Appears in: Working Notes of the AAMAS'16 Workshop on Agent Based Modelling of Urban Systems, Singapore, May 2016

Migration, Refugees, and Urban Dynamics: Towards an Agent-Based Simulation of Housing in Urban Beirut

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Abstract. Advances in agent-based modelling have led to theoretically-grounded spatial agent models of urban dynamics, capturing the dynamics of population, property prices, and regeneration. We leverage a recent agent-based model founded on the rent-gap theory, as a lens to study the effect of sizeable refugee migration in an abstracted model of a densely-populated Mediterranean city. Our exploratory work provides the foundation for calibration with real data, and offers a step towards a tool for policy makers asking what-if questions about the urban environment in the context of migration.

Keywords: urban simulation, rent-gap theory, migration, agent-based modelling, Lebanon, NetLogo

1 Introduction

The study of cities and their dynamics is a field where agent-based models (ABMs) have challenged econometric models [11]. Contemporary cities manifest themselves as complex and interconnected socio-technical systems. The literature uses ABMs to reproduce the evolution of the urban form [30], to model the urban dynamics typical of cities in the developed world, such as segregation (from [24] onwards) and gentrification [21], and to model dynamics typical of the megacities of the developing world, such as the emergence and evolution of informal settlements [19,8].

At the time of writing, rapid international migration of significant populations is generating profound implications for, not least, countries in Europe. Our motivation in this paper is to develop an ABM to capture the existence of such migrant and refugee flows, and to explore the effect on urban dynamics.

Our previous work constructed a micro-level ABM, derived from the *rent-gap theory* (RGT) – an economic hypotheses on the dynamics of investment in

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housing – in an effort to model the economic mechanics of property investment along with their effects on the cultural and social diversity of urban areas. We examined the price dynamics triggered by different levels of capital flowing in a city and the patterns of spatial inequality that may emerge [21], and we developed a model of housing regeneration, centred on the economic aspects and the mechanics of urban renewal, and applied it to a real-world regeneration programme in Manchester, UK, examining outcomes in property prices and social composition [20].

In this paper we extend our previous model and ground our work in the city of Beirut, Lebanon. This densely-populated Mediterranean city is the capital of a middle-income country which, according to official estimates [32], has experienced a refugee influx of 50% of its population in the last 3–4 years, determining huge pressure on the housing stock. Our model is particularly well suited to investigate the possible societal consequences of such pressure, since it was specifically designed to explore the interrelation of urban economic and cultural dynamics. We extend and adapt the ABM to the Beirut context, embedding ethnic and religious profiles, the tenure and price structure of residential areas across the city, immigration and emigration rates, and peculiar government policy regarding maintenance in Beirut's city centre. The outcome is an abstracted model of the city that simulates the residential mobility of agents – based on their ability to afford residential locations – along with changes in the price structure determined by investment in property. Such a model is useful to explore economic and social indicators under different plausible scenarios.

Results of our simulation model, implemented in NetLogo [33], indicate how sizeable migration into a city of low income populations impacts the number of slum locations, population density and over-population, prices, and income. Depending on the capital circulating in the economy and the rate of mobility, we find that excessive shock of refugees to the housing market can render neighbourhoods uninhabitable and in permanent disrepair, excluded from regeneration cycles, and hence cause both refugee and non-refugee populations to leave the city.

Section 2 provides the background of our work, including the rent-gap theory, and discusses related works. Section 3 describes our abstracted ABM of the city of Beirut. Section 4 reports our exploratory results from the model to date. Section 5 concludes the paper with a discussion of future directions.

2 Background and Related Work

Agent-based modelling and simulation is regarded as an ideal tool for understanding complex socio-technical systems like cities [17]. As surveyed by Huang et al. [13], the preferred approach in most residential mobility models is to centre on individual or household-level agents as the main actors and describe emerging patterns as purely bottom-up outcomes of the interaction of such agents. This approach poses a risk, in our view, of underestimating the broader economic processes that impact the urban form and constrain individual behaviour. A traditional line of research in human geography that has seen recent revival [12,27], views the socio-spatial phenomena that shape contemporary cities – suburban sprawl, income segregation, gentrification – as consequences of the varying influx of capital towards urban systems, rather than as strictly originating from individual-based residential choices.

Within this theoretic tradition the rent-gap theory, to which our model is inspired, is a supply-side approach to housing investment, noted in economics especially for its use in studying gentrification, i.e., "the process of renewal and rebuilding accompanying the influx of middle-class or affluent people into deteriorating areas that often displaces poorer residents" (Merriam-Webster). The rent gap is the difference between the actual (current) economic return from land, and the maximum potential return if the land were put to its "highest and best use" [26]. The rent gap is due to progressive decline in maintenance which properties undergo, together with changes in technologies which render dwellings obsolete. Restoration or rebuilding increases the economic return that a portion of land or a dwelling generates, bringing it to the maximum possible according to the theory. The locations with the highest difference between actual and potential economic return will be the ones more likely to attract investment capital and be put to best use. Although the RGT was proposed to explain a specific phenomenon, gentrification, in our view it can serve as a valid conceptualisation of general housing investment behaviour in capitalist economies, suitable for a broad exploration and not incompatible with other approaches, including standard economic theory [3].

