Wang, Y., & Baddeley, M. (2016). The problem of land value betterment: a simplified agent-based test. *Annals of Regional Science*, *57*(2-3), 413-436. https://doi.org/10.1007/s00168-015-0675-z

The Problem of Land Value Betterment: A Simplified Agent-based Test

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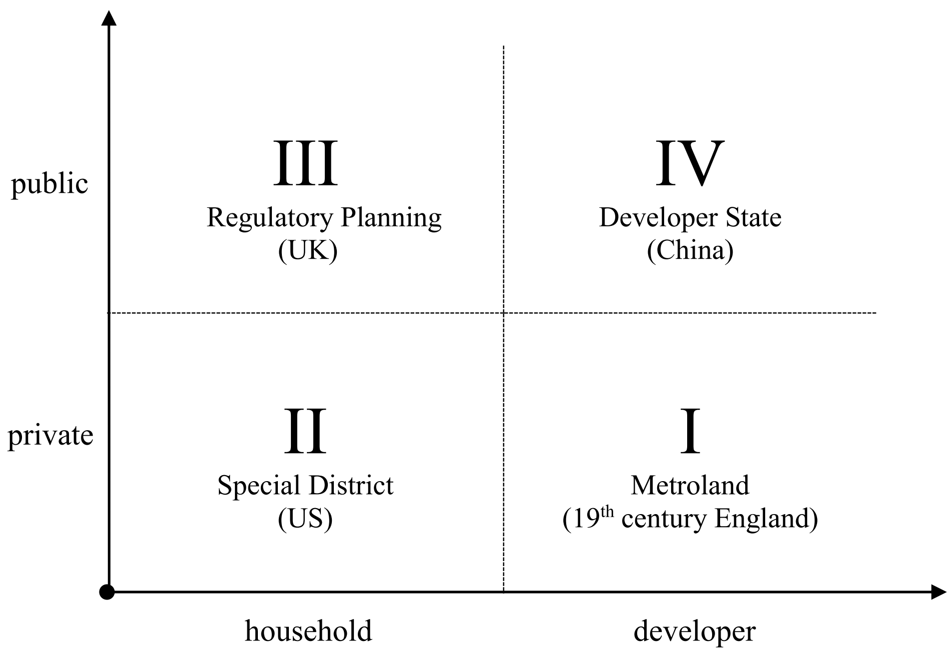
Abstract:
In this paper, we employ behaviour-driven cellular automata as a simplified agent-based modelling approach to test the seminal Coase Theorem, with a policy focus on the land value betterment effect of urban infrastructure provision. Four prototypical development regimes are identified from international practice: I) the private developer-oriented Metroland model dating back to the suburbanisation of London in the 19th century England; II) the private household-led special district model, which can be observed in many contemporary US suburbs; III) the public planning-regulated model, as featured in most post-war European welfare state countries, including the present-day UK; IV) the public state-as-developer model, which arguably characterises what has been taking place in China. A repeated ANOVA analysis based on the results of a large number of cellular automata simulations suggests no significant difference between models I and II in terms of their welfare outcomes measured by aggregate utility. However, models III and IV are both found to generate significantly less welfare than models I and II, under strict assumptions of zero transaction costs, perfect information, perfect capital markets and perfect competition.

Keywords: Infrastructure Development, Coase Theorem, Agent-based Modelling, Behaviour-driven Cellular Automata

Figure 1: A Dual Dichotomy of Land and Infrastructure Development



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1. Introduction

Land value betterment is a wide-reaching problem relating to many aspects of the built environment, especially physical and social infrastructures, including transportation links, schools and hospitals. These facilities often yield substantial positive economic externalities that are capitalised in local land values, potentially leading to land price rises. While the betterment effect is well-recognised in the literature, in practice there are different ways and diverse perspectives worldwide about how to deploy land value to fund infrastructure development (Peterson, 2009).

This paper provides a synoptic view of the problem of land value betterment and policy solutions building on Coasian approaches to the analysis of infrastructure development. Coase's (1960) insights about the problem of social costs highlighted divergences between private costs and social costs (and by extension divergences between private benefits and social benefits) and our analysis explores the impact of positive externalities on infrastructure development. An important policy question is whether or different allocations of ownership rights and development rights affect the final outcomes. In his own interpretation of Coase, Stigler (1989) popularised what is now known as "the Coase Theorem" (CT) - postulating that, regardless of the initial allocation of property rights, perfect markets will ensure that Pareto optimal allocations are achieved via a process of voluntary exchange. CT is based on assumptions of zero transaction costs, perfect information and fully allocated property rights. We will be exploring these insights in the context of infrastructure development and we identify four prototypical models of infrastructure development:

I. This model underpins the English history of suburbanisation in general and, in particular, the growth of Metroland as a northwest London suburb since the mid-19th century (Levinson, 2008). In this classic model, a private developer was entitled to and responsible for development. They invested initially in major infrastructures, such as railways, and later managed to recoup most of the cost by selling land or residential properties upon the land they had owned near the rail network.

II. A different version of privately funded infrastructure development, a present-day variant of the Metroland model, can be observed in many contemporary American suburbs, such as those around the city of Denver, Colorado (Billings and Thibodeau, 2013). This second model features an allocation of land development rights and financial duties directly to individual households, who fund the relevant local projects collectively by repaying a so-called special district bond through local property tax.

III. The third model arguably characterises the land use planning practice of many European welfare state countries, notably modern UK, where the right to develop infrastructure regulated and/or nationalized (Munoz-Gielen, 2014, Lee et al., 2012, Barlow and King, 1992). Yet the public sector in this case becomes obliged to subsidise the construction and maintenance of major infrastructures, mostly via general tax income and/or government debt instruments.

IV. Post-socialist China characterises the fourth model. Not only is the land development right, as in the European case, reserved to the eminent domain, but the Chinese state also constitutionally owns all of the urban land (National People's Congress, 2004: Article 10).[1] The government monopoly over the land market incentivises local authorities to play the role of private developer in the classic English model. This "developer state" pro-actively supplies infrastructure, in the expectation that they will accumulate profits in the future by leasing the nearby land plots with improved land value to private parties (Lichtenberg and Ding, 2009).

Focusing on these four prototypical models allows us to conduct a tractable international comparison and captures the intellectual and institutional diversity that characterises the analysis of land value betterment. To understand and compare the four models in more conceptual depth, we follow Webster and Wu (2001) by conducting a series of behaviour-driven cellular automata simulations as a simplified agent-based modelling approach (Batty, 2009), which enable us to identify differences in net welfare outcomes across four different land development right regimes. Our ANOVA analysis suggests that, in a spatially explicit game setting with zero transaction costs, the classic English and contemporary American models are associated with statistically significantly higher levels of welfare than their European (including modern UK) and Chinese counterparts. However, the ubiquity of transaction costs, imperfect/asymmetric information and principal-agent problems may explain why there are limits to real-world convergence in terms of welfare outcomes across the different systems: the real-world co-existence of different outcomes reflects varying local socio-political circumstances and institutions.

This paper is organised as follows. In the next section, we review the four models of land use and infrastructure development as documented in the recent literature. Following that, we present the design of our behavior-driven cellular automata as a simplified agent-based model, which is developed with an analytical framework designed around two dimensions that capture the four scenarios outlined above: public versus private ownership, and household versus government. A range of starting conditions are modelled including a chequerboard pattern to represent an even spread of households and developers and a further two simplified representations of common real-world spatial patterns of households versus developers: a monocentric pattern as a simplified representation of monocentricity in cities such as Shanghai and London; and a polycentric pattern, as a simplified representation of polycentric urban areas, e.g. as seen in many North American cities. The simulation results are reported and discussed before an exploration of the limitations and potential future refinements to our simple abstract model. The paper concludes with a discussion of some conclusions, policy implications and recommendations.

