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An agent model of urban economics: Digging into emergence

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ABSTRACT

This paper presents an agent-based 'monocentric' model: assuming only a fixed location for firms, outcomes closely parallel those found in classical urban economic models, but emerge through 'bottom-up' interaction in an agent-based model. Agents make buying and movement decisions based on a set of simple costs they face from their current location. These spatial costs are reduced to two types: the costs of moving people and goods across geographical distances and the costs (and benefits) of 'being here' (the effects of being at a particular location such as land costs, amenities or disamenities). Two approaches to land cost are compared: landlords and a 'density cost' proxy. Emergent equilibrium outcomes are found to depend on the interaction of externalities and time. These findings are produced by looking at how agents react to changing four types of cost, two spatial and two non-spatial: commuting, wage, good cost and good delivery. The models explore equilibrium outcomes, the effect of changing costs and the impact of heterogeneous agents, before focusing in on one example to find the source of emergence in the externalities of agent choice. The paper finishes by emphasising the importance of thinking about emergence as a tool, not an end in itself.

1. Introduction

In the 'monocentric' model tradition, a market, firm or central business district (CBD) is set at a central location surrounded by land. This tradition examines the choices economic agents make as they optimise between distance to the centre and the cost of land. As well as being useful for investigating real-world settlements with fixed central areas, it is also effective for thinking about the polarity and magnitude of spatial economic forces.[1]

The concept of spatial equilibrium is at the heart of traditional monocentric models (Fujita, Krugman, & Venables, 2001, p. 17). While originally a verbal argument (Thunen, 1826), modern variants of the model have taken Launhardt's initial mathematical approach (Launhardt, 1885) to develop the modern version of spatial equilibrium (Blaug, 1997, p. 600). This made its way into urban economics via Alonso (1964), becoming in time the Alonso–Muth–Mills (AMM) monocentric framework, as outlined in Glaeser (2008).

As Glaeser puts it (ibid. p.4), spatial equilibrium is "the bedrock on which everything else in the field stands… essentially, there must be no arbitrage across space". No agent can unilaterally make themselves better off by choosing a different location (Lemoy, Raux, & Jensen, 2010, p. 7). The assumption that this arbitrage has already taken place provides a solid mathematical foundation – that all agents' utility has become equal and static across distance; $du = dd = 0$ (where u is utility and d is distance) as one moves from $d = 0$ at the centre point to the edge of the settlement. All other deductions are built on top of this assumption. In the simplest (and most powerful) finding, spatial equilibrium is used to show that "rents must decline with distance to exactly offset the increase in transportation costs" (Glaeser, 2008, p. 20).

In contrast, rather than assume equilibrium, Agent Based Modelling (ABM) asks how system-level properties *emerge* through the interaction of individual economic agents, each with their own behaviour. As Bonabeau argues (2002 p. 7280), ABM is "the canonical approach to modelling emergent phenomena". Emergence is as central to ABM as equilibrium is for analytic economics. So a natural ABM approach to the monocentric model is to ask whether spatial equilibrium is an emergent property. Can interacting agents create a stable, equal-utility settlement pattern?

A small number of theorists have applied ABM to monocentric models showing, in different ways, how agent interaction can create emergent settlement patterns (the work of Lemoy et al. does a particularly thorough job; see below). ABM, however, often suffers

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[1] As Blaug says, this was a point made by von Thunen: "in reality, Thunen observes, differences in fertility of the soil which are not themselves related to location will give rise to ground rent in the same manner as do differences in proximity to the central town." (Blaug, 1997, p. 598).

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from a 'method-centring' malady (Maslow, 1966, p. 15) where emergence becomes a goal in itself. This paper digs a little deeper into emergent spatial equilibrium, asking: why does spatial equilibrium emerge from agent interaction? What role is space actually playing in spatial equilibrium?

The answer proposed is this: space provides a medium for agent choice *externalities* (the effects of each agent's choices on others) to interact over time. These externalities will accrete into a settlement where all agents share the same utility. Time is equally important: the model provides agents with the ability to make independent, objectively valid decisions at their own time point. The spatial environment itself is a store for their decision, simply in the form of their location choice, so that subsequent agents face an altered landscape.

To do this, an agent-based monocentric model is presented with some additions to the traditional framework. These are kept simple. The *spatial costs* that agents face are broken down into two types. First, **distance costs**: the cost of moving people *and* goods across geographical distances (rather than just people as traditional monocentric models tend to focus on). Second, **proximity costs**: the cost of 'being here' – that is, the effects of being at a particular location such as land rent, amenities or disamenities.

The usual proximity cost in monocentric models is the rent paid to occupy a plot of land. Land costs are the keystone of urban economic models: they provide the reason for distance to exist at all in a model trying to explain spatial morphology "as an endogenous outcome of the economic process" (Storper 2010, p.315). A limited stock of land is an essential component of the traditional monocentric model, and its impact on morphological outcomes well-known in urban economics (land is a normal good; better-off people wish to consume more). In this paper, a land market is implemented in a way that avoids many of the complexities of bidding processes commonly faced in ABM market models.

