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Contiguous land use as a driver for land allocation

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Contiguous Land Use as a Driver of Land Allocation

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1 Introduction

Most analyses of urban land use allocation have been based upon theories which rely on land price gradients in relation to some monocentric or polycentric urban loci, with transport costs as the underlying prime mover. This paper presents an alternative (though not mutually exclusive) theory, by focusing on the relative preferences of different land users (residential, commercial and industrial) as the driver of land allocation. The paper considers how, under free-trade, preference-heterogeneity for contiguous land use will determine the distribution of land utilisation across urban space. We assume land is initially distributed evenly between the three types of land use and that residential land users prefer sites with housing as the main Contiguous Land Use (CLU) to sites with industrial or commercial CLU. *Ceteris paribus*, residential land users will be willing to trade more than one unit of land with industrial CLU for a unit with residential CLU. In contrast, industrial land users, who are assumed to be indifferent between different CLUs, are willing to exchange residential CLU land for industrial CLU land at

the initial exchange rate being offered by residential land users. Commercial land users are indifferent between residential and commercial CLU, but averse to industrial CLU. Assuming constant marginal utility of land consumption, residential, commercial and industrial land users trade land units until no further exchange can be made without making at least one trading partner worse off. It is anticipated that once equilibrium is reached, housing suppliers have fewer units of land overall, and these units tend to be clustered. In contrast, industrial land users have more units of land overall, and these plots are more likely to be scattered than clustered. It is ambiguous whether commercial land users gain land, but it is likely that their final allocation of plots will be sandwiched between residential and industrial land use.

The paper also discusses the implications for property supply elasticities of contiguous land use preference heterogeneity. In particular, preference heterogeneity has an adverse effect on the substitutability of land plots with different CLUs. This has important implications for the responsiveness of new construction to the release of vacant land, particularly in relation to whether the land allocation system is zoned or random.

1.1 Plan of paper

The paper will begin with an overview of the existing literature. We will then develop the basic CLU model, and describe a worked example using hypothetical utilities and endowments. The implications of the model are then considered for land release policy and the price elasticity of supply of housing.

2

3 Background Literature

It is not within the scope of this paper to provide anything like a comprehensive review of the urban spatial structure literature, and since a fairly recent attempt at this task has already been published (Anas, Arnott, & Small, 1998; see also Fujita, 1989) there would be little to gain anyway. ‘Academic as well as other observers have long sought explanations for urban development patterns and criteria by which to judge their desirability’ (ibid, p. 1426) and so it is not surprising that this literature is truly vast. The general understanding of the development of modern cities focuses on advances in transport and communication as the main drivers of the modern urban spatial structure. Moses and Williamson (1967), for example, show how transport and scale economies develop around locations with access to transport links (such as harbours and railway stations) and how residences tend to surround this emerging central business district (CBD).

This view of urban development came to be embodied in the Monocentric City Model which came to dominate the theoretical analysis of urban spatial structure for more than twenty years. Originating in von Thunen’s (1826) theory of agricultural land use and Alonso’s (1964) formulation, the model has been developed in various directions (in particular, following early developments by Mills, 1967, 1972; and Muth, 1969) to incorporate transport, housing, and production. It has become such an influential and flexible paradigm because ‘it provides a rigorous framework for analyzing the spatial aspects of the general-equilibrium adjustments that take place in cities, and for empirically measuring and comparing the degree of centralisation across cities and time periods’ (Anas et al, p. 1434).

More recently, however, the monocentric model has been displaced by theories which allow for polycentric development, given the ‘tendency of economic activity to cluster in several interacting centres of activity’ (op cit, p. 1439). Agglomerations of economic activity in non-uniform patterns have been explained in a number of ways. First, spatial inhomogeneities (such as soil, climate, mineral deposits, access to waterways etc) can give rise to ‘backyard economies’ even with constant returns to scale in production (Berliant and Konishi, 1996). Second, economies of scale in some part of the production process, such as the loading and unloading of goods. This formed the basis for the original conceptualisation of urban monocentricity, based on the economies of scale associated with harbours, but for modern means of transport, most notably road haulage, only small scale loading/unloading equipment may be needed and so many centres of activity arise. Stiglitz (1977) suggested the production of local public goods (temples, marketplaces, theatres, libraries etc.) as another source of scale economies

Third, agglomeration can arise out of external economies, and incorporate both economies localisation (causing cities to be specialised) and of urbanisation (causing cities to be diversified). Interindustry linkages arise because inputs to one industry are produced by another and these may encourage co-location to reduce overall costs. External economies may also be dynamic, such as those arising from knowledge transfer and its effect on technological progress (Romer, 1986), and some may fit both the localisation and urbanisation categories (such as economies of mass reserves – Robinson, 1931; Hoover, 1948).

Fourth, imperfect competition models have been developed in a spatial context to show how ‘critical mass’ and ‘big-push’ effects can shape the urban structure (see Gabszewicz and Thisse, 1986 for a review). These basic driver of these models is the conditions under which different producers have incentives to co-locate (Schulz and Stahl, 1996; Bacon, 1984; Krugman, 1991b, 1993).

More recently, a new category of analysis has emerged, labelled by Anas et al as ‘Noneconomic Dynamic Models’. These essentially draw inspiration from recent developments made in modelling natural processes, which have highlighted the nonlinear dynamic nature underlying many natural phenomenon (included in this category are chaos theory, complex systems, fractals, dissipative structures, and self organisation). What they have in common is ‘some form of positive feedback ... which in the urban growth context takes the form of development at one location somehow enhancing the development potential of nearby locations’. Strictly speaking, this is not a separate category, but a means of expressing tradition agglomeration economics in a dynamic fashion which is able to simulate the often profound consequences of feedback effects (Arthur, 1990, Nelson, 1995).