[1] On the other hand, all the land in Chinese countryside is owned by rural collectives as per the same article of the Constitution.

2. Four Models

Figure 1: A Dual Dichotomy of Land and Infrastructure Development

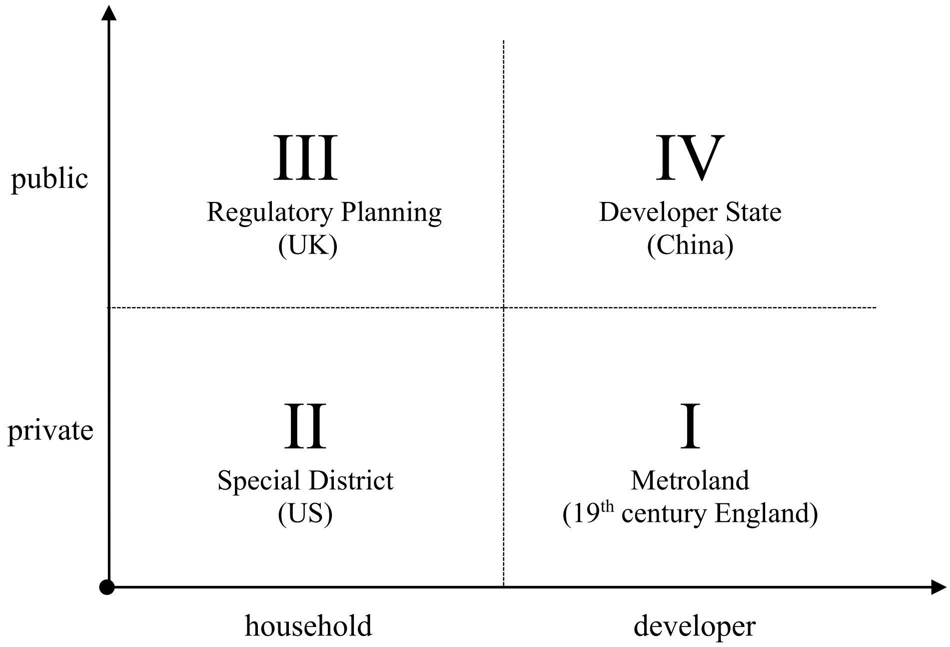


Figure 1 captures different models of land use and infrastructure development within a coordinate system. The horizontal axis measures the degree of professional developer's entitlement to initiate a development – with the origin characterising a scenario wherein the right to develop is purely vested with individual households. Likewise the vertical axis is a spectrum capturing the extent to which public entities, such as the state, can orchestrate developments. The origin hence signifies an absolute private control of the right to develop. Two dashed lines cut through, respectively, the midpoints of the two axes, dividing the Cartesian space into four quadrants and thus presenting a dual dichotomy. Note that the lines are dashed rather than solid, because the conceptual distinction between private versus public is inherently fuzzy (see eg Geuss, 2001), while there can certainly be occasions when a household and a developer agree to share rights based on mutual interests.

This schema extends a Coasian approach by allowing that interactions are driven not only by rights to initiate developments – which would ordinarily coincide with ownership – but also by rights to orchestrate or manage developments. In theory, this introduces the complication of principal-agent problems: if the owner and developer are separate entities then the property owner – who can initiate developments and will gain financially from infrastructure development – may not be able to trust their agent to deliver profitable improvements – this applies to I and IV where the householder divests some aspects of decision-making to a private or state developer. Given asymmetric information, opportunities for rent seeking by the developer agent, whether public or private, may reflect a complex range of motivations and opportunities depending on the contractual structures. In this analysis we abstract from these complications and, in the main analysis, will assume that there are no problems of incentive misalignment though in section 6 will analyse the implications of these problems for refinements of the model in later research.

2.1 The Metroland Model

A classic model of private developer-led land use, financing and infrastructure development, which features in much of the 19th century English history of residential suburbanization, is captured in Quadrant 1 of Figure 1 (Levinson, 2008). The story about Metroland is revealing. On 10 January 1863, the Metropolitan Railway was opened to the public and linked central London to the Middlesex countryside, some 15 miles northwest to the City of London. The Metropolitan Railway Company (referred to as "the Met" hereafter), originally set up in 1853, was and actually remained as a privately owned company until 1933 (Jackson, 1986). The Parliament had not only commissioned the Met to build the railway, but also allowed it to keep much of the surplus land after the construction (Levinson, 2008). Since the 1880s, while further extending the Metropolitan Railway northwest bound into the Middlesex hinterland, the Met had begun to pave roads, supply sewage and other civil infrastructures alongside the rail network, before selling the developed land plots to house builders. In 1919, the Met entered the housing market directly by establishing the Metropolitan Railway Country Estates Limited. The term Metroland was from then on coined in the company advertisements to appeal to the potential City customers who aspired to the picturesque rural English landscape and tranquil lifestyle. While few have managed to track down the exact figures of the Met's total investment in Metroland:

> "A comparison of the census returns for 1921 and 1931 shows a population increase of nearly 11% for Greater London as a whole, with a much higher rate of growth in the north west suburbs between five and ten miles from the centre. The Metro-land districts of Harrow, Ruislip-Northwood, Uxbridge and Wembley all experienced increases of more than 50%. In 1929 the Metropolitan Railway's Commercial Manager estimated that between 1919 and 1928 some 12,000 houses had been built within half a mile of the stations between Willesden Green, Uxbridge and Watford and that a further 17,000 were planned."(Green, 2004: Introduction)

2.2 The Special District Model

Quadrant II in Figure 1 captures the second model of development. This model differs subtly yet importantly from the Metroland model. While both represent privately funded infrastructure and land use development, in the second model the right and duty to develop are assigned to individual households instead of private developer. With potential negative externalities from development, this redistribution of property rights justifies compensation from the developer to the affected households (Webster and Wu, 2001). Analogously, in a mirror image scenario, where the development yields positive externalities, the homeowners are entitled to buy into the development directly rather than, as in the Metroland case, let the developer charge the households implicitly through an inflation of the property price (Brueckner, 1997, Billings and Thibodeau, 2013).

Self-organised local homeowner associations play an indispensable role in this context and have been a defining element of the contemporary US suburbanization (Teaford, 1997, Mckenzie, 1994). For instance, a recent paper by Billings and Thibodeau (2013) studies special district as a kind of spontaneous local homeowner association, based on a sample of circa 34,000 households near the city of Denver in the US state of Colorado. A special district in Colorado was formed voluntarily by a community of local households who opted collectively to issue development district bonds as a financing instrument for local infrastructure provision. Debts are to be repaid typically over a 30 year period through deductions from local property tax. According to Billings and Thibodeau (2013), for similar infrastructure conditions, the prices of comparable homes are significantly lower within the special districts than outside them.

2.3 The Regulatory Planning Model

Quadrant III captures the third development model. Like the special district model, it captures the primacy of local households in terms of "securing a decent home for everyone" (Town and Country Planning Association, 2009). However, this protection is not directly administered by the local community itself. Rather, public authorities act as the agents of local homeowners to regulate development, often based on formal land use planning laws. The problem with this approach is that, with asymmetric information, the incentives of the principals (homeowners) and their agents (public authorities) may be misaligned. Rent-seeking by public authorities may reduce consumer welfare. In either case, outcomes will be Pareto sub-optimal. Albeit to different extents, most European welfare state countries typically follow this model, for example France, Sweden and UK (Barlow and King, 1992).