Indeed, the literature holds a number of ABMs inspired by rent-gap theory in which the problem of identifying the highest and best use has been addressed by employing the notion of neighbourhood effect. We refer to Picascia et al. [21] for a survey. Prior to our work, Diappi and Bolchi's model [5,6] was the most complete implementation of the mechanics of the RGT, although it lacks any consideration of the demand side of the housing market and it does not consider migrant flows.

Besides models inspired by the RGT, the literature has a rich vein of ABMs that study aspects of residential mobility, either at the city level or at the national level. Among these, Ge [10] develops an agent-based spatial model of the US housing market, obtaining "sensible aggregated outcomes that capture important characteristics in the housing market." Zhang and Li [34] study the housing market in Beijing, China, with an ABM built on a model of buyer and seller search behaviours; we refer to their work for a wider survey of ABMs related to housing markets.

Among others disciplines, the sociology, urban design, and political economy literatures have considered the case of Beirut. The property market is described as "neo-liberal"; affordable housing is limited; public institutions are weak and regulations often not enforced [14,7,28].

We are not the first to recognize the relevance of agent-based modelling to approach the complexities and non-linearities of the socio-economic situation of Lebanon. Srour and Yorke-Smith [28,29] apply agent-based simulation to study import–export processes at the Port of Beirut. Their work does not address questions of urban dynamics that we do here.

Our ABM is implemented in the well-known agent-based social simulation platform NetLogo [33]. The convenience of the relatively simple NetLogo platform is suitable for a model where agents have rule-based behaviours and no explicit deliberation. Relevant to urban ABMs with more complex agent behaviours, Singh and Padgham present a paradigm for integrating agent models (particularly, for instance, in the Belief-Desire-Intention tradition) and simulation models (particularly, technical simulation engines or social simulation platforms) [25]. Demazeau et al. [9] argue that, as the agents become more complex, agent-oriented software engineering practices are relevant, and present a case study of a stylized urban dynamics model.

3 Abstract Model

We describe our agent-based model of an entire city, with multiple pre-defined districts. The entities represented in the simulation model are: (1) individual locations (residential properties), defined by their value, repair state, and population; (2) individual agents that represent households, characterised by an income, mobility propensity, and cultural configuration; and (3) economic forces, represented in the form of exogenous 'capital' level, aiming at profiting from redevelopment/restoration of residential locations. In the sequel we summarize the key points of the model, including the extensions over our earlier model; we refer to an earlier paper [21] for full details of the model variables and the emergent cultural 'allure' effect of neighbourhoods.

3.1 Locations: city structure and economic dynamics

Following our earlier model formulation of [21,20] we represent the city as a 21x21 square grid of 441 residential locations (Fig. 2, upper left) characterised by a value, V, a maintenance level, or repair state, r, and a population count, P. Locations are grouped into nine districts which we label by their compass coordinates: nw, n, ne, e, c [for centre], w, sw, s, se. In each district, locations closer to the centre of the district have greater allure for agents: the city is poli-centric.

Metropolitan Beirut is approximately square (Fig. 1), bounded by the sea to the north and west and by the Beirut River to the east. The Central Business District (CBD) is the top middle of the nine districts, i.e., 'n'. Other notable districts are Ras Beirut ('nw'), the cosmopolitan university district; Achrafieh ('e'), a high-end district; and poorer areas in the south-west. Upon model initialisation, r is randomly distributed in the range $[0, 1]$ and V is set at $V = r + 0.15$, assuming that at $t = 0$ the repair state of a dwelling and its monetary value are strongly correlated, as proposed in the abstract formulation of O'Sullivan [18]. Values and repair state for locations falling in the districts described above 'n', 'e', 'nw', and 'sw' are subsequently adjusted within specific ranges to reflect

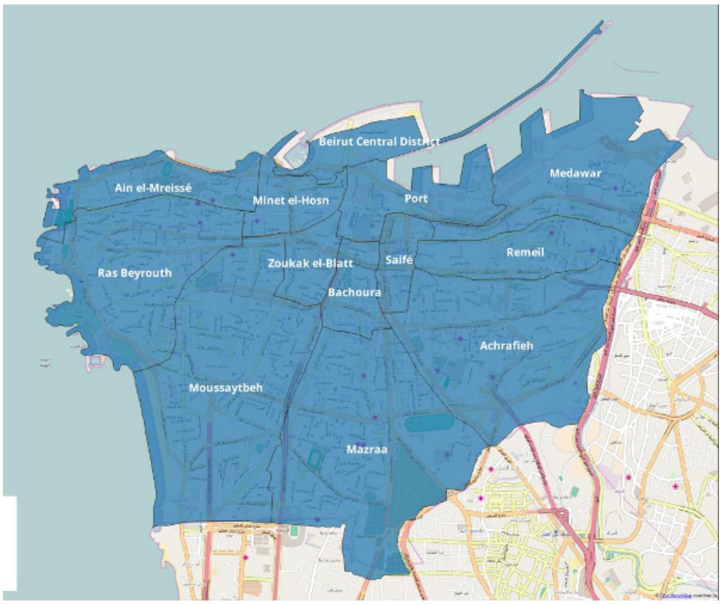


Fig. 1: The Beirut metropolitan area and its neighbourhoods.

their status relative to the rest of the city: locations in 'n' (the CBD) are well maintained and their median value is 60% above the city average; locations in 'nw' and 'e' are also well maintained and values 40% above city average; locations in 'sw' are in below average repair state and their median value is 40% below Beirut's average.