It is against this detailed and well trodden mass of literature, then, that we attempt to proffer an ‘additional’ process driving the formation of urban spatial structure. In contrast to the explanations based on transport costs, imperfect spatial competition etc, we suggest that land use may be driven by preference heterogeneity of different sectors for the contiguous land use (CLU) characteristics of available plots. We now go on to outline the basic structure of the model, followed by a detailed worked example.

4 CLU Model

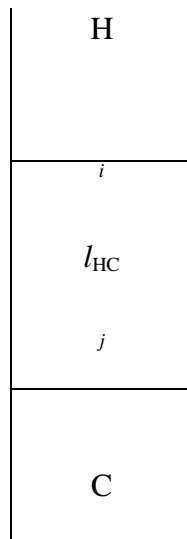
Assume there are three types of utility maximising land users: $H, C, I \in U$

suppliers of housing services: H

suppliers of office/retail based services: C

suppliers of industrial goods: I

Each land unit l has 2 contiguous regions and so is indexed l_{ij} where i is the upper boundary and j is the lower boundary. Thus, l_{HC} can be thought of as a sequence of plots with no vacant land:



The total land space can thus be conceived of as a single linear strip of land partitioned into segments and joining end to end rather like a cylinder, torus, or sphere (see Figure 1, Figure 2 and Figure 3). If the total land space is a cylinder, then each land plot is a

rectangular surface (this has the disadvantage of having two surplus ‘neutral’ sides); if the total land space is a torus, then each land plot is a cylinder; and if the total land space is a sphere, then each land plot is an eye shaped segment. Of the three, the cylinder is probably the least favourable as a conceptualisation because it still leaves two sides which are not adjacent to any other plot, whereas in the torus and the sphere, all sides are contiguous with one other plot.

Figure 1 Total Land Space Conceived as a Cylinder

Figure 2 Total Land Space Conceived as a Torus

Figure 3 Total Land Space Conceived as a Sphere

Because each of these configurations of land space can be represented as a one dimensional sequence, it can be fully indexed with just one co-ordinate, written as an underlined integer: $l = \underline{1}, \underline{2}, \underline{3}, \dots, \underline{L}$. Ownership of l by user type X is denoted as a superscript: l_{ij}^X .

4.1 Fundamental Transition Rules

Under free trade and well established property rights, any land owner can exchange plots of land with other landowners, and so land plots can move between different uses.

However, the transfer of use effects not only the characteristics of plot itself but also of all adjacent plots. The rules underlying these effects are as follows: for a given plot of land under the ownership and use of landowner type M , l_{ij}^M , transfer of this plot to another landowner type, denoted by N , the contiguous land use of adjacent plots will change from iM to iN and Mj to Nj for plots to the north and to the south respectively. Thus,

$$\begin{aligned}
 l_{ij}^M &\rightarrow l_{ij}^N &\Rightarrow & l-1_{iM} \rightarrow l-1_{iN} \\
 & &\Rightarrow & l+1_{Mj} \rightarrow l+1_{Nj}
 \end{aligned}$$

4.2 Preferences and Endowments

4.2.1

4.2.2 Housing Land Users

The initial endowment of H is given by,

$$e^H = \sum l_{ij}^H \quad \text{where } i,j \in K$$

So, for example, if H initially has five plots, then $5l^H = e^H = l_{ij}^H + l_{ij}^H + l_{ij}^H + l_{ij}^H + l_{ij}^H$.

The total utility of this endowment is given by:

$$U^H(e^H) = \sum u^H(l_{ij}^H) = u^H(l_{ij}^H) + u^H(l_{ij}^H) + u^H(l_{ij}^H) + u^H(l_{ij}^H) + u^H(l_{ij}^H).$$

It is assumed that housing land-users have a joint utility function and strong preferences regarding CLU. The complete ordering of preferences is listed below:

$$u^H(l_{HH}^H) > u^H(l_{HC}^H) > u^H(l_{CC}^H) > u^H(l_{HI}^H) > u^H(l_{HH}^H).$$

This can be written as,

$$l_{HH}^H \succ l_{HC}^H \succ l_{CC}^H \succ l_{HI}^H \succ l_{IC}^H \succ l_{II}^H$$

or as an ordered set, $u^{\sim H} = (u^H(l_{HH}^H), u^H(l_{HC}^H), u^H(l_{CC}^H), u^H(l_{HI}^H), u^H(l_{HH}^H))$ or as a vector, $\underline{u}^H = (u^H(l_{HH}^H) \ u^H(l_{HC}^H) \ u^H(l_{CC}^H) \ u^H(l_{HI}^H) \ u^H(l_{HH}^H))$.

4.3

4.3.1 Commercial Land Users

Commercial land users, C, have initial endowment $e^C = \sum l_{ij}^C$, and total utility $U^C(e^C) =$

$\sum u^C(l_{ij}^C)$. They also wish to maximise utility, and have preferences described as follows,

$$4.3.2 l_{HH}^C \sim l_{HC}^C \sim l_{CC}^C \succ l_{CI}^C \sim l_{IH}^C \succ l_{II}^C$$

4.3.3 Industrial Land Users

Industrial land users, I, have initial endowment $e^I = \sum l_{ij}^I$, and total utility $U^I(e^I) = \sum$

$u^I(l_{ij}^I)$. They aim to maximise utility, and have preferences described as follows,

$$l_{HH}^I \sim l_{HC}^I \sim l_{CC}^I \sim l_{CI}^I \sim l_{IH}^I \sim l_{II}^I$$

They are thus indifferent between different CLUs.

4.4 The Basis of Trade

It is assumed that trade is carried out on the basis of 100% recyclability of all land. There are no transport costs, and no money. Trade is entirely on the basis of barter. Indivisibility of land units will therefore preclude certain trade possibilities since exchange rates have to be achievable through exchange of whole plots in order to be feasible.