In post-war UK, land development rights were not only separated from landownership, but were also *de facto* nationalised by the 1947 Town and Country Planning Act, which required almost every development proposal to go through a planning application process and to obtain a corresponding planning permission (Lee et al, 2012; Munoz-Gielen, 2014). These planning systems have contributed to the large and lumpy transaction costs that characterise the dysfunctionality of UK property markets. Nonetheless this planning control system has since then largely persisted in the UK, although the Barker review (2006) acutely criticised it for being too rigid and time-consuming, hence discouraging private sector involvement. As a practical result, the public sector has taken on a dominant role in financing infrastructure development, whether in the case of new town development (Cullingworth and Nadin, 2002), urban regeneration (Tallon, 2013, Jones and Evans, 2013), or most recently, the planned construction of high speed rail two to link southeast England with its northern counterpart (Tomaney and Marques, 2013). Government taxation and borrowing invariably constitute the major sources of public finance for those megaprojects (National Audit Office, 2013).

2.4 The Developer State Model

Quadrant IV in Figure 1 is perhaps the most intriguing development model. On one hand, it resembles the Metroland case in terms of prioritising the developer's right to develop. On the other hand, it is similar to the European regulatory planning system of command

and control. Significantly, this model perhaps reflects what has happened in the post-socialist China since the early 1980s.

The Chinese government is often considered to be a typical "developmental state" (Johnson, 1995, White, 1988) because it tries actively to intervene in markets ostensibly to promote economic growth (Xia, 2000, Zhu, 2004). For example, the central authority in Beijing aims to construct, by 2015, a total of 45,000 km of high-speed railways and 83,000 km of national highway network to support a target urbanisation rate of 51.5% measured by population (National People's Congress, 2011). These projects are to be funded mostly by direct fiscal investment, as in the case of a recently released $586 billion stimulus package to mainly finance public transport infrastructures, such as high-speed electric rail links (Batson, 2008).

An important reason for the Chinese government's proactivity in infrastructure development lies in the country's land tenure system. According to Article 10 of the Constitution, all of the land in urban China belongs to the state while land in the countryside belongs to the rural collectives (National People's Congress, 2004). Article 43 of Land Management Law further restricts almost all types of non-agricultural development to state-owned land (National People's Congress, 1998). This means in practice that any collectively owned rural land plots have to be expropriated by the state before they can be legally developed. These laws enable the Chinese state to monopolise the land market and to easily accumulate surplus profits by developing the infrastructure, raising the land value, and then leasing the land to private house builders (Deng and Huang, 2004, Wu et al., 2012, Lichtenberg and Ding, 2009, Wang, 2014). In this sense, the developmental Chinese state is actually playing the role of private developer in the Metroland model and is therefore a form of developer state.

2.5 A Synoptic Approach

The four models of development, alongside the entire dual dichotomy presented in figure 1, can be understood within a Coasian framework as popularised by Stigler as the Coase Theorem (CT) – described by Blaug as "nothing but the first fundamental welfare theorem in disguise" (Blaug 2007, p.200).[2] A comparison of outcomes from these different models is a test of the CT. If CT holds, then it should not matter which Quadrant describes reality –if rights are fully allocated and freely exchanged and if free exchange is unimpeded by the economic friction of transaction costs then, according to CT, markets will ensure that the outcome is Pareto optimal. The allocation of property and development rights, whether to the developer or household, should not affect welfare. CT is also dependent on an assumption of perfect information – as mentioned above, in the presence of imperfect information and more importantly asymmetric information, divergences in rights of ownership and rights to develop will generate principal agent problems where the agent developer is able to opportunistically exploit their informational advantages in a way that does not achieve the principal's goals – namely to maximize the value of their land.

[2] Stigler's interpretation is not necessarily true to Coase's original insights - see Coase's (1992) response to Stigler.

In their analysis of CT, Webster and Wu (2001) use cellular automata to emulate a spatial pricing system involving negative externalities due to environmental pollution and concluded that the British system delivered a better pattern of land use than other systems. They found mixed evidence in support of CT – different allocations of property rights had the same partial equilibrium impacts but their results also showed that the allocation of property rights had an impact on the global equilibrium – in contradiction to the CT. They concluded that social welfare is greater when communities hold development rights. Their model was limited because it contained two private parties – the developers and the households – thus essentially dealing only with the horizontal dichotomy in our figure 1. We introduce two innovations into the Webster-Wu methodology: firstly by exploring a different though analogous scenario with regard to the problem of land value betterment as an instance of positive externalities; and secondly by introducing two more types of actors or agents – *viz.* a planning regulator and a developer state – whose intervention behaviours are implanted directly into the cellular automata simulation, making it essentially a simplified agent-based model (Batty, 2009).

3. Behaviour-driven Cellular Automata

Webster and Wu's (2001) cellular automata approach was developed in more recent publications (e.g. Benenson et al. 2009, Grauwin et al. 2009, Panc and Vriand 2007, Heikkila and Wang, 2009, Wang, 2013) and it suggests an innovative method for capturing the interactions between private choices and public institutions. This stream of research typically involves the application of a suite of bottom-up computational modelling techniques, such as cellular automata and agent-based simulation, for the purpose of emulating an artificial socioeconomic system with discrete spatial and temporal units, often based on some quintessential assumptions about human behaviour (Batty, 2007). In this paper, we set up a stylized behaviour-driven cellular automata model as a simplified agent-based simulation approach to study the four prototypes of land use and infrastructure development as mentioned above. The specific modelling procedures are elaborated below as well as illustrated in the appended flowchart.

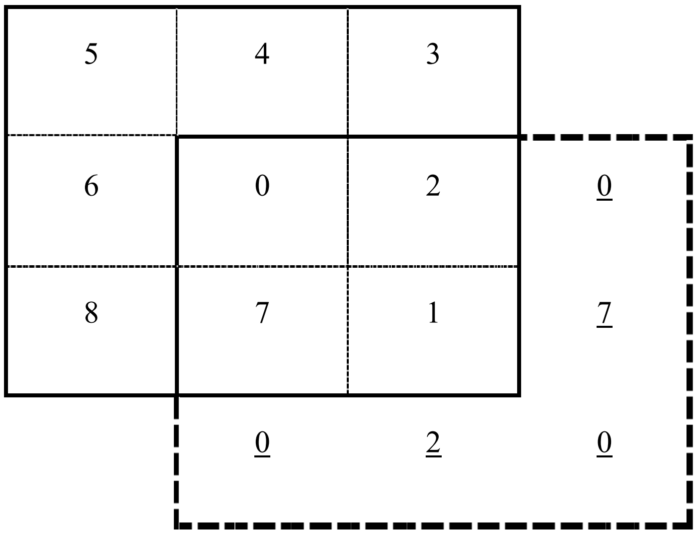
3.1 Moore Neighbourhood in a City State

We assume that there is a city state[3] which consists of an overseeing bureaucracy (*B*) and a population of citizens who live within a specifically delineated urban boundary. This spatial structure can be analysed as a Moore Neighbourhood – a central cell with 8 neighbourhood cells. Overall, the urban space contains $N \times N$ cells as land units, available either for housing or infrastructure development, although no land is allowed to be left vacant. A citizen may either join a firm (*D*) as an employee to develop local infrastructure or stay at home as a member of a resident household (*H*). The size of every *D* versus every *H*, in terms of population, is exactly the same. Every *D* faces a risk of dissolution and, when that happens, must release employees to make up a new household – *H*. *Vice versa*, an *H* may register to become a new *D* given favourable business conditions.