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 to 0 (becomes inhabitable) in 70 years (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. We also assume that in case of prolonged emptiness of the dwelling (>6 steps) both decay and depreciation factors are increased by 20%. These factors also increase for over-populated locations.

The model represents investment in housing renovation/redevelopment as the fundamental economic force. The 'Capital' parameter, K, represents the maximum number of locations that can be redeveloped in the current economic climate, expressed as a fraction of the total number of residential locations of the city, similarly to Diappi and Bolchi [5]. The selection of the locations where investment lands is carried out deterministically, based on the value-gap of a location with the neighbouring properties, in accordance with the RGT. The relevant value gaps are determined in accordance with the *neighbourhood effect*, the principle that the amount of rent or the sale value attainable by a given location is always bounded by the characteristics and the desirability of the area where the property is located. We set the new value nV of a redeveloped property p at the average of the surrounding locations in a radius of 2, plus 15% (representing a premium for a newly-restored property):

$$nV_p = 1.15 * \text{avg}(V_{radius2}) \tag{1}$$

We also assume that if no locations surrounding p are inhabited, then $V_{radius2}$ is reduced by 35%. This mechanism implements the principles of the rent-gap hypotheses, but tries to mitigate its strong supply-side focus, by embedding a demand-side consideration in the price formation mechanism: i.e., should there be little demand for a location then the value of properties will reflect that. In our work on UK cities, we found (1) to be more effective than value gaps based on the average of the Moore neighbourhood or the district of p.

The value gap for location p will be $G_p = nV_p - (V_p + C)$, or 0 if $G_p < 0$. Here C 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 nV_p and its repair state is set at $r = 0.95$.

We also model government policy that mandates properties in the CBD to be maintained to a minimum standard and to have a lower maximum population than other districts, and imposes price controls to ensure a high rental value.

3.2 Agents: residential mobility and cultural exchange

Agents in the model represent individuals or households. Each agent is endowed with an income level, i, a mobility propensity, m, and a tuple that represents its cultural configuration, including ethnicity and religion. The agent's income level is strongly correlated with its ethnicity, reflecting the stratification of highly unequal Libanese society; incomes are normalised to the interval $[0, 1]$ and represent the highest price that the agent is able to pay for the right of residing in a property. Agents of most ethnicities, refuges excluded, are able to apply for credit that multiplies their purchasing power.

Agents of Lebanese or Arab nationalities (excluding refugees) are able to own property. If the property is owned, its condition depreciates more slowly. There can be at most one owner for each location, and owners have a reduced propensity to move compared to renters. Further, in contrast to renters, owners are not forced to leave their current residence if rental prices increase.

The agent's culture is modelled as a tuple of t multi-valued *traits*, inspired by Axelrod's classic ABM of cultural interaction [1] and originally applied to the urban context by Benenson [2]. The tuple represents an individual's 'memetic code' or 'cultural code'. Each cultural trait can assume v variations, giving rise to v^t possible individual combinations. The semantics of traits are emergent, with

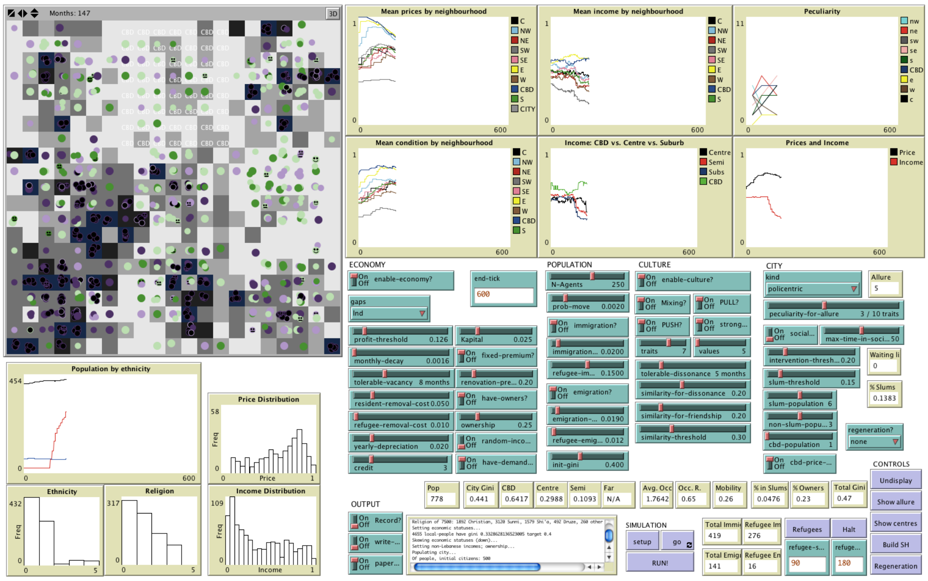


Fig. 2: Simulation interface in NetLogo [33]. City districts are seen upper left. Plots of price, income, condition are upper right. Plots of demographics are lower left. Parameter settings, outputs, and controls are centre and lower right.

