r_t + \nu_t \quad (4)$$

$$p_t - p_{t-1} = \lambda(p_t^* - p_{t-1}) \quad (7)$$

In the second stage, we estimate the structural equations (1) and (2) using the predicted values for p_t derived in the first stage, i.e., p_t^* by equation (3). This gives respectively the demand and supply sides:

$$q_t = \delta_0 + \delta_1 y_t + \delta_2 p_t^* + \delta_3 r_t + v_t \tag{5}$$

$$q_t = \mu_0 + \mu_1 c_t + \mu_2 p_t^* + \mu_3 r_t + \tau_t \tag{6}$$

The demand and supply equations (1) and (2) have their partial adjustment processes estimated in the second stage respectively as follows:

$$q_t = \alpha(\alpha_0 + \alpha_1 y_t + \alpha_2 p_t^* + \alpha_3 r_t) + (1 - \alpha) q_{t-1} \tag{12}$$

$$q_t = \beta(\beta_0 + \beta_1 c_t + \beta_2 p_t^* + \beta_3 r_t) + (1 - \beta) q_{t-1} \tag{13}$$

	Demand	Supply
Income elasticity	0.979	–
Cost elasticity	–	-3.162
Price elasticity	-0.670	1.212
Interest elasticity	-0.0106	-0.0369

Parameters of the model - I

Locations can be occupied by zero or more residents, up to specified population limits. If the population exceeds the limit – or if the location's condition falls too low ($r \leq 0.15$) – then the location is deemed to be a slum. Dwellings progressively decay in their condition by a factor $d = 0.0012$ assuming that, if unmaintained, a location goes from 1 (perfect) to 0 (inhabitable) in 70 years (since 1 simulation step = 1 month). In order to match the theoretical assumption of a decline in property price over time, we set the value of the dwelling as decreasing by a depreciation factor of 0.02 / year, as proposed by Diappi & Bolchi (2006). We also assume that in case of prolonged emptiness of the dwelling (beyond 6 months) both decay and depreciation factors are increased by 20%. These factors also increase for over-populated locations.

the characteristics and the desirability of the area where the property is located. We set the new value V' of a redeveloped property x at the average of the surrounding locations in a radius of 2, plus 15% (representing a premium for a newly-restored property): $V'_x = 1.15 * \text{avg}(V_{\text{radius2}})$. The value gap for location x will be $G_x = V'_x - (V_x + C_r)$, or 0 if $G_x < 0$; C_r is the cost of removing the present residents if the location is occupied. The cost of removing a refugee (0.01) is lower than for a non-refugee (0.05), but there can be more refugees in a location (maximum population 6) than non-refugees (maximum 3). Once a location is selected for investment, its value is set at V'_x and its repair state is set at $r = 0.95$.

Parameters of the model - II

The process of finding a new location is bounded by the agent's income: a new dwelling has to be affordable ($V \leq i * credit$) and in relatively good condition (at a minimum, not a slum); and closer to the CBD is preferable (since Beirut is a monocentric city). If no affordable and available location is to be found, the agent is forced to leave the city. The exception is refugees, who will consider moving to a location of poor condition or of high population, and only leave the city if even no slum is to be found.

- The simulation

the variables associated with location.

Name	Type/Range	Description
`r`	float, {0,1}	maintenance state
`V`	float, {0,1}	value (at market rates)
`G`	float, {0,1}	value-gap: difference with neighbourhood value
`d`	integer	distance from the centre of city
`te`	integer	time empty (months)
`o`	boolean	occupied?

Variables associated with the Agent:

Name	Type/Range	Description
m	float, {0,1}	mobility propensity
c	list t=10, v=4	culture: memetic code
i	float, {0,1}	income level
d	float, {0,1}	cognitive dissonance level
th	integer	time here: months spent in the current location