[3] City-states as an urban form have existed since ancient Greek, for example Athens and Sparta (see eg Fine, 1983)

In terms of land use, every unit of land or cell must be occupied by either a *D* or *H* at any one time. Whether a *D* or *H* takes up a cellular land plot, it considers its neighbourhood as made up of the immediately surrounding eight cells. For example, whoever occupies cell 0 in figure 2 only sees a Moore neighbourhood that contains cells 1 to 8 altogether. Conceivably, if a *D* or *H* happens to be located in the city periphery, it may have less than eight neighbours due to boundary constraint, for the example of cell 1 in figure 2. In that circumstance, a mirror image of cell 1's physical neighbourhood (i.e. cells 0, 7 and 2) would be projected onto wherever necessary (i.e. cells 0, 7, 2) so as to make up a virtual Moore neighbourhood.

Figure 2: An Illustration of Moore Neighbourhood



3.2 Household and Developer Utility Functions

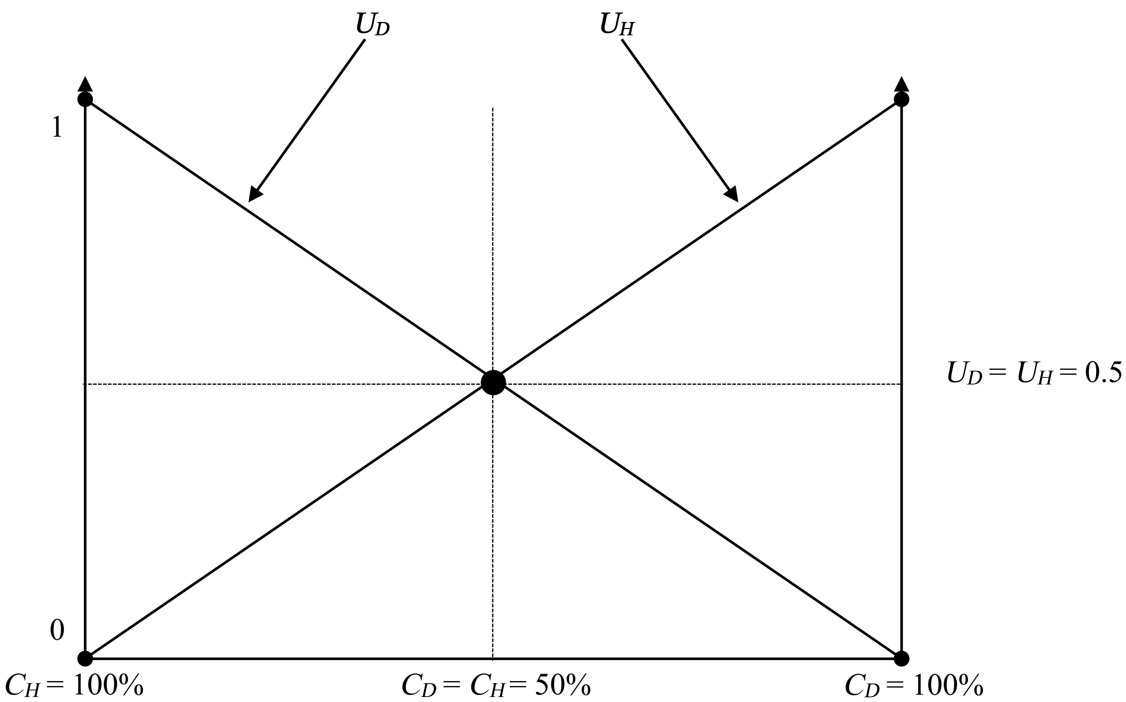
Equation [1] characterises this preference by showing that a developer's utility (U_D) has a maximum of 1 and is perfectly and negatively correlated with the percentage of developer population (C_D) in its neighbourhood. We also assume a profit maximizing developer and so U_D is perfectly correlated with profits. Each *D* would prefer to move into a neighbourhood where infrastructure is undersupplied and where its production can be more favourably priced generating greater profits. This will reflect relatively large marginal productivity of capital when capital is relatively scarce and/or a greater willingness to pay from consumers because the marginal utility from consumption of scarce infrastructure is relatively large. In other words, U_D equates to the relative composition of resident households (C_H), given $C_D + C_H = 1$. Likewise, equation [2] describes the preference structure (U_H) of a resident household (*H*). An *H* would prefer to live in a neighbourhood with fewer other families to avoid congestion or, in another way of thinking, to have more developer neighbours so that a relatively cheaper local infrastructure provision will be readily available.

$$U_D = 1 - C_D = C_H \quad [1]$$

$$U_H = 1 - C_H = C_D \quad [2]$$

Figure 3 illustrates a local partial equilibrium condition between the two types of actors. The equilibrium takes place when a neighbourhood is perceived to contain an equal number of developers versus resident households, leading to an equality in terms of the utility outcome, i.e. $U_D = U_H = 0.5$ and therefore no tendency to move.

Figure 3: A Local Partial Equilibrium between *D* and *H*



3.3 Private Land Bidding

Every cellular location will be allocated to either a *D* or *H* throughout a bidding process. Nothing prevents *de jure* bidding between two developers, for example. However, since all of the *D*s can only be differentiated spatially and are identical otherwise, a bidding game within the developers group would not make a difference. The same logic applies to any households. In a nutshell, the bidding is all about competition between *D* and *H*.

In a perfectly competitive market with zero transaction costs, the maximum bid an actor can offer would be equal to the maximum utility it could achieve at a target location. The price of land thus depends on its highest use value, which conforms to Ricardo's (1891) classic theoretical assertion. From equations [1] and [2], it is evident that $U_D + U_H = 1$. Therefore, if a developer has a utility of less than 0.5 upon location *i* at time *t*, it will be outbid by a household who expects to be better off at the same location. In that case, the firm has to be replaced by a household. Thus $s^{i,\,t+1}$, which stands for the state of location *i* at time *t + 1,* can be predicted accordingly as per equation [3]. The same logic applies to a household who cannot make a utility of 0.5 upon location *i* at time *t*. They will either be relocated by a developer or become a developer themselves in order to retain the land at time *t + 1*.

$$s^{i,t+1} = \begin{cases} \{D \mid U_D^{i,t} > 0.5\} \\ \{D \mid U_D^{i,t} = 0.5; I\} \\ \{H \mid U_H^{i,t} = 0.5; II\} \\ \{H \mid U_H^{i,t} > 0.5\} \end{cases} \quad [3]$$

There is conceivably a draw when $U_D^{i,t} = U_H^{i,t} = 0.5$. Two of the aforementioned four models of infrastructure and land use development become relevant here. Specifically, in a Metroland scenario (noted as scenario *I* in equation [3]), a household has to give way to a developer, even if the two are making equivalent bids for a same location. This is because the developer has a privileged right to develop in this case. Analogously, in a special district scenario (i.e. scenario *II* in equation [3]), a household always displaces a developer, because this time the former has a priority to develop without having to involve the latter.

