Location and existence of retail centres in cities: a theoretical spatial agent-based experiment

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Abstract

Recent discussions in urban planning point to the desirable emergence of '15-minutes cities', where citizens can fulfil their needs within a time threshold from their home. In parallel, post-COVID working patterns show a permanent rise in work-from-home, with potential impacts on commercial floorspace in cities. In addition, there are conflicting trends between 'buying-local' tendencies and the rise of online shopping. These 3 changes pose a fundamental question for cities worldwide: what will be of urban retail?

In order to address this issue, this paper proposes a theoretical agent-based model with micro-economic foundations, considering firms and households. The model simulates where retail firms emerge and cluster in a theoretical space and seeks to identify the conditions and forces that lead to the existence of retail and different location patterns. The model is then used to analyse how buying-local preferences and online-shopping behaviour when traded-off against transport costs affect these patterns. Early results show that a minimum preference for deliberately buying locally can significantly change the pattern of location of shops in a city. Citizens deliberately choosing to buy locally tend to lead to a more decentralised shopping landscape, making '15-minute city' goals more feasible from a public policy perspective.

Keywords: agent-based modelling, retail location, localism, online shopping

1. Introduction

1.1. Motivation

Recent discussions in urban and regional planning point to the desirable emergence of a so-called "15-minute city" (Pozoukidou and Chatziyiannaki, 2021). It evolves from more traditional ideas (i.e. the "neighbourhood unit"), that amenities such as shops, restaurants, recreation areas, schools and clinics should be reachable from every household within a certain threshold of either time or distance. In other words, every household should be served by an amalgam of nearby services to fulfil their basic needs. The "15-minute city" discussion is fueled with arguments towards reducing transportation-related emissions in cities. Having services and amenities near living places reduce the length of trips and allow for more non-motorised transportation choices, such as walking or cycling (Carpio-Pinedo, Benito-Moreno and Lamíquiz-Daudén, 2021). This also promotes local employment opportunities, which in turn would tend to reduce even more the need for longer motorised trips, namely for commuting purposes. Overall, the idea of a "15-minute city" is related to a higher efficiency of resource and time utilisation, optimising accessibility for households in cities, thus improving their quality of life.

Fostering local employment also emerges as reasoning for another set of ideas: the "Localism", or the "buy-local" tendency (Ferguson and Thompson, 2021). Localism is defined by both giving preference to local businesses, owned by members of a local community instead of large multinational chains; as well as privileging products originated in nearby production sites. Environmental issues also overarch localism's reasoning, since global value chains pose an extra burden on the environment due to indiscriminate international outsourcing and subsequent shipping demands. The localism movement, however, comes as a conflicting idea with current consumption trends. Online shopping habits have gained momentum in recent years, and this emergence pulverises previously prohibitive shipping costs over long distances (Barska and Wojciechowska-Solis, 2020).

These conflicting forces pose a challenge to the future of retail spaces in cities, and the future of urban land-use in general. Together with the rise in teleworking, it is still uncertain how commercial floorspace will be transformed in the coming years. Office and residential floorspace, however, are more easily convertible to one another than retail space to either. Moreover, the economic viability of retail depends on a concentration and movement of people in their vicinities. It is, therefore, essential to understand the most recent centripetal and centrifugal forces behind locational decisions of retail firms in cities, and how these conflicting forces are balanced out in the long run.

1.2. Research objective & questions

This work has as main objective to understand the emergent patterns of retail firms' location decisions in a theoretical city. To fulfil this objective, it makes use of an agent-based model with microeconomic foundations with two types of agents: households and firms. This is done in order to answer three main research questions:

- Where do retail firms emerge and cluster in an open, agent-based, two-dimensional theoretical urban model?
- How do centripetal and centrifugal forces play a role in forming these patterns?
- How can online-shopping behaviour and buying-local preferences affect the location of retail subcentres in a city?

2. Methods

This research makes use of a stylised theoretical urban model, using a 2-dimensional agent-based setting with simplified dynamics and rules. It has as basis two types of agents: firms and households. Phenomena addressed in the modelling process include: online shopping behaviour, buying-local preference levels, commuting trips, shopping trips, a simplified rental market generating density gradients, increasing returns to scale for firms, among others. This is done using microeconomic foundations, described in the following sections.

2.1. Environment and basic settings

The environment consists of a two-dimensional landscape with discrete locations called here lots. The lots are initially occupied by farmers paying a uniform agricultural rent (r_a), assuming their products incur no transportation costs, and an exogenously defined Central Business District (CBD) in its absolute centre. The CBD provides employment for households, which pay rent to absentee landowners. Households consume a uniform product sold by retail firms (shops) and commute to the CBD and travel to its patronised shop. Shops pay rent, buy products from the outer-world by a fixed price per product and a fixed importing cost, sell them for a profit to households. The simulation starts with $t = 0$ and evolves one unit t per step. For every step, a new household enters the landscape until the long-run equilibrium condition is satisfied. In case it can make any profit, a firm enters the landscape within the same step. Household and firm behaviours, interaction dynamics and parameter definitions are described in the next sessions.