4.4.1 Minimum Exchange Rate Rule

If H owns plot(s) of land l_{ij}^H and is offered plot(s) l_{fg} in exchange for l_{ij}^H , then the maximum rate of exchange he is willing to offer, $x l_{ij} : y l_{fg}$, is given by:

$$u^H(l_{ij}) : u^H(l_{fg}) = u^H(l_{ij}) / u^H(l_{fg})$$

If the exchange rate on offer is greater than or equal to this ratio of utilities, then the owner will not trade. Thus, H will only trade if,

$$x/y < u^H(l_{ij}) / u^H(l_{fg})$$

4.4.2 Exchange Rate Arbitration

Because each land user wants to maximise utility, each will also want to trade at the limit of the others reservation rate. For trade to take place, it is assumed that an independent arbiter takes the list of possible exchange rates lying between the two trading partners reservation exchange rates and selects the median as the basis for exchange. If there are an even number of possibilities, and a unique median cannot be identified, both central rates are taken as possibilities.

4.4.3 Decision Rule for Exchange

It is assumed that in each round of trade, only one bilateral transaction can take place. Thus, either H trades with I, or I with C, C with H. Each player chooses to trade with the land user offering the most favourable deal. Thus it is possible that that no trade will take place because, for example, H would rather trade with I, but I would rather trade with C, and C would rather trade with H. Similarly, trade will not trade place if more than one player faces exchange rates lower than his reservation exchange rate.

Obviously, each player would choose to purchase the plot combination which offers him the most substantial total utility. However, this may not coincide with the trade combination that is most favourable to his trading partner. Because land users have an incentive to inflate their true utilities ascribed to each exchange package on offer, the dilemma cannot be solved on the basis of declared total utilities (i.e. cannot simply choose the option which gives the highest total happiness to all). Instead, it is done on the basis of each player revealing his ordering of plot combinations. By each player

ascribing a rank to each package (1 for the highest, 2 for the second highest, and so on), the sum of ranks is calculated. The package with the smallest sum of ranks is chosen and where a tie occurs between packages, a coin is tossed to finalise the deal (i.e. a choice is made through random selection) unless there is a complete opposite ordering and the median coincides for both players.

For example, trade negotiations between H and I reveal the following ordering of preferences for plot combinations $p_z = p_1, p_2, p_3, \dots, p_z$ (where $p_{z+1} = p_1$ and $p_{1-1} = p_z$):

<i>Plot Combinations:</i>	p_1	p_2	p_3	p_4
<i>I's Ranking of combinations:</i>	1	2	3	3
<i>H's Ranking of combinations:</i>	4	1	2	3
<i>Sum of ranks:</i>	5	3	5	6
<i>Chosen Package:</i>		X		

Similar negotiations between H and C reveal another set of ranks:

<i>Plot Combinations:</i>	p_5	p_6	p_7	p_8
<i>C's Ranking of combinations:</i>	2	2	1	3
<i>H's Ranking of combinations:</i>	1	3	2	3
<i>Sum of ranks:</i>	3	5	3	6
<i>Chosen Package (random selection between p_5 and p_7):</i>			X	

Thus, H will trade with C if $u_H(p_7) > u_H(p_2)$, and trade with I if $u_H(p_7) < u_H(p_2)$. If utilities are equal, H will again toss a coin to choose.

5 Worked Example

To summarise what has been said so far, the preferences of H, C and I are such that industry is happy to locate anywhere, commercial suppliers prefer to locate near other offices or near housing, and housing suppliers prefer to locate near other housing, and definitely avoid industry. Whole plots can be traded on the basis of mutual gains. Assuming constant marginal utility of consumption, a sequence of trading rounds can be simulated based on an initial set of utilities and endowments. Let, the utility vectors for each land user be,

	HH	HC	CC	CI	II	HI
\underline{u}^H	(16	8	4	2	1	3)
\underline{u}^C	(6	6	6	2	1	2)
\underline{u}^I	(5	5	5	5	5	5)

and let the endowment vectors in round 1 of trade be,

	HH	HC	CC	CI	II	HI
\underline{e}_{t1}^H	(0	0	0	5	0	0)
\underline{e}_{t1}^C	(0	0	0	0	0	5)
\underline{e}_{t1}^I	(0	5	0	0	0	0)

This suggests a total utility of initial endowment of,

$$\mathbf{u}^H(\underline{\mathbf{e}}^H_{t1}) = \underline{\mathbf{u}}^H \underline{\mathbf{e}}^H_{t1}{}^T = 10$$

$$\mathbf{u}^C(\underline{\mathbf{e}}^C_{t1}) = \underline{\mathbf{u}}^C \underline{\mathbf{e}}^C_{t1}{}^T = 10$$

$$\mathbf{u}^I(\underline{\mathbf{e}}^I_{t1}) = \underline{\mathbf{u}}^I \underline{\mathbf{e}}^I_{t1}{}^T = 25$$

Reservation exchange rate matrices are given by,

$$\mathbf{x}_{\min}^H = \begin{array}{c} \text{HH} \\ \text{HC} \\ \text{CC} \\ \text{CI} \\ \text{II} \\ \text{HI} \end{array} \begin{array}{c} \text{HH} \quad \text{HC} \quad \text{CC} \quad \text{CI} \quad \text{II} \quad \text{IH} \\ \left[\begin{array}{cccccc} 1 & 1/2 & 1/4 & 1/8 & 1/16 & 3/16 \\ 2 & 1 & 1/2 & 1/4 & 1/8 & 3/8 \\ 4 & 2 & 1 & 1/2 & 1/4 & 3/4 \\ 8 & 4 & 2 & 1 & 1/2 & 1 \\ 16 & 8 & 4 & 2 & 1 & 3 \\ 5 & 1/3 & 2 & 2/3 & 1 & 1/3 \end{array} \right] \end{array}$$