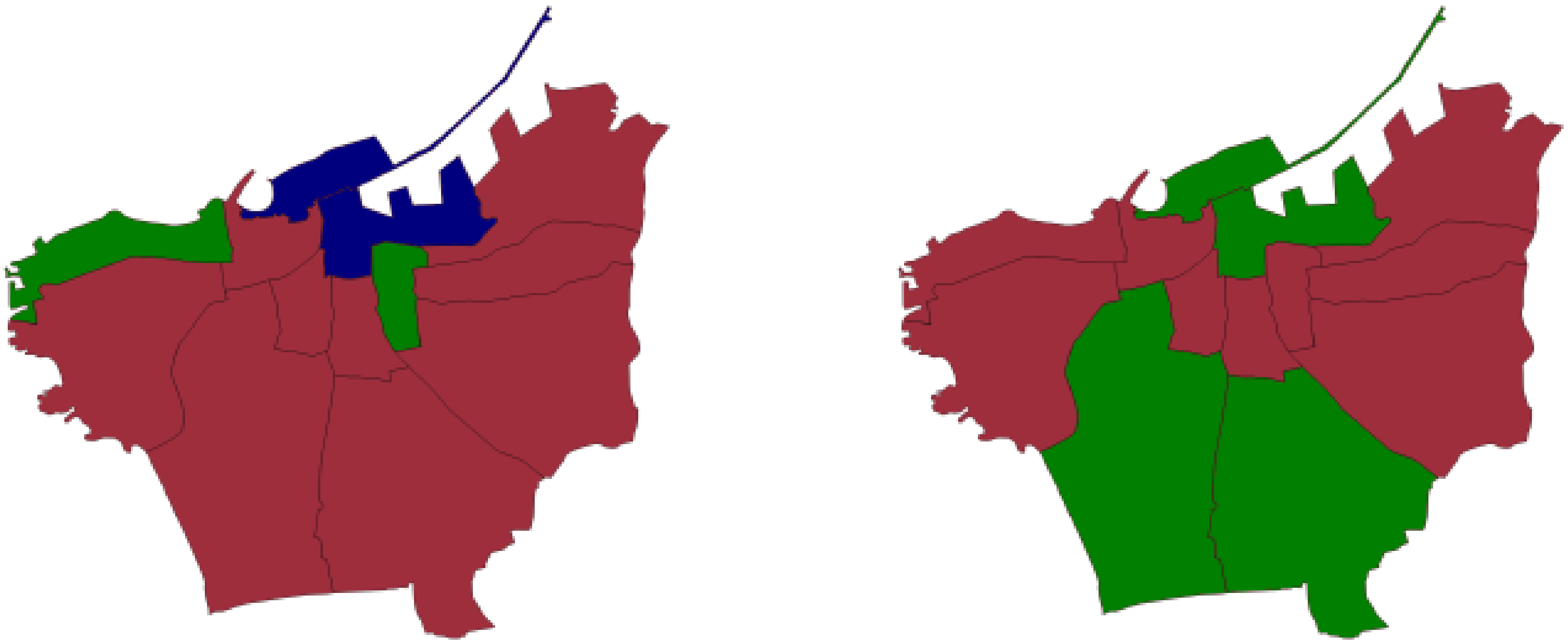


Figure 3: Comparison with historical data by district. Red indicates increased mean price from 2009 to 2015, green indicates stable price, blue indicates decreased price. Left: Simulated prices. Right: Actual prices.