the exception of the first two traits which have reserved meaning. Namely, first, ethnicity may be one of five values: Lebanese, (Arab) refugee, affluent Arab non-refugee, professional non-Arab (e.g., from the west), and working class non-Arab (e.g., domestic servants from south-east Asia); ethnicity does not change. The second reserved trait models religion, which may be one of five values: Christian (various sects), Sunni Muslim, Shi'a Muslim, Druze, or other; religion has a small possibility of changing according to the process described next. Ethnicities are set according to 2010–12 estimates (the country has no official census since 1932) [4,15]; religion of each ethnicity is set accordingly. Initial income is set according the estimated Gini coefficient of Lebanon and of non-Lebanese [31,32].

In our model each of the non-reserved traits is susceptible to change under the influence of other agents. Cultural influence is localised: agents that have been neighbours for more than 6 consecutive steps are likely to interact and exchange traits, thus rendering the respective cultural tuples more similar. At the same time a cultural 'cognitive dissonance' effect is at work, implementing Portugali's concept of *spatial cognitive dissonance* [22,23]. Similarity between two agents is defined as the proportion of traits they share.

Agents who spend more than six months surrounded by neighbours with few common traits increase their mobility propensity each subsequent time step. The mobility propensity attribute represents the probability that an agent will abandon the currently-occupied location in the subsequent time step. Mobility propensity is affected by the conditions of the currently occupied dwelling and the cognitive dissonance level. A special circumstance is when the price of the dwelling currently occupied exceeds the agent's income. This represents an excessive rent increase, unsustainable by the agent. The process of finding a new location is bounded by the agent's income: a new dwelling has to be affordable ($V \leq i * credit$), in relatively good condition (at least, not a slum), and as close as possible to the centre of the district which contains it. 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.

4 Exploratory Results

Due to lack of access to GIS data and reliable property price indicators, for our current phase of work we have deliberately constructed an abstracted model of Beirut. To this end, property prices and agents' incomes are normalized to $[0, 1]$ scales. As noted earlier, each tick of the simulation corresponds to one month. We begin the simulation after the period of the Lebanese Civil War (approx. 1975-1990) and the following reconstruction, and prior to the influx of refugees from the Syrian Civil War (approx. 2011–). As described in Section 3, agent demographics are initially set proportional to estimated figures prior to the influx of Syrian refugees, which began in 2012–13.[4]

It is not among our research questions at this time to attempt to reproduce the historical evolution of population and property prices in Beirut after the Lebanese Civil War. There are many factors which make this difficult, not least the paucity of historical data about property prices (there are no published indices prior to 2016), multiple exogenous factors (including the 2006 conflict with Israel), legal changes which favoured redevelopment, legacy rental controls for pre-war tenants, debt-financed government reconstruction of the CBD, and extensive undocumented or illegal practices in Lebanon. While we do not validate our model in such a way yet, we have previously validated our earlier iterations of the ABM in the British cities of Manchester [20] and London [unpublished]. Although post-industrial Britain and contemporary Lebanon have obvious economic and societal differences, the underlying economic model, the RGT, is argued to be applicable in all housing markets in capitalist economies, as the fundamental processes described by the theory – profit-driven investment in house building – are not too dissimilar across different property markets. Our previous validation suggests that the model captures at least some of the dynamics involved in such process. More substantial differences between property markets are to be found in the distribution of wealth, income, and tenure, in government policy, in the amount of investment capital available in the economy. The model, despite its present decidedly abstract form, makes effort to account for these factors.

[4] We do not consider other refugee populations, including those of Palestinian origin.

Our main research questions in the present work concern the effects of mass refugee inflow into Lebanon. With demographics of Lebanon being a delicate matter for sectarian and political reasons, estimates circa 2010 put the Lebanese population living in the country at around 4 million[5], plus approximately 0.5 million Palestine refugees from 1948 and later. By 2015, the UN recorded more than 1 million official refugees from Syria, whereas including undocumented refugees and those who have emigrated, e.g., to Europe, through Lebanon, the estimates are as high as 2 million, i.e., 50% of the Lebanese population. Profound consequences of such a large influx of population in a short (3–4 year) time period include social, economic, security, and political aspects. Our research questions focus on the first two aspects, as follows:

1. Can an abstracted model of Beirut housing be developed?
2. Can qualitative effects of the refugee influx to Beirut be seen?
3. What effects does a sudden large influx of low income people have on the economic housing cycle?
4. What public or Non-Governmental Organization (NGO) intervention actions might be effective?