$$\mathbf{x}_{\min}^C = \begin{array}{c} \text{HH} \\ \text{HC} \\ \text{CC} \\ \text{CI} \\ \text{II} \\ \text{HI} \end{array} \begin{array}{c} \text{HH} \quad \text{HC} \quad \text{CC} \quad \text{CI} \quad \text{II} \quad \text{IH} \\ \left[\begin{array}{cccccc} 1 & 1 & 1 & 1/3 & 1/6 & 1/3 \\ 1 & 1 & 1 & 1/3 & 1/6 & 1/3 \\ 1 & 1 & 1 & 1/3 & 1/6 & 1/3 \\ 3 & 3 & 3 & 1 & 1/2 & 1 \\ 6 & 6 & 6 & 2 & 1 & 2 \\ 3 & 3 & 3 & 1 & 1/2 & 1 \end{array} \right] \end{array}$$

$$\mathbf{x}_{\min}^I = \begin{array}{c} \text{HH} \\ \text{HC} \\ \text{CC} \\ \text{CI} \\ \text{II} \\ \text{HI} \end{array} \begin{array}{c} \text{HH} \quad \text{HC} \quad \text{CC} \quad \text{CI} \quad \text{II} \quad \text{IH} \\ \left[\begin{array}{cccccc} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{array} \right] \end{array}$$

5.1

Round 1 of Trade

Round 1: Trade Between H and C

Housing				Commercial			
$e_{t1}^H = 5I_{CI}$				$e_{t1}^C = 5I_{IH}$			
(i)	CI	:	IH	(i)	CI	:	IH
	3	:	2		1	:	1
Reservation Rates							
Median of Feasible Rates							
= 4:3							

The median of 4:3 was calculated by ordering the all trade combinations, ordering them, and then selecting the median of the feasible list as follows:

1 determine exchange rate

	CI:HI Trade combs	CI:HI Trade Combins & reservn exchange rates	Ordered &	
eh = 5CI ec = 5HI				
1	1	1	1	1/2
2	2	1/2	1	1/4
3	3	1/3	1/2	1/3
4	4	1/4	1/3	2/5
5	5	1/5	1/4	1/2
		2	1/5	1/2
		2/3	2	3/5
		1/2	2/3	2/3
		2/5	1/2	3/4
		3	2/5	4/5
	1	1/2	3	1
		3/4	1 1/2	1 1/4
		3/5	3/4	1 1/3
		4	3/5	1 1/2
		2	4	1 1/2
	1	1/3	2	1 2/3
		4/5	1 1/3	2
		5	4/5	2
	2	1/2	5	2 1/2
	1	2/3	2 1/2	3
	1	1/4	1 2/3	4
			1 1/4	5

(i) $4l^H : 3l^C$

Having agreed upon this exchange rate, both parties agree to offer all plots on this basis because any trade will alter the CLUs of each plot anyway. The binomial distribution formula states that for n possibilities and k selections there are $n!/k!(n-k)!$ possible combinations. Since C and H have a total of 10 plots between them, and after trade, 4 of these belong to H, this formula means that there are 210 possible combinations. However, there are only a handful of equivalent types in terms of their utility values for C and H, and an even smaller subset which H and C would consider given that most will yield utility levels below their initial endowment and so be rejected. The table below lists the main combination-categories of trade if H was to trade 4 plots for 3 with C:

R1	p1	p2	p3
H	H	C	H
I	I	I	I
C	C	H	H
H	C	H	H
I	I	I	I
C	H	H	H
H	C	H	C
I	I	I	I
C	H	C	H
H	C	C	C
I	I	I	I
C	H	C	C
H	C	C	H
I	I	I	I
C	C	C	C

p1 for example is will not be acceptable to H because it yields an overall utility of 8, which is below that received from the initial endowment. p3 yields a utility just equal to

the initial endowment and so will be superseded by any offer that improves on the initial endowment for H.

This leaves p2 as a feasible plot combination, yielding the following revised endowments and utilities:

H:

\underline{u}^H	HH	HC	CC	CI	II	IH	
	(16	8	4	2	1	3)	
$p_1^{H\&C} p_2 =$	(0	0	0	0	0	4)	

$$u^H(p_1^{H\&C} p_2) = 3(4) = 12$$

C:

\underline{u}^C	HH	HC	CC	CI	II	IH	
	(6	6	6	2	1	2)	
$p_1^{H\&C} p_2 =$	(0	0	0	6	0	0)	

$$u^C(p_1^{H\&C} p_2) = 2(6) = 12$$

5.2 Round 1 of Trade between H and I

Round 1: Trade Between H and I

Housing		Industrial
$e_{H1}^H = 5l_{CI}$		$e_{I1}^I = 5l_{HC}$
(i) CI : HC 4 : 1	Reservation Rates	(i) CI : HC 1 : 1

Median of Feasible Rates = 5:3

The median of 5:3 was calculated by ordering the all trade combinations, ordering them, and then selecting the median of the feasible list as follows:

H and I:

eH = 5CI eI = 5HC	Trade combs	Trade Combs and exchange rates	Trade reservn Combs and reservn exchange rates ordered
1	1	1	4 1/5
1	1	1/2	1 1/4
2	2	1/3	1/2 1/3
3	3	1/4	1/3 2/5
4	4	1/5	1/4 1/2
5	5	2	1/5 1/2
		2/3	2 3/5
		1/2	2/3 2/3
		2/5	1/2 3/4
		3	2/5 4/5
	1	1/2	3 1
		3/4	1 1/2 1 1/4
		3/5	3/4 1 1/3
		4	3/5 1 1/2
		2	4 1 2/3
	1	1/3	2 2
		4/5	1 1/3 2
		5	4/5 2 1/2
	2	1/2	5 3
	1	2/3	2 1/2 4
	1	1/4	1 2/3 4
		1	1/4 5