3.4 Public Interventions

An overarching bureaucracy (*B*) is allowed to intervene in the land market. *B* is capable of knowing the utility/land value gains and losses of each and every developer (*D*) and household (*H*) at any one time, *t*. μ_t in equation [4] measures the average household utility at time *t* across the city, with n_H^t denoting the total number of households within *B*'s jurisdiction. Likewise, η_t in equation [5] gauges the mean developer utility, while n_D^t counts the development firms. A weighted average of μ_t and η_t gives ψ_t, the mean utility of the entire city (see equation [6]). ψ_t may be understood as a measure of the city's overall land use efficiency reflecting its level of aggregate welfare.

$$\mu_t = \left\{ \sum_{i=1}^{n_H^t} U_{s^{i,t}}^{i,t} / n_H^t \mid s^{i,t} = H \right\} \quad [4]$$

$$\eta_t = \left\{ \sum_{i=1}^{n_D^t} U_{s^{i,t}}^{i,t} / n_D^t \mid s^{i,t} = D \right\} \quad [5]$$

$$\psi_t = (\sum_{i=1}^{n_H^t} \mu_t + \sum_{i=1}^{n_D^t} \eta_t) / N^2 \quad [6]$$

B also has the authority to reverse any transactions that it deems undesirable. However, its actual interventions can follow two different fashions, which correspond respectively to the European regulatory planning system (*III*) and the Chinese developer state model

(IV). In the former case, B attempts to ensure that the average household utility does not decline after a single market transaction, or in other words, acts to rule out any potential welfare loss for any households

Equation (7) formally defines this rule, with $\tau^{i\leftrightarrow j,t\rightarrow t+1}$ assessing the impact of a potential land use change from $s^{i,t}$ to $s^{i,t+1}$, with respect to another household on cell j ($j \neq i$). $\tau^{i\leftrightarrow j,t\rightarrow t+1} > 0$ if, for instance, a developer replaces a first household in location i, which is a location within the neighbourhood of a second nearby household in location j. Positive externalities in the form of land value betterment arise in this case, because the second household essentially enjoys a positive spill-over effect from a private transaction which only involves its neighbour. The reverse happens, if a household is going to displace a developer on cell i and thus $\tau^{i\leftrightarrow j,t\rightarrow t+1} < 0$, leading B, the public authority, to call off the deal as per equation [7].

$$\mu_{t+1} = \mu_t + \sum_{j=1}^{n_H^t} \sum_{i=1}^{n_H^t} \tau^{i\leftrightarrow j,t\rightarrow t+1} / n_H^t \text{, only if, } \tau^{i\leftrightarrow j,t\rightarrow t+1} \geq 0 \qquad [7]$$

$$\Rightarrow \mu_{t+1} \geq \mu_t \forall t$$

$$\eta_{t+1} = \eta_t + \sum_{j=1}^{n_D^t} \sum_{i=1}^{n_D^t} \sigma^{i\leftrightarrow j,t\rightarrow t+1} / n_D^t \text{, only if, } \sigma^{i\leftrightarrow j,t\rightarrow t+1} \geq 0 \qquad [8]$$

$$\Rightarrow \eta_{t+1} \geq \eta_t \forall t$$

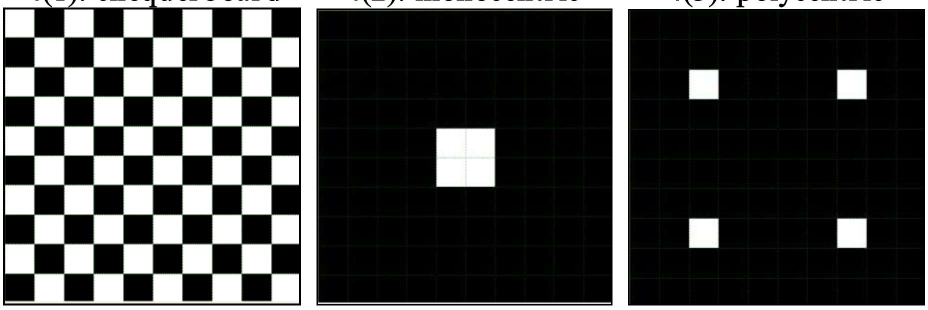
Equation [8] is the counterpart of equation [7], if B follows a Chinese developer state model (IV). Equation [8] differs from equation [7] only in that, this time, the aim of intervention is to assure a never declining welfare for every developer instead of household.

3.6 Initial Patterns

Given the stepwise nature of cellular automata, we need to initiate a geographic distribution of developers (Ds) versus households (Hs) within the artificial city. In our model, we experiment with two different sets of initial conditions. For the first set of initial conditions the simulation begins from a starting pattern analogous to general equilibrium with the local equilibria depicted in figure 3 holding everywhere in the city, as illustrated in figure 4. It is readily clear that, given this kind of checkerboard pattern, $U_D^{i,0} = U_H^{i,0} = 0.5 \forall i$. Our interest is to see whether this general equilibrium would be sustained under four different regimes of land use and infrastructure development. In the second instance (not illustrated), we represent disequilibrium starting conditions by populating the $N \times N$ cells with a random number of Ds and Hs in a random spatial distribution pattern. Note that the number of Ds versus Hs may well change during the course of simulation, depending on the results of the location bidding process.

Figure 4: Three Initial Starting Patterns (N=10, t = 0, H in black, D in white)

4(1): chequerboard 4(2): monocentric 4(3): polycentric



The initial starting patterns shown in Figure 4 are included as simplified representations/caricatures of a balanced pattern versus common real-world urban patterns. The chequerboard pattern in Fig 4(1) represents a balanced spread of households and developers and a spatial equilibrium condition with a total welfare of $\psi_0(1) = 0.5$. The other two images are simplified representations of common real-world spatial patterns of household versus developers: Fig 4(2) is a monocentric pattern, a simplified representation of monocentricity in cities such as Shanghai and London and in welfare terms is sub-optimal, with $\psi_0(2) = 0.05$; Fig 4(3) is a polycentric pattern, a simplified representation of polycentric urban areas with an intermediate level of welfare $\psi_0(3)$=0.08, e.g. as seen in many North American cities.

3.7 Stopping Conditions

We also define the following stopping conditions for our simulations. Over the course of every simulation, we track the change in average aggregate utility (ψ_t) and stop a simulation when value of ψ_t remains constant for N iterations (see equation [9]). Otherwise, a simulation should also stop after a sufficiently large number of iterations, which equals to the total number of cells, $N \times N$, as involved in this model.

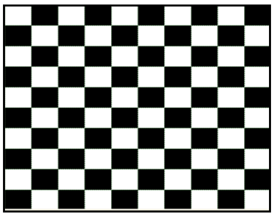
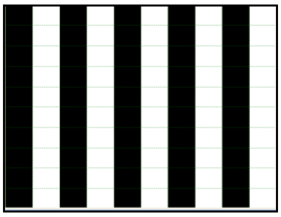
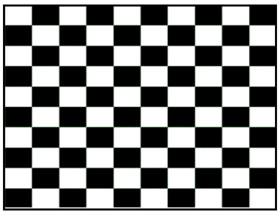
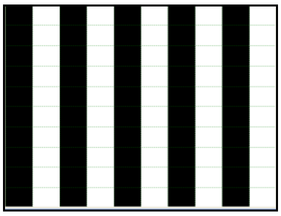
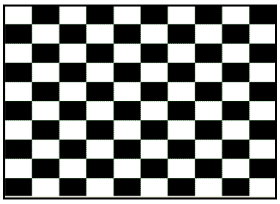
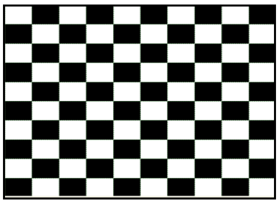
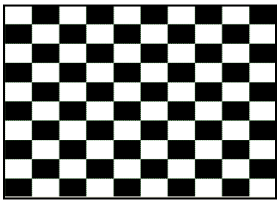
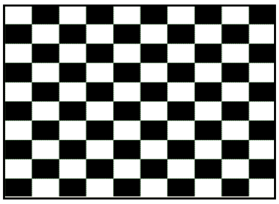
$$\psi_{T+N} = \psi_{T+N-1} = \dots = \psi_T \qquad [9]$$

4. Simulation Results

4.1 Simulations beginning from one Equilibrium Condition

Four simulations are conducted, using the software package of Visual Basic. The simulations began from the same three equilibrium starting conditions as shown in figure 4. Table 1 presents the simulation results from the chequerboard starting pattern represented in Fig 4(1). The first two simulations respectively follow the Metroland model as in scenario *I* and the development district model as in scenario *II*. In the both simulations, private transactions are free to proceed without any interference from the public sector, unless when there is a draw bid, in which case the rule of the game either favours a developer in the first model or a household in the second one. Notwithstanding this subtle difference between the two models, they quickly reach the same final pattern as indicated in table 1. It takes two iterations in the first simulation while just one step in the second simulation to find an identical new general spatial equilibrium. This new equilibrium yields an average utility that is 0.25 units higher than in the initial conditions i.e. an increase of 50% - hence achieving a higher level of welfare from overall land use than in the original condition.