We measure a number of output variables from the simulation, including location condition and prices, neighbourhood allure and cultural mix, population income and cultural traits, occupancy rates and mobility, and immigration and emigration counts. In particular, for the experiments reported below, we periodically recorded: (1) % of slum locations ($r \leq 0.15$), (2) % of well-maintained locations ($r > 0.5$), (3) % of over-populated locations ($P > 3$), (4) median price of all locations, (5) median income of all people, (6) the district with largest number of refugees, and (7) % of Lebanese, refugees, or another ethnicity

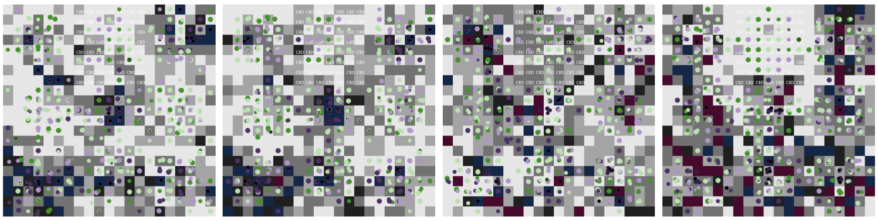
We conducted three exploratory experiments directed towards our research questions. Simulation parameters were set as in our previous work [21], which in particular explored the effect of capital K and the type of rent gap computation; additional parameters settings are reported below.

4.1 Experiment 1: Impact of Refugee Influx

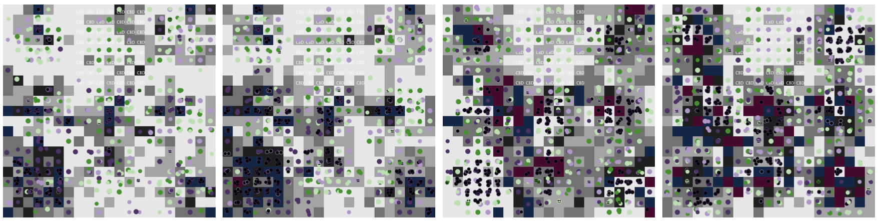
We simulate a refugee influx beginning at tick 90 and continuing until tick 180; the simulation runs until tick 600. The immigration rate for refugees, 0.15, is much higher than the rate for non-refugees, 0.02; the emigration rates are 0.012 and 0.019 respectively. The immigration and emigration rates reflect that after refugees arrive in Lebanon, many settle for an extended period of time before either obtaining access to a country of aslyum (e.g., Germany), returning to their own country (e.g., if the situation improves), or becoming de facto residents.

Fig. 3 shows longitudinal views of the city districts under four settings: top, no refugees (i.e., refugee immigration rate is the same as other populations: there

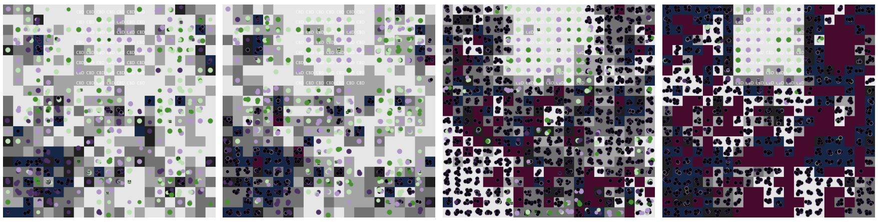
[5] The Lebanese diaspora is estimated to be 8–14 million [15]. They influence the housing market by ownership for investment or, in some cases, planned future repatriation. We treat these as exogenous factors and exclude from our model.



(a) t=100 (b) t=200 (c) t=400 (d) t=600



(e) t=100 (f) t=200 (g) t=400 (h) t=600



(i) t=100 (j) t=200 (k) t=400 (l) t=600

Fig. 3: City districts over time. Top row = no refugees, middle row = refugee influx between $t = 90$ and $t = 180$, bottom row = ongoing refugee influx from $t = 90$. Slum locations are dark blue, uninhabitable locations are dark purple.

is no influx); middle, refugee influx as described above; bottom, ongoing refugee influx, described below in the second experiment. Capital $K = 0.025$.

City districts are shaded according to their condition. The darker the shade of grey, the lower the condition of the location. Locations which have reached slum condition ($r \leq 0.15$) are coloured dark blue; locations which have become inhabitable ($r = 0$) are coloured dark purple.

Agents are depicted by colour, shape, and size. Colour denotes the income of the agent: darker green indicates highest quintile ($i \geq 0.8$), brighter green indicates above average ($0.8 > i \geq 0.5$), brighter purple indicates third quartile ($0.5 > i \geq 0.25$), and darker purple indicates bottom quartile ($i < 0.25$). Shape denotes the ethnicity of the agent: Lebanese are shown as filled circles, refugees as hollow circles, affluent Arab non-refugees as smiling faces, professional non-Arab as flat faces, and working class non-Arab as sad faces. Size denotes ownership: owners appear larger than non-owners.