Having agreed upon the exchange rate of 5:3, both parties agree to offer all plots on this basis, yielding the following main categories of plot combinations:

R1		p1	p2
H		I	H
I		I	I
C		C	C
H		I	H
I		H	I
C		C	C
H		I	H
I		H	H
C		C	C
H		I	H
I		H	I
C		C	C
H		I	H
I		I	I
C		C	C

p1 will not be acceptable to H since it only yields an overall utility of 6. p2 is feasible, however, because it suggests utilities of 18 and 35 to H and I respectively:

H:

	HH	HC	CC	CI	II	IH	
\underline{u}^H	(16	8	4	2	1	3)	
$\mathbf{p}_2^{H\&I}$	(0	2	0	1	0	4)	

$$u^H(p_2^{H\&I}) = 8(2) + 2(1) = 18$$

I:

	HH	HC	CC	CI	II	IH	
\underline{u}^I	(5	5	5	5	5	5)	
$\mathbf{p}_2^{H\&I}$	(0	1	0	6	0	0)	

$$u^I(p_2^{H\&I}) = 5(7) = 35$$

5.3 Round 1 of Trade between C and I

Round 1: Trade Between C and I

Commercial				Industrial				
$e_{t1}^C = 5l_{HI}$				$e_{t1}^I = 5l_{HC}$				
(i)	HI	:	HC	Reservation Rates Median of Feasible Rates = 5:3	(i)	HI	:	HC
	3	:	1		1	:	1	

The median of 5:3 was calculated by ordering the all trade combinations, ordering them, and then selecting the median of the feasible list as follows:

C and I

			Trade combs	Trade Combs	Trade
				and	Combs
				exchange	and
				rates	reservn
					exchange
					rates
					ordered
$eH = 5l_{CI}$	ec	$=$	1	3	1/5
	$5/HC$				
1	1		1/2	1	1/4
2	2		1/3	1/2	1/3
3	3		1/4	1/3	2/5
4	4		1/5	1/4	1/2
5	5		2	1/5	1/2
			2/3	2	3/5
			1/2	2/3	2/3
			2/5	1/2	3/4
			3	2/5	4/5
1	1/2		3	3	1
	3/4		1	1/2	1 1/4
	3/5			3/4	1 1/3
	4			3/5	1 1/2
	2			4	1 2/3
1	1/3			2	2
	4/5		1	1/3	2
	5			4/5	2 1/2
2	1/2			5	3
1	2/3		2	1/2	3
1	1/4		1	2/3	4
			1	1/4	5

This yielded the following main categories of plot combinations:

R1	p1	p2
H	H	H
I	I	I
C	I	I
H	H	H
I	C	C
C	I	I
H	H	H
I	C	C
C	I	C
H	H	H
I	C	I
C	I	I
H	H	H
I	I	I
C	I	I

p1 is not acceptable to C since it suggests an overall utility of 6 compared with the utility of 10 associated with its initial endowment. p2, however, is acceptable to both parties:

C:

\underline{u}^C	HH (6	HC 6	CC 6	CI 2	II 1	IH 2)	
$\mathbf{p}_2^{C\&I}_{t2} =$	(0	2	0	0	0	1)	

$$u^C(p_2^{C\&I}_{t1}) = 6(2) + 2(1) = 14$$

I:

\underline{u}^I	HH (5	HC 5	CC 5	CI 5	II 5	IH 5)	
$\mathbf{p}_2^{C\&I}_{t2} =$	(0	1	0	0	0	6)	

$$u^I(p_2^{C\&I}_{t1}) = 5(7) = 35$$

5.4 Results of Round 1

These results can be summarised as follows:

	Trading Partner		
	<i>H</i>	<i>C</i>	<i>I</i>
$u^H(p_1^{H\&V}), u^H(p_2^{H\&V}), \dots, u^H(p_z^{H\&V})$	-	12, 8	6, 18
$u^C(p_1^{C\&V}), u^C(p_2^{C\&V}), \dots, u^C(p_z^{C\&V})$	12, 8	-	6, 14
$u^I(p_1^{I\&V}), u^I(p_2^{I\&V}), \dots, u^I(p_z^{I\&V})$	35, 35	35, 35	-

It can be seen from the following two tables that the ranking procedure is trivial for *H* and for *I*:

H and C

	Tradable Plot Combinations Ranked		
	$p_1^{H\&C}$		
<i>H</i>	1		
<i>C</i>	1		

H and I

	Tradable Plot Combinations Ranked		
		$p_2^{H\&I}$	
<i>H</i>		1	
<i>I</i>		1	

C and I

	Tradable Plot Combinations Ranked		
		$p_2^{C\&I}$	
<i>C</i>		1	
<i>I</i>		1	

$$H: p_2^{H\&I} \succ p_1^{H\&C}$$

$$C: p_2^{C\&I} \succ p_1^{H\&C}$$

$$I: p_2^{C\&H} \sim p_2^{C\&I}$$

Thus, *H* would prefer to trade with *I* and so would *C*. *I* is indifferent between the trading partners.

5.5 Round 2

Assume I randomly selects H for trade, the plot combination actually traded is $p_2^{C\&H}$.

Endowments for round 2 become:

$e_{t2}^H =$	HH	HC	CC	CI	II	IH	
$u^H(e_{t2}^H) = 18$	0	2	0	1	0	0	
$e_{t2}^C =$	1	0	0	0	3	1	
$u^C(e_{t2}^C) = 6 + 3 + 2 = 11$							
$e_{t2}^I =$	0	1	0	6	0	0	
$u^I(e_{t2}^I) = 35$							

Note that even though C did not trade, its endowment has been changed by the bilateral trade between I and H , and as a result, C 's total utility has risen from 10 to 11.