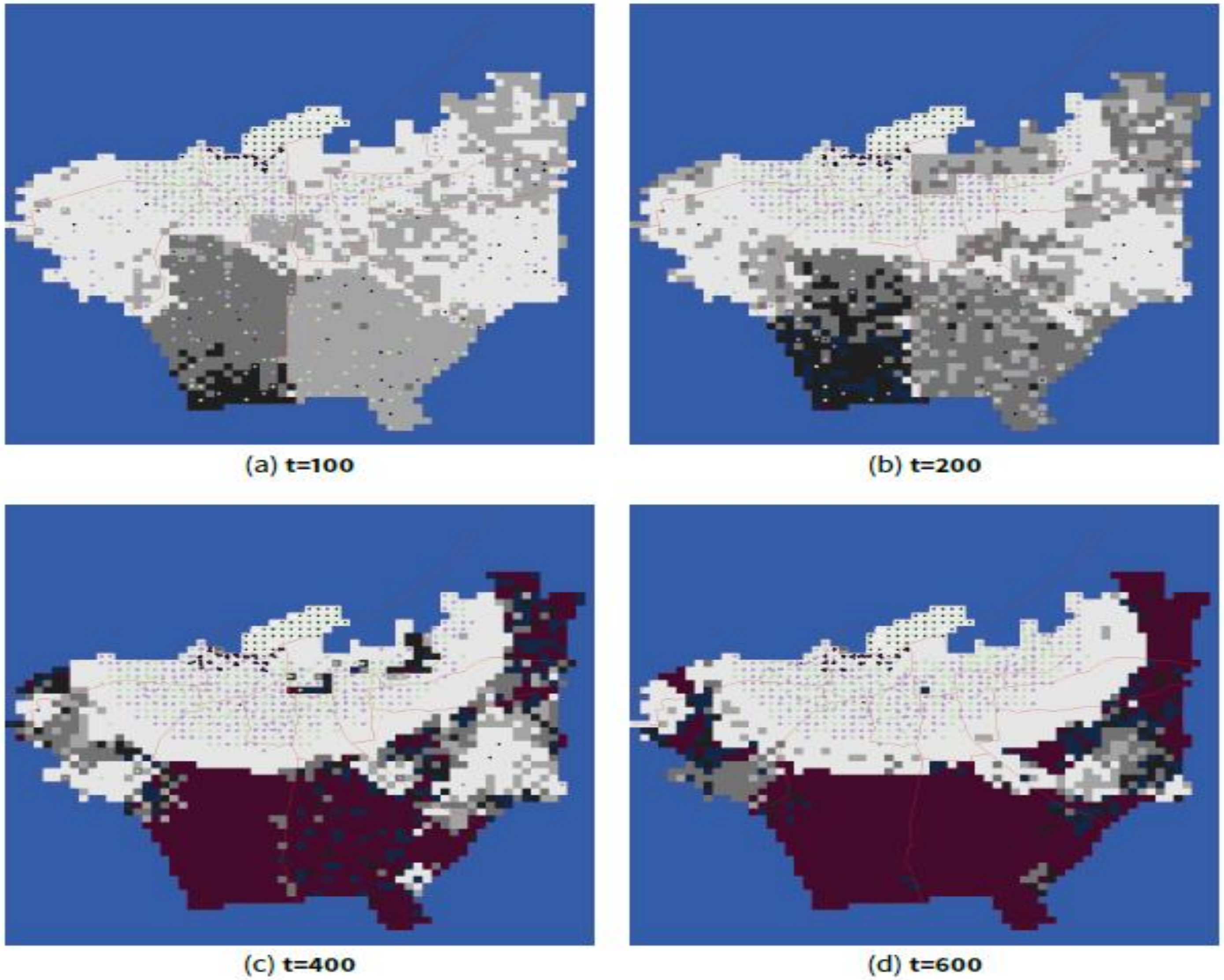
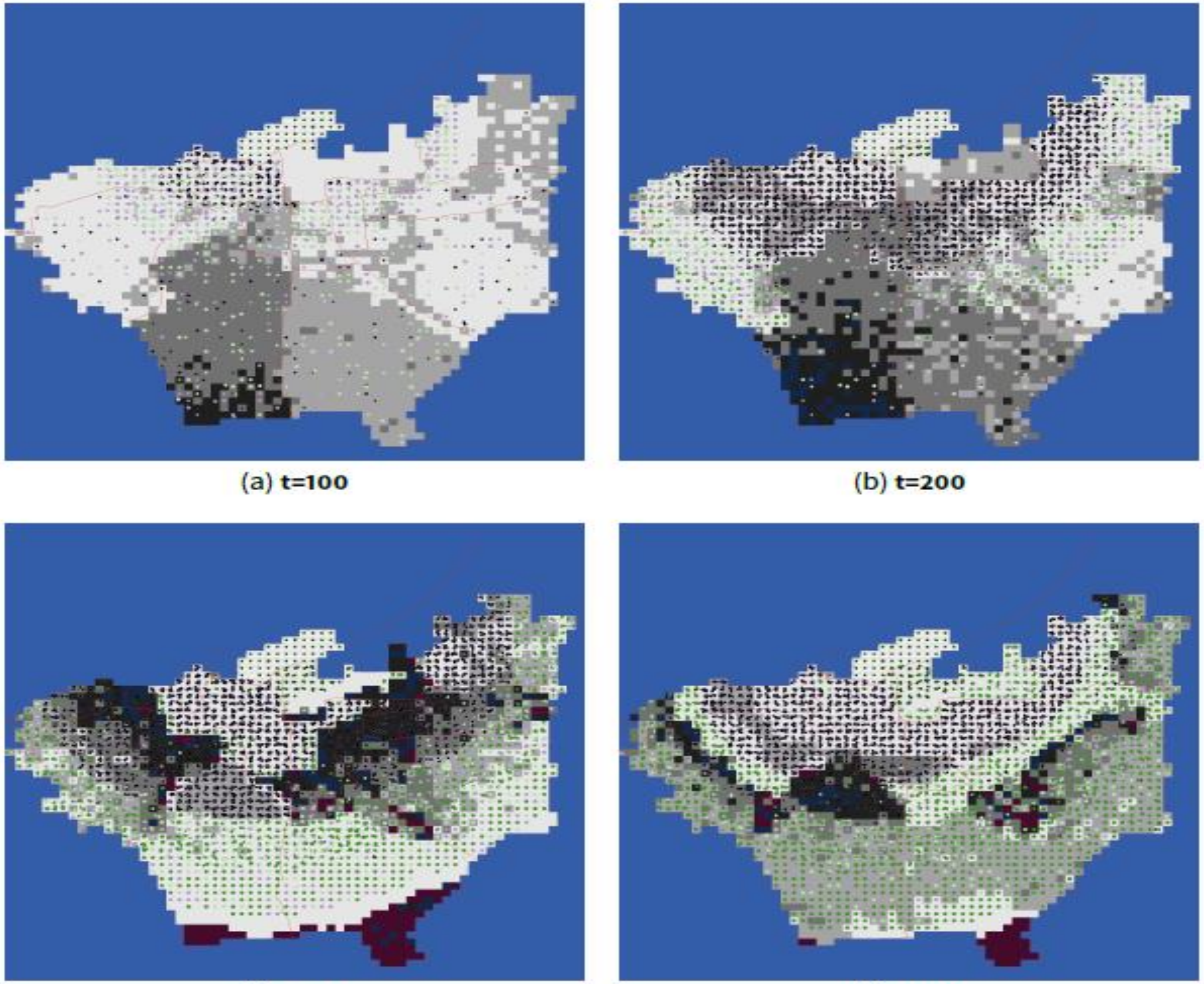


Figure 5: City locations over time. No refugees. $K = 0.025$. Slum locations are dark blue, uninhabitable locations are dark purple.