A second proximity cost is also introduced – a 'density cost' derived solely from the proximity of other agents. This approach is a simple way to avoid the 'black hole' outcome where actors do away with space altogether if they can, collapsing into a single point (Fujita, 1999, p. 58).[2] A land market is thus considered a specific case of the more general proximity cost. This point is then used to make the case for the role of externalities working through proximity costs.

The following section looks at ABM and the idea of emergence, as well as agent-based approaches to the monocentric model. The model's structure is then explained in detail, before the results are presented – a series of models illustrating how spatial equilibrium is reached, as well as how agents react to key cost changes, heterogeneous wealth of various forms, and how they react if given heterogeneous preferences.

Both distance and proximity costs are necessary conditions for spatial equilibrium to emerge. Section 4.4 takes a closer look at the decision sets of two- and three-agent scenarios, in order to examine how spatial equilibrium comes about through these two types of spatial cost interacting with externalities.

2. Agent-based modelling, emergence and space

In ABM, the 'agents' are distinct code objects, programmed to interact with their environment and each other. ABM's use ranges from the most abstract artificial life to 'autonomous' agents earning their keep controlling real-world infrastructure. ABM developed in tandem with Object-Oriented Programming (OOP); this approach has been the prime determinant of agent modelling theory and practice (Robinson & Sharp, 2009, p. 211). Wooldridge defines objects as "computational entities that encapsulate some state, are able to perform actions on this state, and communicate by message passing" (Wooldridge, 2009, p. 28). Objects are created from classes; a real-world metaphor would be that classes are the blueprint and objects the physical form. Thus, a model may have a single 'Firm' class but many 'Firms' created from that blueprint, replicating a structure but each with their own internal state.

ABM's power as a method is rooted in its ability to investigate *emergent* outcomes – system-level properties that result from the interaction of many agents, but that are qualitatively different from those agents (Bonabeau, 2002, p. 7280). A common physical analogy is that atoms do not have temperature and pressure – these are system-level properties of their interaction that cannot be deduced by examining atoms in isolation (Flake, 1998, p. 134). Emergence is thus as central to ABM as equilibrium is to classical economic models.

The role of emergence as ABM's default focus has led to some rejecting system-level analyses – adopting honorary proto-ABM theorist (Miller & Page, 2007; Vriend, 2002, p. 2) Friedrich Hayek's earlier insistence that "we must show how a solution is produced by the interactions of people each of whom possesses only partial knowledge" (Hayek, 1945, p. 530), dismissing system-level descriptions as 'fallacies of misplaced concreteness' (Hoover, 2001, p. 108). It is perhaps unsurprising, then, that many see ABM as a rejection of equilibrium economics, where an assumed system-level end-state is essential to the whole approach. In this view, ABM offers a "a pioneering break from a moribund Newtonian worldview" (Manson, 2001, p. 412) that is "simply wrong: stability is not the norm in complex systems" (Colander & Rothschild, 2010, p. 286).

The common rejection of equilibrium approaches seems to go hand in hand with an overly 'method-centred' (Maslow, 1966, p. 15) outlook: identifying emergent outcomes has dominated over using it to dig deeper into an understanding of the system being modelled. Epstein's claim that "if you didn't grow it, you didn't explain it" (Epstein, 1996, p. xii) is a highly cited case of making emergence the goal rather than the tool. In this view, equilibrium outcomes, if they exist at all, can only be explained through emergence. Explanation is a heavy burden for emergence to bear – if 'growing' it explains it, there is nothing else to ask. The result, as Di Paolo et al. say, is often that any deeper understanding of why a system acts as it does is "brush[ed] under the carpet of emergence" (Di Paolo, Noble, & Bullock, 2000, p. 8).

Users of the equilibrium assumption seem to suffer less from this method-centring; there is a general self-awareness of its limitations. As Glaeser says of spatial equilibrium, "no-one thinks that this assumption is a literal depiction of reality. Still, models based on the concept . . . do a generally good job of actually explaining the real world." (Glaeser, 2008, p. 4). Most importantly, the equilibrium approach, while acknowledged as limited, is put to use as a tool to answer questions.

This is perhaps why equilibrium approaches have continued to dominate in spatial economics, despite ABM's enormous potential. In ABM, the fundamental spatial questions – "who produces what, where and why?" (Ohlin, 1933 quoted in Brakman et al., p. 81; cf. Stanilov, 2012) – have been overshadowed by the technology itself.

Applying ABM to spatial economics is even more challenging since, historically, spatial economic questions have fallen through the cracks in the research field. Agent-based Computational Economics (ACE) – "the computational study of economies modelled as dynamic systems of interacting agents" (Tesfatsion, 2006, p. 834) – suffers from the same problem as much of mainstream economics: space is ignored altogether, sticking to a "wonderland of

[2] As Alonso put it, "if the only criteria for residential location are accessibility to the centre and the minimising of the costs of friction, and considerations of the size of the site are excluded, all residence would be clustered around the centre of the city at a very high density." Alonso (1964, p. 9).