Round 2: Trade Between H and C

Housing		Commercial
$e_{t2}^H = 2l_{HC} + 1l_{CI}$		$e_{t2}^C = 1l_{HH} + 3l_{II} + 1l_{IH}$
(i) HC : HH 2 : 1	Reservation Rates	(i) HC : HH 1 : 1
	Median of Feasible Rates = 2:1 or 1:1	

(i) (a) $2l_{HC} : 1 l_{HH}$

The table below lists the main combinations of trade if H and C were to trade 2 plots for

1.

R1	R2	p1	p2	p3	p4	p5	p6
H	I	I	I	I	I	I	I
I	I	I	I	I	I	I	I
C	C	C	C	C	H	H	
H	I	I	I	I	I	I	I
I	I	I	I	I	I	I	I
C	C	C	H	C	H	C	C
H	H	H	C	H	H	C	H
I	H	H	C	C	C	C	C
C	C	C	C	H	C	C	C
H	H	C	H	C	C	C	C
I	I	I	I	I	I	I	I
C	C	C	C	C	C	H	C
H	I	I	I	I	I	I	I
I	I	I	I	I	I	I	I
C	C	C	C	C	C	C	C

	HH	HC	CC	CI	II	IH
\underline{u}^H	16	8	4	2	1	3
$\underline{p}_1^{H\&C} \quad \underline{p}_2 =$	0	2	0	0	0	0

$$u^H(p_1^{H\&C}, p_2) = 16$$

It can be seen that none of these combinations will allow trade, since the most favourable for H would be p1 yielding a utility of 16, lower than its endowment at the start of round two.

(i) (b) $1l_{HC} : 1 l_{HH}$

The table below lists the main categories of combinations of C and H trading one for one.

R1	R2	p1	p2	p3	p4	p5
H	I	I	I	I	I	I
I	I	I	I	I	I	I
C	C	C	C	C	H	H
H	I	I	I	I	I	I
I	I	I	I	I	I	I
C	C	C	H	C	C	C
H	H	H	H	H	H	H
I	H	H	H	C	H	C
C	C	H	C	H	C	H
H	H	C	C	H	C	C
I	I	I	I	I	I	I
C	C	C	C	C	C	C
H	I	I	I	I	I	I
I	I	I	I	I	I	I
C	C	C	C	C	C	C

It can be seen that H would only contemplate p1 or p2, so the other combinations can be discarded. But C would not contemplate p1 since it would effectively be trading one l_{HH} for one l_{HI} which carries considerably lower utility. Thus, p2 is the only feasible combination:

H		HH	HC	CC	CI	II	IH	
\underline{u}^H		16	8	4	2	1	3	
$\mathbf{p}_2^{H\&C}$	$t_2 =$	1	1	0	0	0	1	

$$u^H(\mathbf{p}_2^{H\&C}, t_2) = 16(1) + 8(1) + 3(1) = 27$$

C		HH	HC	CC	CI	II	IH	
\underline{u}^H		6	6	6	2	1	2	
$\mathbf{p}_2^{H\&C}$	$t_2 =$	0	1	0	3	2	0	

$$u^H(\mathbf{p}_2^{H\&C}, t_2) = 6(1) + 2(3) + 1(2) = 13$$

Round 2: Trade Between H and C

Housing			Commercial	
$e^H_{t2} = 2l_{HC} + 1l_{CI}$			$e^C_{t2} = 1l_{HH} + 3l_{II} + 1l_{IH}$	
(ii)	HC : II 1 : 8	Reservation Rates Trade not possible (C has insufficient II)	(ii)	HC : II 1 : 6
(iii)	HC : IH 3 : 8	Reservation Rates Trade not possible (C has insufficient IH)	(iii)	HC : IH 1 : 3
(iv)	CI : HH 8 : 1	Reservation Rates Trade not possible (H has insufficient CI)	(iv)	CI : HH 3 : 1
(v)	CI : II 1 : 2	Reservation Rates possible	(v)	CI : II 1 : 2

So, for (v), C effectively advertises $2l_{II}$ for one l_{CI} and subsequent trade is carried out on this basis (i.e. all plots irrespective of CLU are offered at the exchange rate of 2:1 between H and C) even though as soon as trade begins, the CLUs of plots will change.

(v) $1l_{CI} : 1 l_{II} \Rightarrow 2l^H$ for one l^C

The table below lists the main categories of combinations of C and H trading one for two.

R1	R2	p3	p4	p5	p6	p7
H	I	I	I	I	I	I
I	I	I	I	I	I	I
C	C	C	C	C	H	H
H	I	I	I	I	I	I
I	I	I	I	I	I	I
C	C	C	H	H	C	C
H	H	H	C	C	C	C
I	H	H	H	C	C	C
C	C	C	C	C	C	C
H	H	C	C	H	C	C
I	I	I	I	I	I	I
C	C	C	C	C	H	C
H	I	I	I	I	I	I
I	I	I	I	I	I	I
C	C	C	C	C	C	H

None of these combinations would be feasible since H would be made worse of than its initial round 2 endowment.

(vi)	CI	:	IH	Reservation Rates	(vi)	CI	:	IH
	3	:	2	Trade possible at 1:1		1	:	1

However, this yeilds the same results as (i)(b). Thus the only feasible combination for trade between H and C is p2 yielding respective utilities, 27 and 13.

Round 2: Trade Between H and I

Housing				Industrial				
$e^H_{t2} = 2l_{HC} + 1l_{CI}$				$e^I_{t2} = 1l_{HC} + 6l_{CI}$				
(i)	CI	:	HC	Reservation Rates	(i)	HC	:	HH
	4	:	1		1	:	1	
trade possible at 1:1								

(i) (b) $1l_{HC} : 1 l_{HH}$

The table below lists the main categories of combinations of C and I trading one for one.