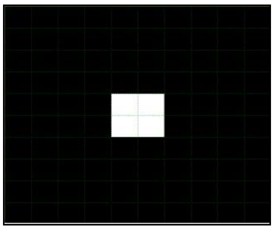
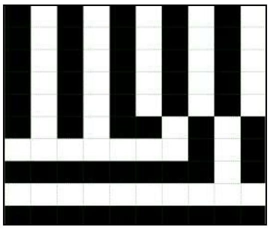
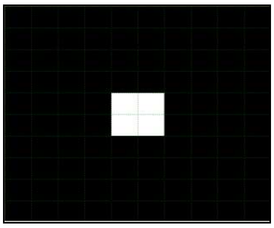
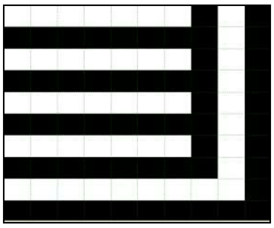
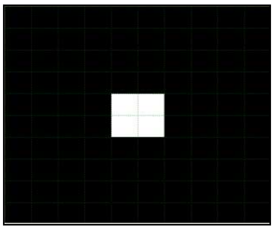
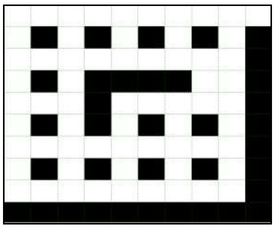
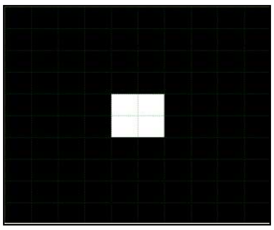
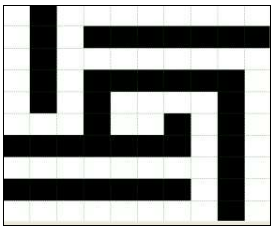
Table 1: Simulation Outcomes from a General Equilibrium ($N = 10$)

Scenario	Initial Pattern ($t = 0$)	Final Pattern ($t = T$)	$\psi_0(1), \mu_0(1), \eta_0(1)$ vs. $\psi_T(1), \mu_T(1), \eta_T(1)$
I		 ($T = 12$)	$\psi_0(1) = \mu_0(1) = \eta_0(1) = 0.5$ vs. $\psi_{12}(1) = \mu_{12}(1) = \eta_{12}(1) = 0.75$
II		 ($T = 11$)	$\psi_0(1) = \mu_0(1) = \eta_0(1) = 0.5$ vs. $\psi_{11}(1) = \mu_{11}(1) = \eta_{11}(1) = 0.75$
III		 ($T = 10$)	$\psi_0(1) = \mu_0(1) = \eta_0(1) = 0.5$ vs. $\psi_{10}(1) = \mu_{10}(1) = \eta_{10}(1) = 0.5$
IV		 ($T = 10$)	$\psi_0(1) = \mu_0(1) = \eta_0(1) = 0.5$ vs. $\psi_{10}(1) = \mu_{10}(1) = \eta_{10}(1) = 0.5$

In contrast, both the third and fourth simulations involve public interventions in the land market, albeit following, respectively, a regulatory planning (*III*) versus developer state (*IV*) fashion. It is clear from table 1 that, in the both simulations, the initial equilibrium condition has withstood since the beginning. In the third simulation, B as a regulatory planner prohibits any infringement upon household interest. This kind of strict planning control, in effect, stablises the original equilibrium and makes it unchangeable. Likewise, the developer state in the fourth simulation tries to protect the interest of every developer.

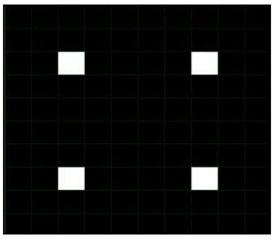
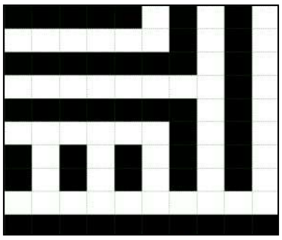
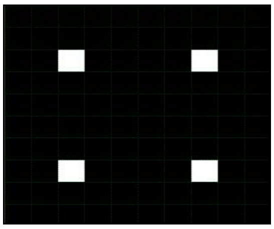
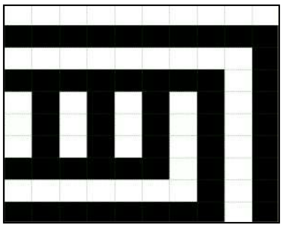
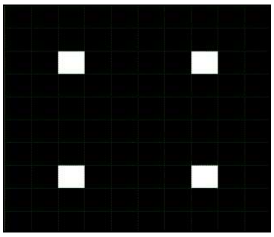
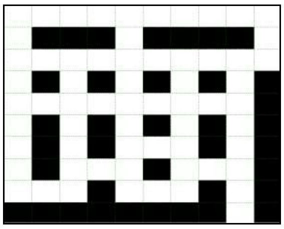
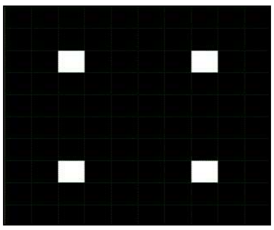
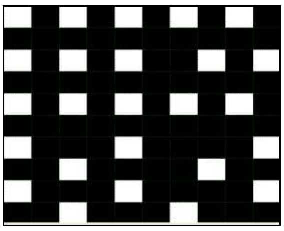
As a result, these systems are locked into equilibrium conditions associated with lower levels of utility and welfare.

Table 2: Simulation Outcomes from a Monocentric Starting Condition ($N = 10$)

Scenario	Initial Pattern ($t = 0$)	Final Pattern ($t = T$)	$\psi_0(2)$, $\mu_0(2)$, $\eta_0(2)$ vs. $\psi_T(2)$, $\mu_T(2)$, $\eta_T(2)$
I		 ($T = 13$)	$\psi_0(2) = 0.050$ $\mu_0(2) = 0.026$ $\eta_0(2) = 0.625$ vs. $\psi_{13}(2) = 0.715$ $\mu_{13}(2) = 0.738$ $\eta_{13}(2) = 0.690$
II		 ($T = 19$)	$\psi_0(2) = 0.050$ $\mu_0(2) = 0.026$ $\eta_0(2) = 0.625$ vs. $\psi_{19}(2) = 0.723$ $\mu_{19}(2) = 0.695$ $\eta_{19}(2) = 0.756$
III		 ($T = 10$)	$\psi_0(2) = 0.050$ $\mu_0(2) = 0.026$ $\eta_0(2) = 0.625$ vs. $\psi_{10}(2) = 0.556$ $\mu_{10}(2) = 0.816$ $\eta_{10}(2) = 0.410$
IV		 ($T = 12$)	$\psi_0(2) = 0.050$ $\mu_0(2) = 0.026$ $\eta_0(2) = 0.625$ vs. $\psi_{12}(2) = 0.695$ $\mu_{12}(2) = 0.729$ $\eta_{12}(2) = 0.672$

In Table 2, the simulation outcomes from monocentric starting condition, as illustrated also in Figure 4(2), are shown. The welfare gains relative to a monocentric are similar to those from the chequerboard pattern, but in relative terms the changes in welfare are magnified relative to the chequerboard starting conditions, with the final total welfare outcomes ranging between 0.556 to 0.723 (versus 0.5 to 0.75 for the chequerboard pattern). This reflects the fact that the final patterns are consistent with a more even distribution of households and developers relative to the initial monocentric pattern, and the welfare gains are greatest for scenarios I and II.