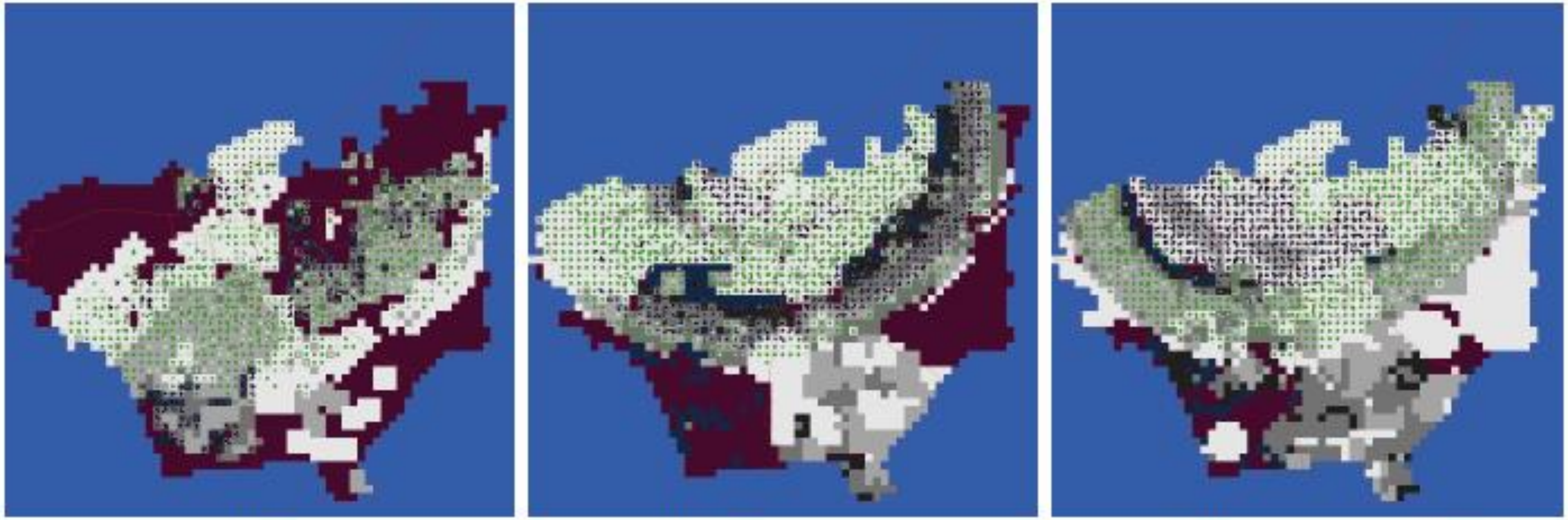
(a) t=100

(b) t=200

(c) t=400

(d) t=600

Figure 6: City locations over time. Refugee influx between $t = 90$ and $t = 180$. $K = 0.025$. Slum locations are dark blue, uninhabitable locations are dark purple.



(a) **None** (b) **Regeneration** (c) **Slum improvements**

Figure 9: Intervention policies. Snapshots at $t = 600$. $K = 0.035$.

Migration	% slums	% overcrowded	price	income
No refugees	0.41	0.20	5560	6750
(Some) refugees	0.28	0.14	5600	8620
More refugees	0.27	0.13	5700	8900
Ongoing	0.51	0.42	6240	4070

Table 10: Metrics at month 600, averaged across K.

Intervention	% slums	% overcrowded	price	income
None	0.28	0.14	5600	8620
Regeneration	0.21	0.16	5170	8470
Slum improvements	0.27	0.15	5580	8530

Table 11: Metrics at month 600, averaged across K, *refugees* condition.

Extension of the baseline model

We make the following modifications to the above ‘baseline’ model:

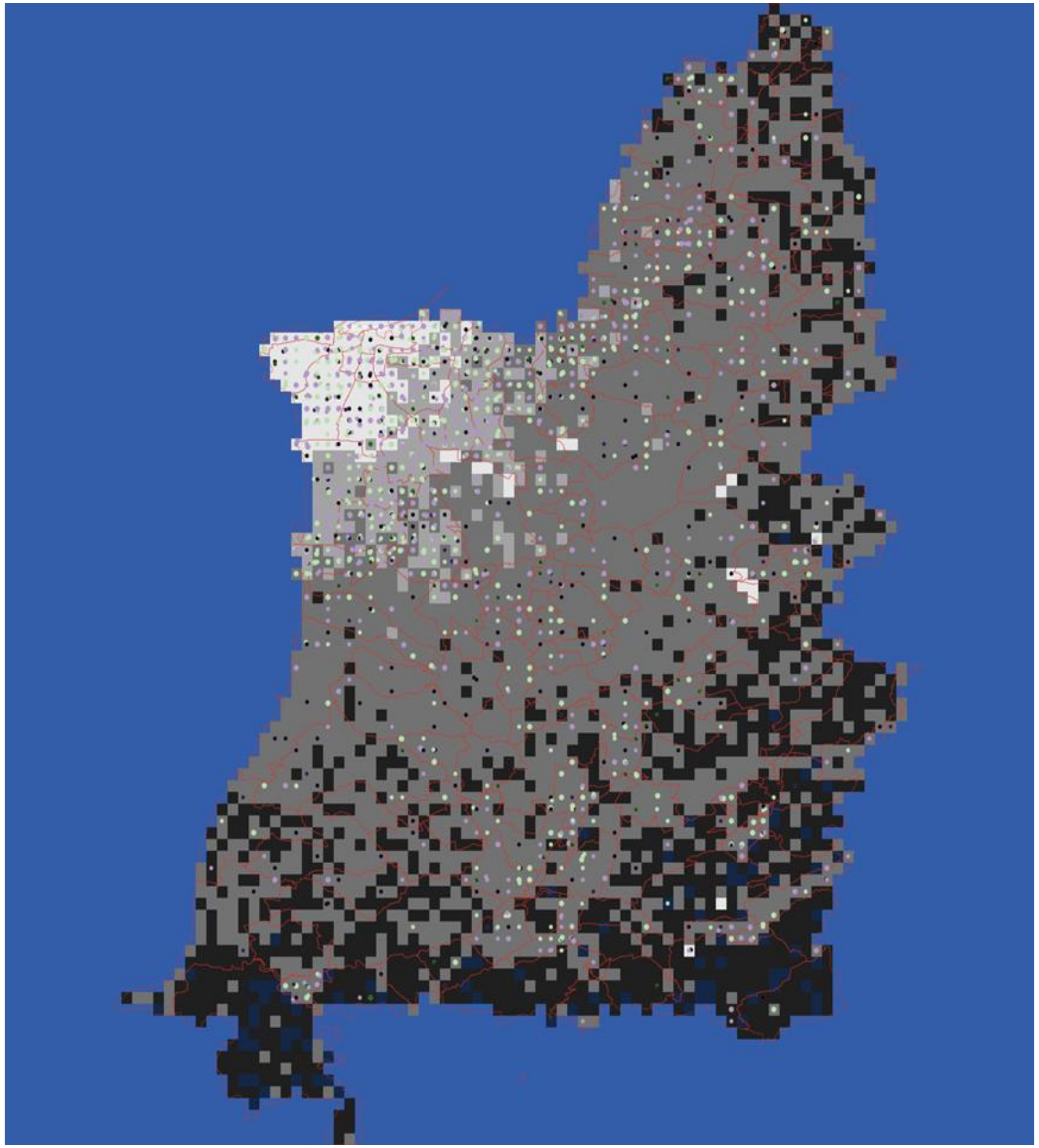
•Extending the geographic range from the strict boundaries of the municipality to a large portion of peri-urban Beirut. This is important because of the urban sprawl and population percentage outside the municipal boundary.

•Including the building density per district. This is important because residential options are not uniform between districts.

• Three cases: by calibrating on housing price and population data for the point in time, and removing refugees’ influx if prior to the Syrian War: Hariri Assassination (2005) and Israel-Lebanon war (2006); Syrian war (2011) and Port explosion and economic collapse (2020).

A visualisation of the ABM is seen here. The model is implemented in the dedicated ABM language NetLogo (Wilensky, 1999), version 6.2. The base model is available at: www.doi.org/10.4121/13033154.

Geographic visualisation of the Greater Beirut region captured in the simulation. Municipal Beirut is seen top left; the Mediterranean Sea borders the west and north. Squares are coloured by the maintenance level of the properties (brighter = better condition). Household agents are depicted by circles; colour denotes income category. District boundaries are shown by red lines.



New Data to be obtained

In order to calibrate the simulation, six items of data are required: geo-physical, demographics, building density, housing prices, property conditions, and (particularly after 2011) refugee population.

- Population Density:

First, we identified our target localities using GIS data. Then we matched the coordinates of these target 223 districts with those of the GIS data and computed population in each district, in addition to population of the five nearest points to each district. We then traced population growth for the periods of the events under study, these are 2005, 2011 and 2020.

- Housing Price

To capture the variation in housing price for each district we included additional variable to the previous econometric model: the distance from each district to downtown Beirut. The econometric model now includes interest rate, building permits, construction cost, in addition to distance. We use the inverse distance for a direct interpretation of the results.

- Building Density and Maintenance Level

We constructed building density by regressing building permits over population and distance from the Beirut Central District (BCD). To compute the maintenance level in 2005 we used a survey from 2017 that was based on expert opinion. Based on that survey we created an instrumental variable by regressing the survey data on house price, population, and distance from BCD . Then we used the regression line to estimate the maintenance levels in 2011 and 2020.

We study the impact on housing and household mobility for eight years after 2005: one scenario as if the 2005 and 2006 events did not occur (baseline scenario) and one if they did.