R1	R2		p1	p2
H	I		I	I
I	I		I	I
C	C		C	C
H	I		I	I
I	I		I	H
C	C		C	C
H	H		H	I
I	H		H	H
C	C		C	C
H	H		I	I
I	I		H	H
C	C		C	C
H	I		I	I
I	I		I	I
C	C		C	C

It can be seen that H would only contemplate p1, so the other combinations can be discarded. But p1 leaves both H and I with only the same endowment and utility as before, so any other combination with proves to offer higher rates of utility than the initial round 2 endowment, will also be preferable to p1.

Round 2: Trade Between C and I

Commercial				Industrial				
$e^C_{t2} = 1l_{HH} + 3l_{II} + 1l_{HH}$				$e^I_{t2} = 1l_{HC} + 6l_{CI}$				
(i)	HH	:	HC	Reservation Rates	(i)	HH	:	HC
	1	:	1		1	:	1	
				trade possible at 1:1				

(i) $1l^C : 1l^H$

The table below lists the main categories of combinations for C and I trading one for one.

R1	R2		p1	p2
H	I		I	I
I	I		I	I
C	C		C	C
H	I		C	I
I	I		C	I
C	C		C	C
H	H		H	H
I	H		H	H
C	C		C	C
H	H		H	H
I	I		I	I
C	C		I	C
H	I		I	I
I	I		I	I
C	C		I	C

Given that I is indifferent between land combinations, it can be shown that p1 would be C's preferred choice, leaving C with only one plot adjacent to industrial sites, and significantly improved utility:

C							
\underline{u}^C	HH	HC	CC	CI	II	IH	
$p_1^{C\&I}_{t2} =$	6	6	6	2	1	2	
	1	1	2	1	0	0	

$$u^C(\mathbf{p}_1^{H\&C}_{t2}) = 6(1) + 6(1) + 6(2) + 2(1) = 26$$

I still has seven sites each yielding 5 units of utility, so I's utility is still 35:

$$u^I(\mathbf{p}_1^{C\&I}_{t2}) = 5(7) = 35.$$

Commercial				Industrial				
$e^C_{t2} = 1l_{HH} + 3l_{II} + 1l_{IH}$				$e^I_{t2} = 1l_{HC} + 6l_{CI}$				
(ii)	HH 1	: 3	CI 3	Reservation Rates trade not possible	(ii)	HH 1	: 1	CI 1
(iii)	II 6	: 1	HC 1		(iii)	II 1	: 1	HC 1
				Reservation Rates Trade possible Median = 2:1				

$$(iii) 2l^C : 1l^I$$

The table below lists the optimal categories of combinations for C and I trading two land plots for one, and four for two:

R1	R2	p2	p3						
H	I	I	I						
I	I	I	I						
C	C	I	I						
H	I	C	I						
I	I	C	C						
C	C	C	C						
H	H	H	H						
I	H	H	H						
C	C	C	C						
H	H	H	H						
I	I	I	I						
C	C	I	I						
H	I	I	I						
I	I	I	I						
C	C	I	I						

Under p_2 , C's utility increases to 20:

C							
	HH	HC	CC	CI	II	IH	
\underline{u}^C	6	6	6	2	1	2	
$\mathbf{p}_2^{C\&I}$	1	1	1	1	0	0	

$$u^C(\mathbf{p}_2^{C\&I}) = 6(1) + 6(1) + 6(1) + 2(1) = 20$$

Under p_2 , I would have eight sites each yielding 5 units of utility, so I's utility would increase to 40:

$$u^I(\mathbf{p}_2^{C\&I}) = 5(8) = 40.$$

Under p_3 , C would still be better off than under the old regime:

C							
	HH	HC	CC	CI	II	IH	
\underline{u}^C	6	6	6	2	1	2	
$\mathbf{p}_3^{C\&I}$	1	1	0	1	0	0	

$$u^C(\mathbf{p}_3^{C\&I}) = 6(1) + 6(1) + 2(1) = 14$$

Under p_3 , I would have nine sites each yielding 5 units of utility, so I's utility would increase to 45:

$$u^I(\mathbf{p}_3^{C\&I}) = 5(9) = 45.$$

5.6 Summary for Round 2

The feasible trading combinations are therefore as follows:

$$\mathbf{p}_3^{C\&I} ; \quad u^C = 14, u^I = 45$$

$$\mathbf{p}_2^{C\&I} ; \quad u^C = 20, u^I = 40$$

$$\mathbf{p}_1^{C\&I} ; \quad u^C = 26, u^I = 35$$

$$p_1^{H\&I} \text{ ; } u^H = 18, u^I = 35$$

$$p_2^{H\&C} \text{ ; } u^H = 27; u^C = 13$$

H would order its options as follows:

$$p_2^{H\&C} \text{ ; } u^H = 27$$

$$p_1^{H\&I} \text{ ; } u^H = 18$$

C would order its options as follows:

$$p_1^{C\&I} \text{ ; } u^C = 26$$

$$p_2^{C\&I} \text{ ; } u^C = 20$$

$$p_3^{C\&I} \text{ ; } u^C = 14$$

$$p_2^{H\&C} \text{ ; } u^C = 13$$

I would order its options as follows:

$$p_3^{C\&I} \text{ ; } u^I = 45$$

$$p_2^{C\&I} \text{ ; } u^I = 40$$

$$p_1^{C\&I} \text{ ; } u^I = 35$$

$$p_1^{H\&I} \text{ ; } u^I = 35$$

It is clear, therefore, that C would prefer to trade with I, and I with C. So this time it is H that is left without a trading partner. However, C and I have different ordering of plot combinations:

	Tradable Plot Combinations Ranked		
	$p_1^{C\&I}$	$p_2^{C\&I}$	$p_3^{C\&I}$
C's ranking	1	2	3
I's ranking	3	2	1

		X	
--	--	----------	--

Because the median package coincides for both players at $\mathbf{p}_2^{C\&I}$, this package is chosen, yielding a new allocation ready for round three:

R1	R2	R3
H	I	I
I	I	I
C	C	I
H	I	C
I	I	C
C	C	C
H	H	H
I	H	H
C	C	C
H	H	H
I	I	I
C	C	I
H	I	I
I	I	I
C	C	I

Already, after three rounds of trade, it can be seen that industry has gained land, commerce has lost one plot, and housing has lost two plots. It can also be seen that housing and commerce have coagulated into homogenous groups of plots, effectively sandwiched between blocks of industrial land use.