Table 3: Simulation Outcomes from a Polycentric Starting Condition ($N = 10$)

Scenario	Initial Pattern ($t = 0$)	Final Pattern ($t = T$)	$\psi_0(3)$, $\mu_0(3)$, $\eta_0(3)$ vs. $\psi_T(3)$, $\mu_T(3)$, $\eta_T(3)$
I		 ($T = 14$)	$\psi_0(3) = 0.080$ $\mu_0(3) = 0.042$ $\eta_0(3) = 1.000$ vs. $\psi_{14}(3) = 0.699$ $\mu_{14}(3) = 0.763$ $\eta_{14}(3) = 0.639$
II		 ($T = 12$)	$\psi_0(3) = 0.080$ $\mu_0(3) = 0.042$ $\eta_0(3) = 1.000$ vs. $\psi_{12}(3) = 0.705$ $\mu_{12}(3) = 0.660$ $\eta_{12}(3) = 0.758$
III		 ($T = 10$)	$\psi_0(3) = 0.080$ $\mu_0(3) = 0.042$ $\eta_0(3) = 1.000$ vs. $\psi_{10}(3) = 0.590$ $\mu_{10}(3) = 0.794$ $\eta_{10}(3) = 0.470$
IV		 ($T = 10$)	$\psi_0(3) = 0.080$ $\mu_0(3) = 0.042$ $\eta_0(3) = 1.000$ vs. $\psi_{10}(3) = 0.460$ $\mu_{10}(3) = 0.280$ $\eta_{10}(3) = 1.000$

In Table 3, the simulation outcomes from polycentric starting condition (as illustrated also in Figure 4(3), are shown. The welfare gains relative to a chequerboard pattern are similar to the monocentric starting pattern models. In relative terms the changes in welfare are magnified relative to the chequerboard starting conditions, with the final total welfare outcomes ranging between 0.46 to 0.709 (versus 0.5 to 0.75 for the chequerboard pattern). Similarly to the monocentric starting pattern results, the final patterns suggest a more even distribution of households versus developers in comparison with the polycentric starting pattern, again with the greatest gains for scenarios I and II.

4.2 A Statistical Analysis of Random Simulation Results

Whilst the findings reported in table 1 could partly be worked out in a classic and elegant analytical fashion (Hotelling, 1929), running a modern computational model with modern computing power and speed bestows an advantage in terms of easily generating a large volume of data for inferential statistical analysis. [4] In the case of this paper, we are particularly interested to know whether there is a generalisable difference in the welfare outcomes – defined in terms of maximum utility - between the four prototypical models of land use and infrastructure development. If there is a significant difference then this suggests that the Coase Theorem does not hold and explanations may reflect various forms of market failure.With that question in mind, we experiment with samples of 100 simulations. Each set contains four different automation procedures, which correspond respectively to four distinct development scenarios (I, II, III, IV), but all of the four procedures start from a same initial land use pattern generated randomly by a computer, including though not limited to the three possibilities shown in Figure (4). Because each of the 100 series of simulations produces data independently and randomly with an *IID* error structure, the simulation results can be used directly for some standard inferential statistical tests.

Table 4: Sampled Final Welfare Outcomes across Four Scenarios

Scenario	Mean ψ_T	Std. Deviation	N
I	.7032	.01941	100
II	.7070	.01790	100
III	.6820	.01967	100
IV	.6779	.02480	100

Table 4 reports the descriptive statistics about a sample of 400 observed final efficiency outcomes (ψ_T), with 100 for each of the four development models (I, II, III, IV). A one-way repeated ANOVA (analysis of variance) suggests that at least one of the four development scenarios tend to have a significantly different population mean of ψ_T compared with the other three (see Table 5).

[4] In theory, a superpower computer can conduct a sufficiently large number of automations which would exhaust all of the possible combinational outcomes. In practice, we just need to test a sample of the underlying population to infer the general differences.

Table 5: Results of a Repeated Measure One-Way ANOVA

Effect	Value	F	Hypothesis df	Error df	p value	Partial Eta Squared
Pillai's Trace	.642	58.029	3.000	97.000	.000	.642
Wilks' Lambda	.358	58.029	3.000	97.000	.000	.642
Hotelling's Trace	1.795	58.029	3.000	97.000	.000	.642
Roy's Largest Root	1.795	58.029	3.000	97.000	.000	.642

Table 6 further presents the results of a pair-wise LSD (least significant difference) comparison regarding ψ_T. It is readily clear that the Metroland and development district models appear to be associated with significantly higher levels of welfare than the regulatory planning and developer state models. Nevertheless, a significant difference is observed neither between the two private nor the two public development models. In this sense, the private-public differentiation along the vertical axis in figure 1 seems to matter more than the horizontal distinction between household versus developer.

Table 6: Pairwise Comparison Between I, II, III, IV

					95% Confidence Interval for Difference[a]	
(L)	(R)	Mean Difference in ψ_T (L - R)	Std. Error	p value[a]	Lower Bound	Upper Bound
I	II	$-.004^{*}$	.002	.076	-.008	.000
	III	$.021^{***}$	.003	.000	.016	.026
	IV	$.025^{***}$	.003	.000	.019	.031
II	I	$.004^{*}$	.002	.076	.000	.008
	III	$.025^{***}$	.002	.000	.020	.030
	IV	$.029^{***}$	.003	.000	.023	.035
III	I	$-.021^{***}$	.003	.000	-.026	-.016
	II	$-.025^{***}$	.002	.000	-.030	-.020
	IV	.004	.003	.193	-.002	.010
IV	I	$-.025^{***}$	.003	.000	-.031	-.019
	II	$-.029^{***}$	.003	.000	-.035	-.023
	III	-.004	.003	.193	-.010	.002

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

(L)	(R)	Mean Difference in ψ_T (L - R)	Std. Error	p value[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
I	II	-.004*	.002	.076	-.008	.000
	III	.021***	.003	.000	.016	.026
	IV	.025***	.003	.000	.019	.031
II	I	.004*	.002	.076	.000	.008
	III	.025***	.002	.000	.020	.030
	IV	.029***	.003	.000	.023	.035
III	I	-.021***	.003	.000	-.026	-.016
	II	-.025***	.002	.000	-.030	-.020
	IV	.004	.003	.193	-.002	.010
IV	I	-.025***	.003	.000	-.031	-.019
	II	-.029***	.003	.000	-.035	-.023
	III	-.004	.003	.193	-.010	.002

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

* Mean differences significant with a 10% significance level

*** Mean differences significant with a 1% significance level

5. Discussion of Results

Unlike Webster and Wu (2001), we find our results partly conform to the CT. Our analysis, though based on a similar behaviour-driven cellular automata approach to that used by Webster and Wu (2000), confirms that the allocation of development right to specific private parties, whether a developer or a household, tends not to affect the overall welfare outcomes as long as transaction costs are zero. We show, given some strict assumptions, that outcomes consistent with CT hold not just for negative externalities but also when land value betterment is associated with endogenously driven positive externalities generated from changing spatial patterns of developers versus households. On the other hand, our study suggests that public sector intervention in which development rights are allocated to special interest groups is associated with significantly lower levels of welfare in our simulations. This adds weight to analyses of the detrimental impacts of rent-seeking in a broader context.[5] In a methodologically similar study, Wang (2013) also shows that even a regulatory effort in directly optimising the aggregate utility (ψ_T) would incur efficiency losses, mainly because of the public

[5] For example see Murphy *et al.* (1993).

institution's myopic behaviour when it attempts to interfere with a path-dependent market adjustment. The same problem also confronts the public authority (*B*) emulated in our model. Although *B* seems "omniscient" in the sense of being able to foresee the outcomes of every transaction at any one time, the intervener is actually incapable of forecasting a future after multiple iterations of private bidding in the market. Therefore, in a repeated game setting with zero transaction cost, there is no welfare justification for conventional government intervention in this model. However, policy making in practice must take into consideration the ubiquity of transaction costs and other market failures in the real world.