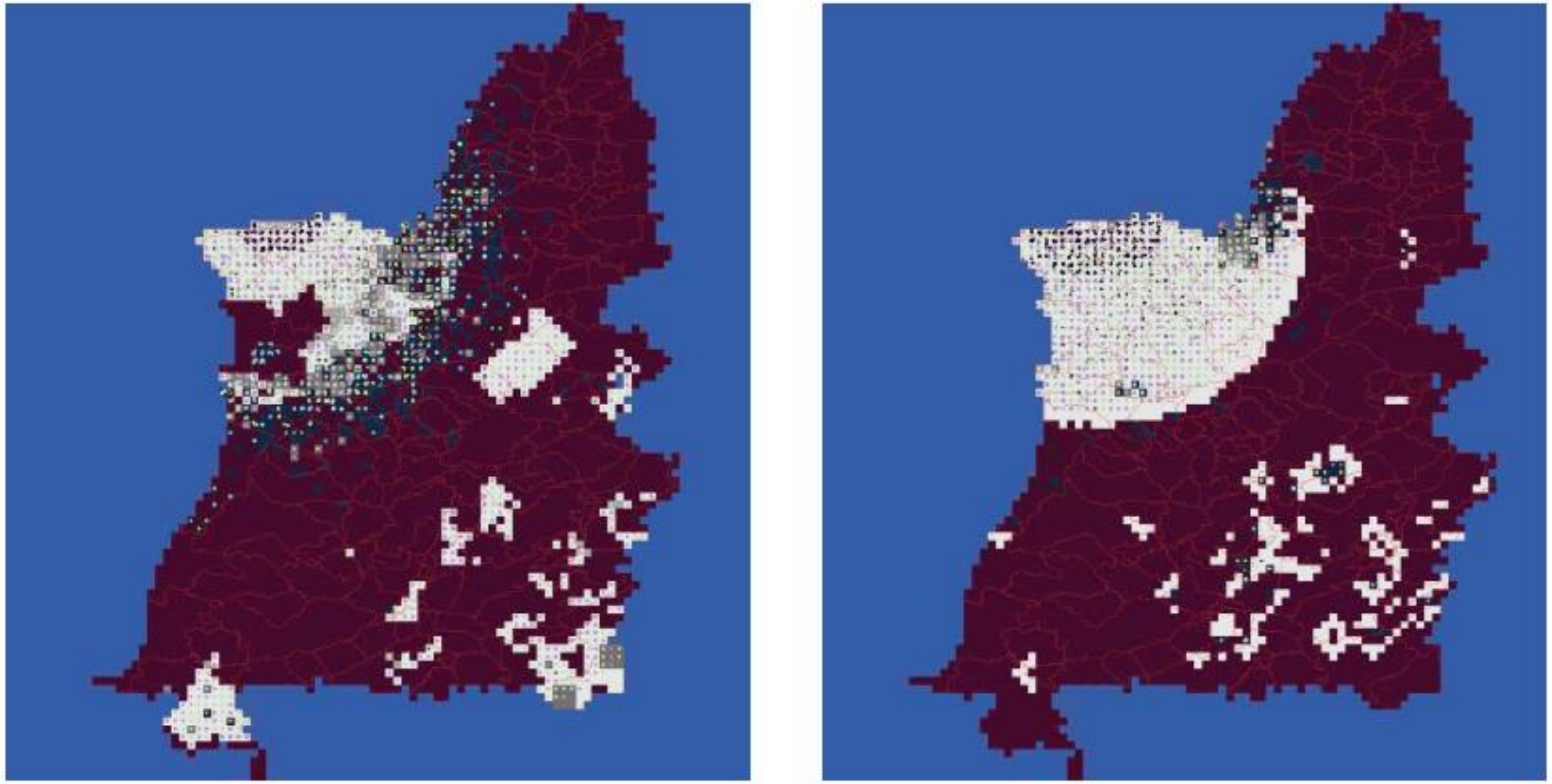


Figure 2: Beirut in 2010, a year prior to the Syrian refugee influx. Scenario with 2005 and 2006 events (left); same time point in the no-events scenario (right).

We ran the simulation from a start date of January 2019, for a period of 10 simulated years. In the shorter term, the effect on the city and its residents can be seen (Figure 4). In the longer term, assuming sufficient capital in the economy, the regeneration process means that residents can move back (Figure 5). Note the greater population and population density in the no-explosion scenario.