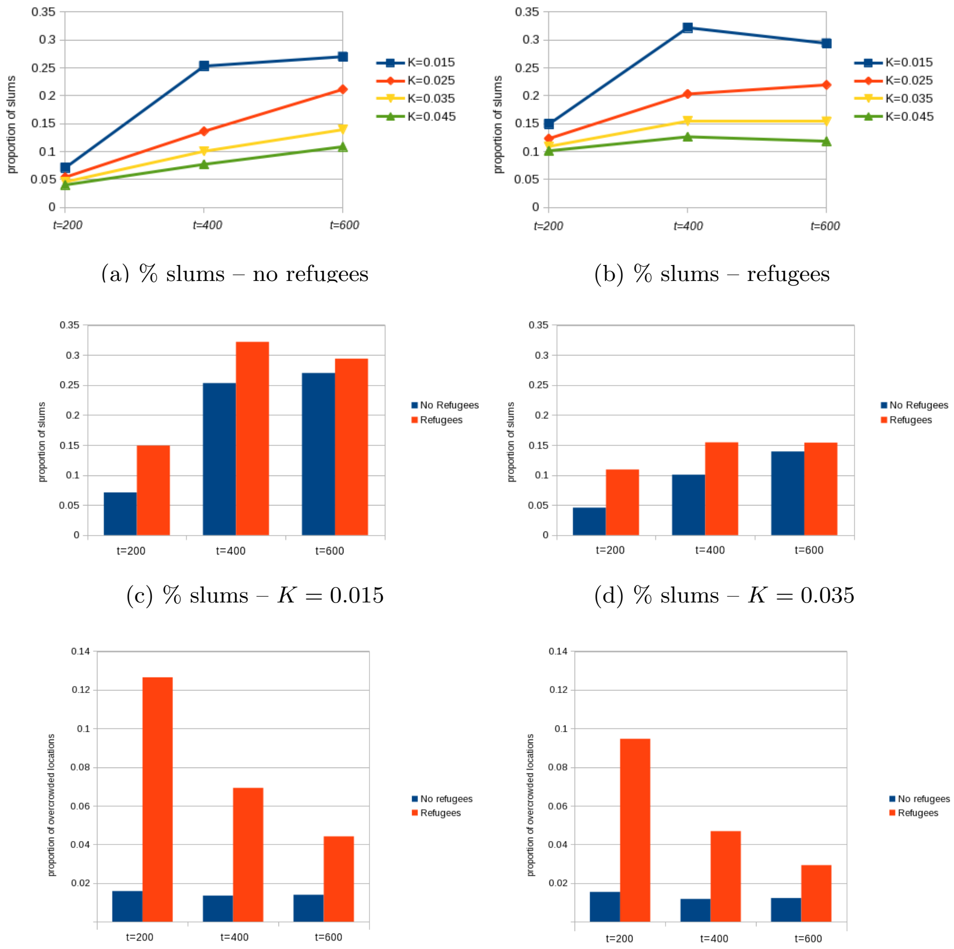
Notice some decline and regeneration – the economic cycle – affecting different city districts in the no-refugees case (top row). For example, the CBD, the north district, starts with relatively high condition, has decayed to medium condition by $t = 400$, and has regenerated to a good condition by $t = 600$, stimulated by the price controls in that district.

Comparing the top two rows of Fig. 3, we see that the number of slum and uninhabitable locations is greater with the presence of refugees. Since refugees can have a higher population per location, the city's population is also greater, and since they are poorer, average income is lower. In the initially poor south-west district, refugees congregate at first. Later, as the economic cycle continues in different districts, we see refugees reside elsewhere. Their presence on one hand can be see as constraining regeneration, but on the other we see regeneration occurring in the south-west district around $t = 400$. In the CBD, from which refugees are excluded by government policy, condition and prices are more stable.

To explore further the impact of the refugee influx, we performed 100 iterations (with random seed) for various parameter settings, and computed output variables shown in Fig. 4. The top row of the figure shows the proportion of slum locations under no refugee (left) and refugee (right) conditions. In each graph, we examine four levels of capital K. At low levels of capital, the ability of owners to regenerate dwellings is limited, whereas at higher levels, they have greater ability. As expected, in both with- and without-refugee conditions, as K increases the proportion of slums decreases.

The middle row of Fig. 4 shows the proportion of slums without (blue leftmost columns) and with (red rightmost columns) refugees, at two levels of capital. As also seen in the top row of the figure, the presence of refugees and the proportion of slums are positively correlated at all levels of capital, albeit the level of capital is by far the main factor affecting the number of under-maintained locations. The impact of refugees on the number of slum areas can be traced back to the fact that refugees, unlike other persons, are willing to occupy nearly-derelict properties that would be empty otherwise. Their presence reduces the profitability of redevelopment in two ways: (1) when a location is occupied there is the resident removal cost C to be paid in order to redevelop it; and (2) since in the model the prices of non-empty locations decline more slowly than empty ones, price-gaps with higher priced neighbouring properties also widen more slowly. This last effect is more pronounced when a large contiguous area is under-maintained but occupied: there is less incentive for private capital to invest and regenerate the locations, so the area keeps declining gently for a longer time and we see more under-maintained properties for a longer period.