The implications of these modelling results for land value betterment in the real world are that a more even distribution of households and developers is associated with higher levels of welfare overall, and these gains are particularly pronounced when the initial distribution is monocentric or polycentric, as is the case for many large cities in the modern world. The range of modelling outputs highlights some of the real world implications - chequerboard starting pattern illustrates in some sense an ideal, a benchmark against which the monocentric and polycentric patterns can be explained, and in terms of the different scenarios. The range of representations of starting patterns, as illustrated in Figure 4 (1)-(3) illustrate how welfare gains from a simple competitive bidding process will be particularly pronounced for scenarios I and II with monocentric and polycentric starting patterns. These findings suggest that the perverse incentives and other market failures that will tend to characterise scenarios III and IV are associated with lower welfare outcomes than in scenarios I – Metrodland and II – Special Districts. Assuming that these findings from the simplified representations outlined here are paralleled in the real world, then the design of better planning policies to ensure that these problems are reduced or eliminated, will lead to better outcomes.

6. Limitations and Potential Refinements

For real-world urban land use policy regimes, there is a wide diversity of economic strategies to deploy land value for infrastructure development (Andelson, 2000, Dye and England, 2010, Peterson, 2009). Almost all of them could arguably be categorised into one of the four quadrants in figure 1 at the outset of this paper. The analysis presented here has however been conducted on the basis of some restrictive economic assumptions, the most important of which are implicit assumptions about perfectly competitive market structures with no opportunities for rent-seeking; perfect, symmetric information, zero transaction costs, and no financing constraints. In addition, the assumption of no vacant land does not rest well with the real-world experience of vacant land in urban settings – too expensive to redevelop because of demolition and site preparation costs. This section will focus on some of the implications of the restrictive economics assumptions.

6.1 Imperfect Competition and Rent-Seeking

The analysis above has assumed perfect competition with many developers and householders. In reality, infrastructure development involves significant monopolistic practices – dominated by large companies – often working with framework agreements and lists of preferred suppliers. Whilst marginal costs are often low, large sunk costs lead to high and falling average costs which means that minimum efficient scale is achieved only at high levels of provision. Thus the even equilibration seen in perfect competition models is unlikely to apply in this case. Imperfect competition also generates opportunities for rent-seeking behavior and these are likely to have profound negative welfare implications at both a microeconomic level, and at macroeconomic level – as explored by Murphy, Shleifer and Vishny (1993).

6.2 Imperfect/Asymmetric Information and Principal-Agent Problems

These models of land use betterment – particularly in the case of scenarios falling into quadrants I and III - may be associated with a divorce of ownership and control because the owners versus developers are different agents. The householder is the principal but, whether voluntarily or not, is relying on an agent to implement infrastructure developments. When the householder is reliant on an agent who has no financial stake or opportunity to profit from land value betterment, then those agents will have an incentive to shirk – creating a moral hazard problem. In addition, there may be adverse selection problems if the true quality of developments is unobservable to the householder – the quality of infrastructure is prone to quality uncertainty. In this way problems of asymmetric information and related principal-agent problems could profoundly change the outcomes.

6.3 Transaction Costs and Lags

The CT is dependent on an assumption of zero transaction costs and, in the case of land value better, perhaps more than for other activities, is prone to large and persistent transaction costs. Planning regulations involve large financial and other opportunity costs associated with the time and effort spent in resolving administrative and bureaucratic burdens. There will also be adjustment costs associated with decision-making, financing, search costs and a wide range of other costs. All these will slow down the efficient operation of markets and will also open up further opportunities for rent-seeking behaviours. Transaction costs are exacerbated by a wide range of lags that slow any investment activity but are likely to be particularly pronounced for complex infrastructure developments – including planning lags, decision-making lags, financing lags, time-to-build and other adjustment lags and costs.

6.4 Financing Constraints

The analysis above has implicitly assumed that finance is available but the availability, type and cost of finance will have implications for real-world outcomes. A key issue relating to the availability of finance is public-private finance. Private finance initiatives are prone to problems of uncertainty and risk-avoidance, particularly in unstable financial times. Speculative property bubbles exacerbate the volatility of private finance availability. For type of finance – mainstream financial theory embeds the Modigliani-Miller assumption of financial neutrality: with perfect capital markets the costs of all types of finance – whether equity, bonds, bank loans and/or retained profits - should equilibrate in a process of arbitrage. In reality different types of financing incur different costs and problems of asymmetric information will mean that different forms of financing may be read as signals of financial health – with implications for the ease with which finance can be found. Public finance generates problems too and, especially in times of fiscal austerity, public finance will not be easy to find and will also be prone to problems of rent-seeking and opportunism outlined above.

Building on the analysis of the limitations outlined above, future research will explore the impact of sources of market failure and will embed them into the modeling/simulation analyses. Addressing these problems in the simulations may intensify the divergences across the four models or generate a different ranking of the models in terms of welfare outcomes. A deeper understanding of how and why the different systems may deliver divergent results could be gained via a proper analysis of the various problems of asymmetric information, excessive transaction costs and impediments to financing - that undermine infrastructure developments. Similarly, insights about private developments' superiority could draw on insights about self-organising systems for the maintenance of common goods and the implications of co-operation within small communities. Further analyses could also explore the implications of vacant land – a significant real-world problem, particularly for brownfield sites, and the extent to which the significant transaction costs associated with property development and further elaborations could include introducing stochasticity via a random utility model, capturing non-linearity in externalities – to reflect negative as well as positive externalities from infrastructure development.

7. Conclusions and Policy Implications

Our analysis has shown that, under strict assumptions, the Coase Theorem may operate to ensure that private rights to orchestrate developments lead to higher levels of welfare within the context of land value betterment. In the simulations presented above, the allocation of development rights to private agents leads to a better outcome than when development rights are allocated either via regulatory planning authorities – as in European and modern UK systems, or via a developer state – as in China, assuming zero transaction costs, perfect information, perfect capital markets and perfect competition.

However, given endemic market failure, the outcomes are unlikely to be so straightforward though, in policy terms, efforts to reduce market failures will pay dividends. Policy implications include reducing the transaction costs, administrative loads and various planning and related lags to increase the ease with which infrastructure improvements can be implemented. Effective regulation will ameliorate problems of monopolistic and rent-seeking practices. Similarly regulation and certification/ standardization initiatives – whether via governments, regulators and/or industry groups – have the potential to reduce problems of asymmetric information and rent seeking. Financial reforms to stabilize financial markets and increase the ease with which efficiently priced financial instruments can be found. For public finance – innovation could focus on proper public private partnerships with project finance initiatives assessed using carefully designed social cost-benefit/ investment appraisal techniques. Project finance instruments could also be designed effectively to align incentives of the various parties – with significant potential benefits and positive externalities for wider communities. Further analysis of these problems and potential solutions using the computational methods outlined in this paper will increase the potential for efficient land value betterment to maximize social welfare and increase the standard of living.

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Appendix: A Flowchart Illustrating the Modelling Procedures