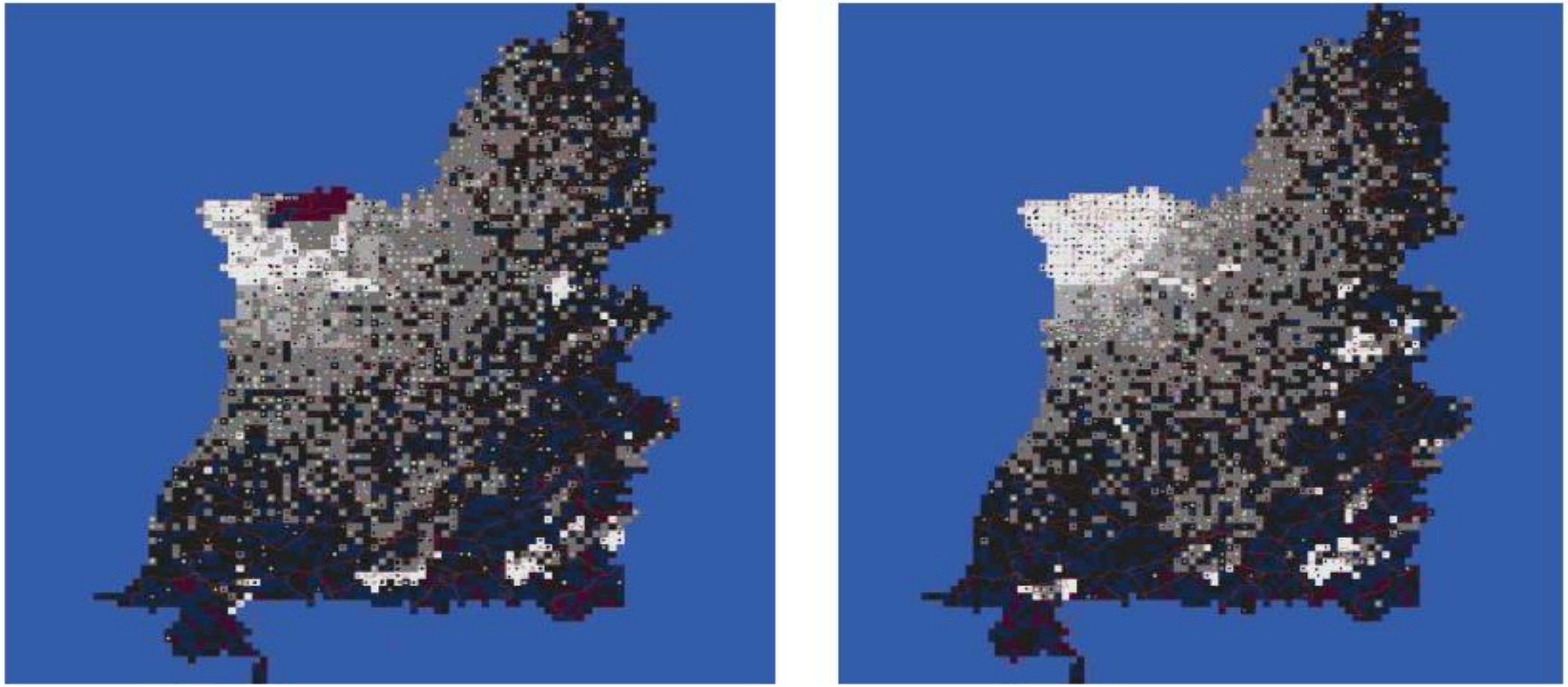


Figure 4: Six months after the explosion (left); same time point in no-explosion scenario (right).

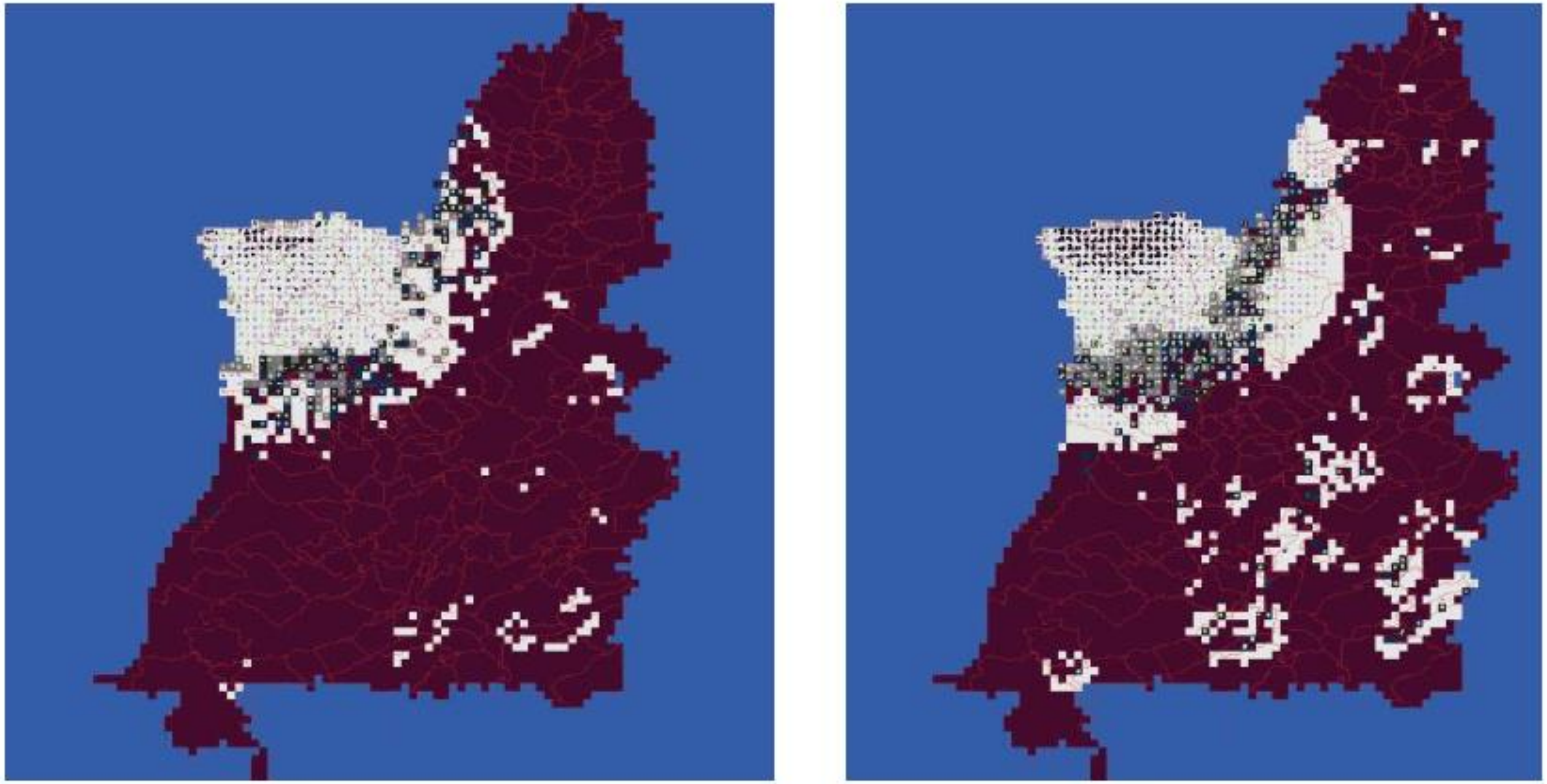


Figure 5: Eight years after the explosion (left); same time point in no-explosion scenario (right).