However, interestingly, as Fig. 4[a–d] shows, in the long run the impact of refugees on the amount of unmaintained locations is negligible. The normal economic cycle of investment is capable of absorbing the shock of the mass refugee influx that ends at tick 180, and by tick 600 the difference between



(a) % slums – no refugees

(b) % slums – refugees

(c) % slums – $K = 0.015$

(d) % slums – $K = 0.035$

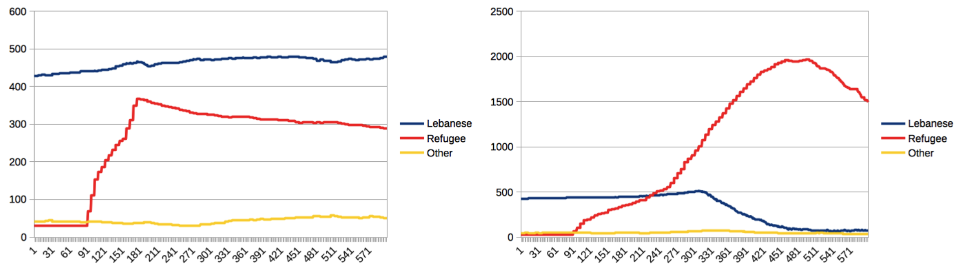
(e) % over-populated – $K = 0.015$

(f) % over-populated – $K = 0.035$

Fig. 4: Proportion of slums by level of capital in refugee and non-refugee conditions (top two rows); proportion of over-populated locations (bottom row).

refugee and non-refugee conditions is minimal. This is not the case when we test an ongoing refugee influx, in Experiment 2 below.

The bottom row of Fig. 4 shows the proportion of over-populated locations, again at the two levels of capital. We observe that refugees have a higher impact on overcrowding (than on slums), as to be expected. The strong influx at $t = 90$ inevitably floods the available properties; overcrowding is seen to decline over time as refugee immigration ceases. By contrast, overcrowding is fairly stable and rare in the non-refugee condition, where only a small minority of the



(a) Migration window (b) Ongoing migration

Fig. 5: Evolution of city population by ethnicity. $K = 0.025$

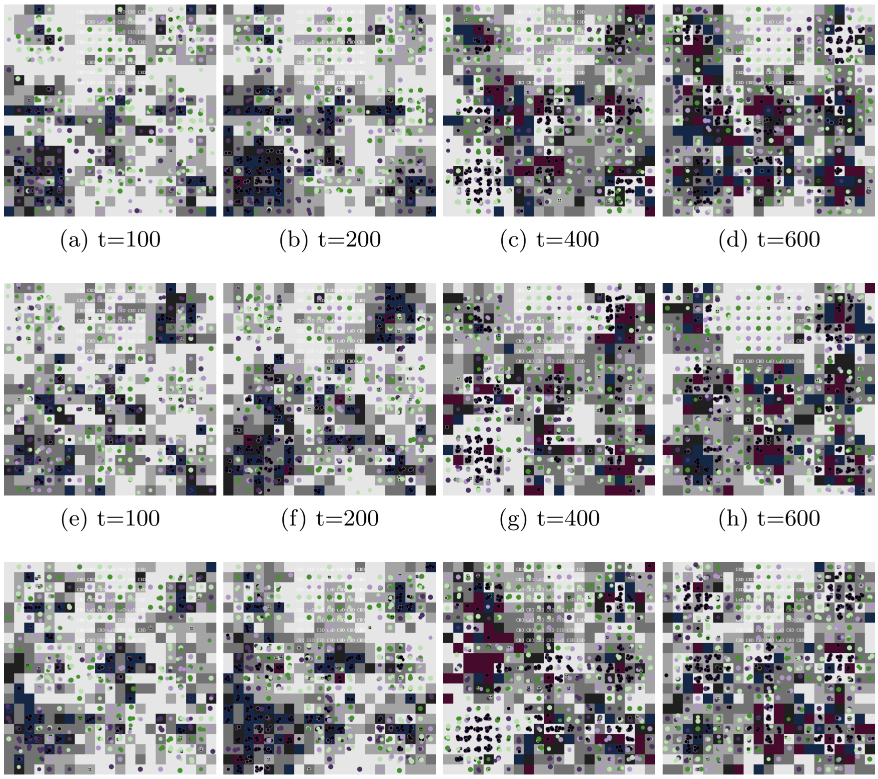
population (working class foreigners) will accept to live in an over-populated location. However, the higher availability of capital does reduce the number of over-populated locations in the refugee condition. This is because with higher capital, more locations are redeveloped and gain in price, becoming unavailable for refugees. At the same time, the number of low maintenance areas – where only refugees concentrate – decreases.

It is worth commenting on an interesting effect seen for all levels of capital: the % of slums reaches a maximum and then levels off or declines (except $K = 0.025$, where the growth rate slows). Looking in detail, we see a correlation between the number of slums and the number of refugees. Median price and income follow the same pattern, but inverted, and see a fall and then some a recovery; for prices, the recovery has an extended time lag. The explanation for this phenomenon is that, especially at lower levels of capital, the number of refugees peaks and, after the influx has ceased, it begins to reduce towards a sometimes much lower stable level than its peak (Fig. 5, left). We see this as due to refugees leaving the city after the peak because they can find no inhabitable place where they can afford to reside (not even a slum with some space). In this case, the large, low income population exacerbates the effect of the low level of capital, in that only a limited set of districts are able to generate price-gaps wide enough to attract investment and participate in the economic cycles[6], while other districts fall in permanent disrepair.