2.2. Household behaviour

Households in the model maximise their utility U by consuming land (S), and the uniform product sold by shops (Z). Utility is defined as a Cobb-Douglas function of these two variables:

$$U(S, Z) = S^{\alpha} Z^{\beta} \tag{1}$$

where $\alpha, \beta \in [0, 1]$ and $\alpha + \beta = 1$. This utility is subject to a budget constraint (Equation 2), where a household's exogenously defined income Y is fully distributed among rent, transportation costs, consumption of a shops' products as functions of the household's location x. The budget constraint function is defined as:

$$Y = r(x)S + d(x)\theta + Z(x)p \tag{2}$$

where θ is the unitary transportation cost, $d(x)$ is the distance travelled by a household, $r(x)$ is the rent per unit of land paid at location x, p is the unitary price for products sold at the patronised shop. As the consumption exhausts the income of households, we can subject equation 1 to the constraining equation 1. Its first-order conditions yield the following Marshallian demands:

$$S^* = \frac{\alpha(Y - d(x)\theta)}{r(x)}, Z^* = \frac{\beta(Y - d(x)\theta)}{p} \tag{3}$$

By substituting the Marshallian demand functions defined in (3) into the utility function defined in (1) we reach the optimal utility function $U^*(S^*, Z^*)$, leading to an indirect utility function $v(x)$ (3) with utility depending on income and prices in relation to location x.

$$v(x) = \left(\frac{\alpha(Y - d(x)\theta}{r(x)}\right)^{\alpha} \left(\frac{\beta(Y - d(x)\theta}{p}\right)^{\beta} \tag{4}$$

It is worth mentioning that the incremental characteristic of this open model, with one household entering the environment every step, holds as long as there is a location x with a higher utility than a predefined outer-world utility (u_0). This also indicates the short-run equilibrium condition (5) for every step of the simulation: with freely mobile agents, the utility reached by the last-entering household i_0 will define a fixed utility $\overline{u}$ for every other household agent already present in the model.

$$\overline{u} = v_{i_0}(x) \tag{5}$$

This short-run equilibrium condition allows to derive the bid-rent function ($\Psi(x)$) for every occupied location x depending on the fixed utility $\overline{u}$.

$$r(x) \equiv \Psi(x) = \overline{u}^{-\alpha}\alpha(Y - d(x)\theta) \left(\frac{\beta(Y - d(x)\theta}{p}\right)^{(\beta/\alpha)} \tag{6}$$

In the long-run equilibrium, the utility of the last-entering household equates that of the outer-world ($\overline{U} = u_0$), and therefore in-migration stops.

The variable $d(x)$ is the distance a household has to travel as a function of location x and is composed of three main elements. Firstly, the Euclidean distance d_{0x} between the CBD and location x. Secondly, the Euclidean distance d_{xj} between location x and shop j. The third element is a composite between the Euclidean distance between CBD and shop j and the previous two elements weighted by trip-chaining frequency parameter $\epsilon \in [0, 1]$. This means for $\epsilon = 0$ no trip-chaining occurs, and households make two round-trips, one to a shop, another to the CBD. For $\epsilon = 1$ both trips are chained, and the household makes a trip to the CBD, one from the CBD to the shop, and one back home from the shop. A household will patronise shop j over all shops J provided it yields the minimum sum between these three elements.

$$d(x) = \min_{j \ldots J} d_{0x} + d_{xj} + \epsilon d_{0j} + (1 - \epsilon)(d_{0x} + d_{xj}) \tag{7}$$

Lastly, it is important to define the price p effectively paid by each household. Without any firms in the simulation, every household imports the uniform product Z from the outer world. This incurs in an importing fee i, that is fixed, and a unitary price c. Importing from the outer world is used in this model as a proxy for online-shopping behaviour. As firms emerge in the landscape, households will choose either to buy from them, incurring an extra shopping-trip cost but saving in the importing fee, or continue to import products, whichever yields a higher utility. The next session defines firm behaviour.

2.3. Firm behaviour

During a step, a new firm enters the simulation if there is a lot in the environment which provides it with a positive profit. A firm is assumed to be a monopolist, or part of an oligopoly as further firms enter the simulation. Therefore, its profit-maximising price is set by equating marginal costs with marginal revenue. A firm's revenue (Equation 8) depends on quantity sold, as a function of the set price. Similarly, its costs (Equation 9) equal the quantity sold as a function of the price multiplied by a fixed cost for each product bought at an external market. A fixed importing fee (i), valid for either firms or households that decide to import the product by themselves, is added to a firm's cost. Finally, a firm has to pay rent ($r(x)$) dependent on location x it chooses. It is expected that a firm marginally outbids a household for land, and will choose the lot with maximum profit.

$$R = pQ(p) \tag{8}$$

$$C = cQ(p) + i + r(x) \tag{9}$$

By equating marginal revenues (R') to marginal costs (C') a firm can calculate its profit-maximising price $p^*(c, i, Y, r(x))$ depending only on external cost of product c, its fixed importing fee i, the representative households' income Y, and rent for chosen location $r(x)$. Its price p^* will define a firm's market-catchment distance $\hat{d}$. Within this distance, a household's shopping-trip to the firm provides a higher consumption of uniform good Z than importing it.

3. Preliminary results

One of the intentions of this model was to test the importance of household preferences in the patterns of retail location. More specifically, whether households deliberately choosing to shop in their vicinity would lead to different long-run configurations of the landscape. This was done by varying the ϵ parameter, that indicates the frequency with which a household is willing to chain his work- and shopping-related trips. For $\epsilon = 1.0$, a household would always be willing to chain their trips if it yields a higher utility, whilst for a $\epsilon = 0.0$ a household would deliberately choose to never chain these trips, despite it generating a potentially higher utility.

Early results for the simulations show that only for $\epsilon = 1.0$ a substantially different pattern emerges. That is the concentration of retail firms in and around the existing CBD. By moving away from $\epsilon = 1.0$ towards $\epsilon = 0.0$, meaning that households deliberately choose not to chain trips, generates a scattering of retail firms around the landscape, any variation resulting only in how tight this scattering is in relation to the CBD. This is an indication that a minimum preference in households for local consumption and privileging local retail already leads to the emergence of local shops, instead of an absolute concentration in the CBD.

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