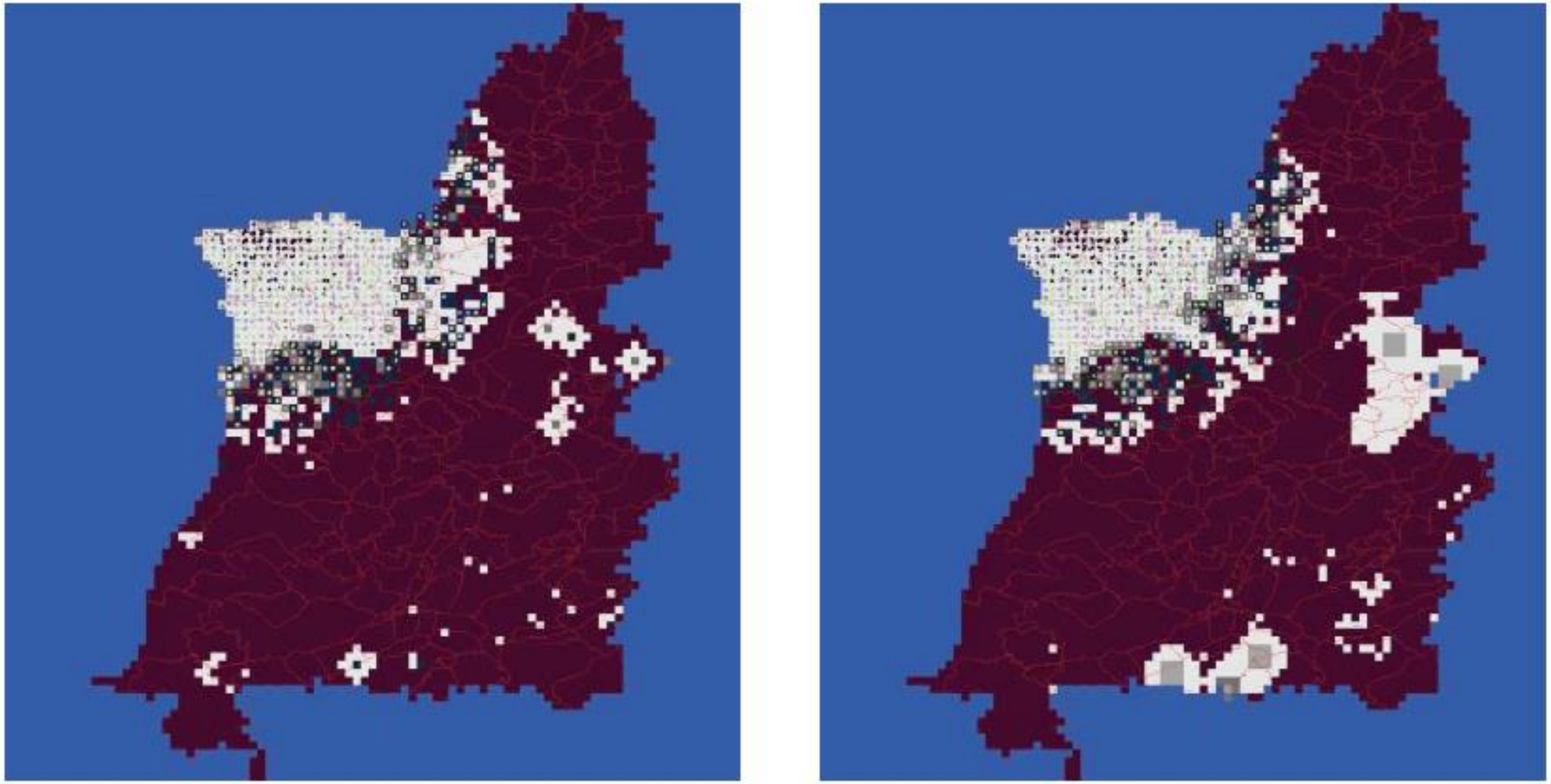


Figure 6: Effect of housing reconstruction aid, eight years after the explosion (left); effect of structural aid to the property market at same time point (right).

Conclusion

- The contributions of the study:

1. We illustrate the feasibility of a data-driven quantitative-qualitative individual-level simulation, a methodological approach complementary to and triangulating with other methodologies such as equation-based quantisation and literature-based enquiry. Further, by using the ABM for ‘what-if’ analysis and for understanding emergent urban outcomes, planners, policy makers and humanitarian organisations have a tool to help in responding to shocks upon the urban environment.

2. We examine a rich vein of macro-economic data analytics that can further inform and complement the ABM: for instance, how Lebanese banks developed non-cash agility in the mortgage market in order to clear out housing supply during the currency crises. This would complement purely econometric analysis of the property market with behavioural aspects from household residential mobility decisions.