4.2 Experiment 2: Impact of Ongoing Migration

When the flow of refugees is ongoing, the effects observed in Experiment 1 are further pronounced. The bottom row of Fig. 3 shows widespread highly population, slum, or even uninhabitable locations by $t = 400$; and by $t = 600$, about a third of the city is uninhabitable. Nonetheless, the economic cycle continues in some districts: observe the regeneration of the south-west between $t = 200$ and

[6] As Smith puts it, “urban development in capitalist economies tends to involve a cyclical process of investment, disinvestment and reinvestment” [26].



(a) t=100 (b) t=200 (c) t=400 (d) t=600

(e) t=100 (f) t=200 (g) t=400 (h) t=600

(i) t=100 (j) t=200 (k) t=400 (l) t=600

Fig. 6: Intervention policies. Top row = none, middle row = government regeneration, bottom row = EU slum improvements.

400, and of parts of the south-east between $t = 400$ and 600. By the end of the simulation, the effect of the refugee exclusion and price controls in the CBD is a marked contrast to other districts.

Interestingly, the decline in location conditions and the spread of locations in permanent disrepair causes several effects. First, as one might expect, other districts become populated as highly as possible. Second, non-refugees leave the city despite falls in prices, as they can find no place of reasonable condition with space to which to move (Fig. 5, right). Third, refugees leave the city when they too can find no place, despite their willingness to accept poorer conditions and greater population density.

4.3 Experiment 3: Interventions

We consider two types of interventions in the housing market. First, as in our previous work, top-down government intervention to regenerate a location of poor condition. This periodic action (on average, every six months with our baseline parameter settings) seeks out one of the locations of lowest condition (it need not have decayed to slum condition), lifts its condition to $r = 0.95$ and also raises its price, and lifts similarly the condition of the surrounding locations. The second type of intervention targets locations that have reached slum condition. It makes specific, targeted, improvements to one such locations, to a condition $r = 0.5$, and it can occur on a monthly basis rather than bi-annually. While the first type of intervention has not occurred in Beirut, it could occur in principle given sufficient funds. In contrast, the second type has occurred in recent years, funded by donor countries, NGOs, or the European Union.

A further type of intervention, designed to assist poorer residents and which could include refugees, is to build social housing, akin to what is done in European countries. Although included as an option in our model, we have not explored this possibility for Beirut due to constraint not only of public funds but also of the issue of finding space in a highly build-up urban area.

Fig. 6 depicts the effect of no intervention (top row), regeneration (middle), and targeted EU slum improvements (bottom row). $K = 0.025$ and refugees immigrate from $t = 90$ to 180. The greatest contrast is seen between some kind of intervention and none. Both top-down neighbourhood regeneration actions and more frequent and targeted slum improvements counteract the dampening effect of the refugee shock on the city's housing market. Interestingly, given the initial property values and conditions, the economic cycle is seen having the same approximate frequency in the initially-poor south-west district. If anything, the more frequent micro-interventions seen in the bottom row of the figure are better able to break out neighbourhood 'clusters' of poor condition dwellings. The suggestion opened for future study is that interventions can have value in sustaining the urban economy and population, mitigating the impact of the shock, and most importantly, improving the living condition of the poorest residents.

5 Summary and Future Work

Our motivation for this work comes from the sizeable contemporary transnational migrations affecting, at the time of writing countries in Europe, especially, and its environs. Our aim is to use ABM to explore the effect of migrant inflows on urban dynamics, and eventually to develop tools to aid policy makers with questions about the urban environment [16].

This paper presented a preliminary step towards such a longer-term goal, in the form of an abstracted simulation model of a Mediterranean city. Our model extends our earlier work by including designated cultural traits, property ownership (rather than a pure rental market), emigration, and refugees.

We found that refugees have impact on levels of slum locations, population density and over-population, prices, and income. Their presence appears to dampen the natural economic cycle, which continues nonetheless with waves of decay and regeneration, although with gentrification at a slower frequency after the shock of refugee influx. We observed an interesting effect depending on the capital in the economy and the rate of mobility, whereupon excessive shock of refugees – and in particular ongoing migration to the city – can render large parts of districts uninhabitable, causing both refugee and non-refugee populations to emigrate from the city.

The next step in this work is to move towards a more fine-grained model based on GIS data, following our work on urban settings in the UK [20]. There are several challenges in modelling Beirut using actual data. Firstly, public reliable geo-referenced data relating to the variables relevant in the model are not easily accessible. Second, prior to 2016, there is no official, published data about population or the housing stock – neither for Beirut nor indeed for the country – leaving only estimates by NGOs and proprietary databases which are partial and costly to access. Nonetheless, in conjunction with colleagues in urban design and economics, we are deriving public GIS models and developing a property price index, which can be applied to our model.

Second, our future work is to expand the geographic scope of the model from the city boundaries of Beirut to include the sub- and peri-urban areas of Greater Beirut. The importance of modelling the larger catchment area is that nearly half the population of Lebanon lives within the greater metropolitan area, with profound effects on property prices, mobility, and traffic [4,7].

Third, since significant migrations are being absorbed not only by regional countries such as Lebanon, but also by certain European countries, we see value in applying our model to cities in countries such as Germany.

Acknowledgments. We thank the anonymous reviewers of the ABMUS 2016 workshop, and thank Joseph Bechara, Bruce Edmonds, Mona Fawaz, Alison Heppenstall, and Ali Termos.

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