6

Implications

6.1 A Means of Connecting Commercial, Industrial and Housing Sectors

A great gap in the existing real estate literature is the lack of work on the links between commercial, industrial and residential sectors. It is evident that they are connected in two main ways. First, through aggregate demand: the demand for commercial, industrial and housing services are driven by fluctuations in general economic activity. Second, they connected via the supply of inputs, particularly labour and land. This is particularly so during boom periods where they may be competing for the same scarce supply of construction workers or suitable development plots. However, the demand for land inputs of these three sectors is not only connected via the overall availability or scarcity of land plots, but also by the effect on the qualitative aspect of land supply of each sectors plot purchase decisions. As the above model has demonstrated, if the demand for land by H, C or I is influenced by the nature of the contiguous land use, then the location decisions of each sector have a direct bearing on the location decisions of each other sector. It seems reasonable, then, to conclude that these contiguous land use preferences and resultant allocations, will feed through to effect supply elasticities in each sector and, thus, the price and quantity volatility of each sector.

Suppose, for example, that we were to introduce money into the above model, and that the financial resources available to each of the three sectors fluctuates with the business cycle, and that these fluctuations are not of equal amplitude. The amplitude of the commercial cycle may be larger than that of housing, for instance, because during booms, the commercial sector is more prone to speculative bubbles (a large proportion of

housing demand is for consumption), and during booms, housing is stabilised by the welfare system. Because they are competing for the same limited land, the corollary would be for the decline in the price elasticity of supply of housing during booms (see Pryce, 1999) to be exaggerated because of the contemporaneous and more expansive boom in the commercial sector. In other words, at the time when new housing is most needed, supply is constrained because of relatively greater increase in purchasing power in the commercial sector. Conversely, during a slump, the increase in the price elasticity of supply of housing is exaggerated because of the contemporaneous slump in the commercial sector and in its demand for land. This means that during recessions, the downward quantity adjustment to falling house prices is exacerbated. The situation is summarised in Figure 4 where the pivoting of the supply curve (exacerbated by interaction with the commercial sector) results in an asymmetric housing quantity adjustment between booms and slumps.

Figure 4 Asymmetric Housing Quantity Adjustment Between Booms and Slumps Due to Interaction with the Commercial Sector

As we have already said, however, they are not strictly competing for the same land because of their heterogeneous CLU preferences. This heterogeneity profoundly affects the substitutability of vacant plots in two senses. First, it affects substitutability between sectors: a vacant plot with a particular CLU will not be equally useful to each of the three sectors. Second, it affects substitutability of different available plots within a sector: two plots of vacant land with different CLUs will not be equally, and this acts as a barrier to substitutability of land inputs, which in turn exacerbates the inelasticity of supply in both commercial and housing sectors (we have assumed industry to be indifferent

between plots with different CLUs and so all land is perfectly substitutable for the industrial sector). This asymmetry has the potential to produce a downward ratchet-effect in housing services: only small increases in quantity during booms and large falls during slumps.

6.2 Land Release Policy

This has implications for land release policy and urban planning. The model has assumed instance and total recyclability of all land, but even with this strong restriction, it is clear that the demand for brownfield land may be weak depending on its location (i.e. its CLU). For example, consider the following clustered allocation of land, R1, arrived at either by a central planning policy of zoning, or by the kind of free trade described in the model.

R1		R2	R3
C	1	C	C
C	2	C	C
C	3	C	C
H	4	H	H
H	5		
H	6	H	H
H	7	H	H
I	8	I	I
I	9	I	I
I	10	I	I
I	11		
I	12	I	I
I	13	I	
I	14	I	I
I	15	I	I

Now suppose that in the next period, two plots (plots 5 and 11) become vacant having been reclaimed by/sold to the central planner by the previous occupier. Maintaining the

assumption of cost free recycleability, it is clear that given the choice of plot 5 or 11, both commerce and housing would prefer plot 5. In fact, assuming the same utility vectors as in the model, even if two plots with industrial CLU were offered (plots 11 and 13 in R3), or even if 15 such sites were on offer, plot five would still be preferable to all of them combined. Of course, if land could not be instantly recycled at zero cost, these preferences would be even stronger.

The irony is, that where land allocation is randomly distributed (even dispersion of land use) rather than zoned (concentrated dispersion of land use), former industrial plots are likely to be more attractive to housing and commercial developers since they are less likely to be surrounded by other industrial sites. The conclusion would appear to be, therefore, that the more clustered the use of land, the more difficult it is to encourage development on former industrial sites.

7 Summary

This paper has developed a model of land allocation based on heterogeneous contiguous land use preferences and free trade of land (with the assumption that all plots were instantly recycled upon use-transfer). The result was that housing and commercial sectors preferred to have fewer plots clustered together than more plots dispersed amongst industrial sites. The paper also discussed the implications of the model for the price elasticity of supply of housing and also for land release policy.

8 Future Research Ideas

- Introduce plots with more sides (e.g. four sides \Rightarrow squares; six sides \Rightarrow

hexagons).

- Introduce transport preferences: H, for example, may prefer to travel to work via H and avoid driving through I. O may prefer to have access to both I and H and other O plots. I also may wish to have access to O and other I plots:

8.1.1 H: H <-----> H <-----> O

8.1.2 O: H <-----> O <-----> O <-----> I

8.1.3 I: I <-----> I <-----> O

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Figure 1
Total Land Space Conceived as a Cylinder

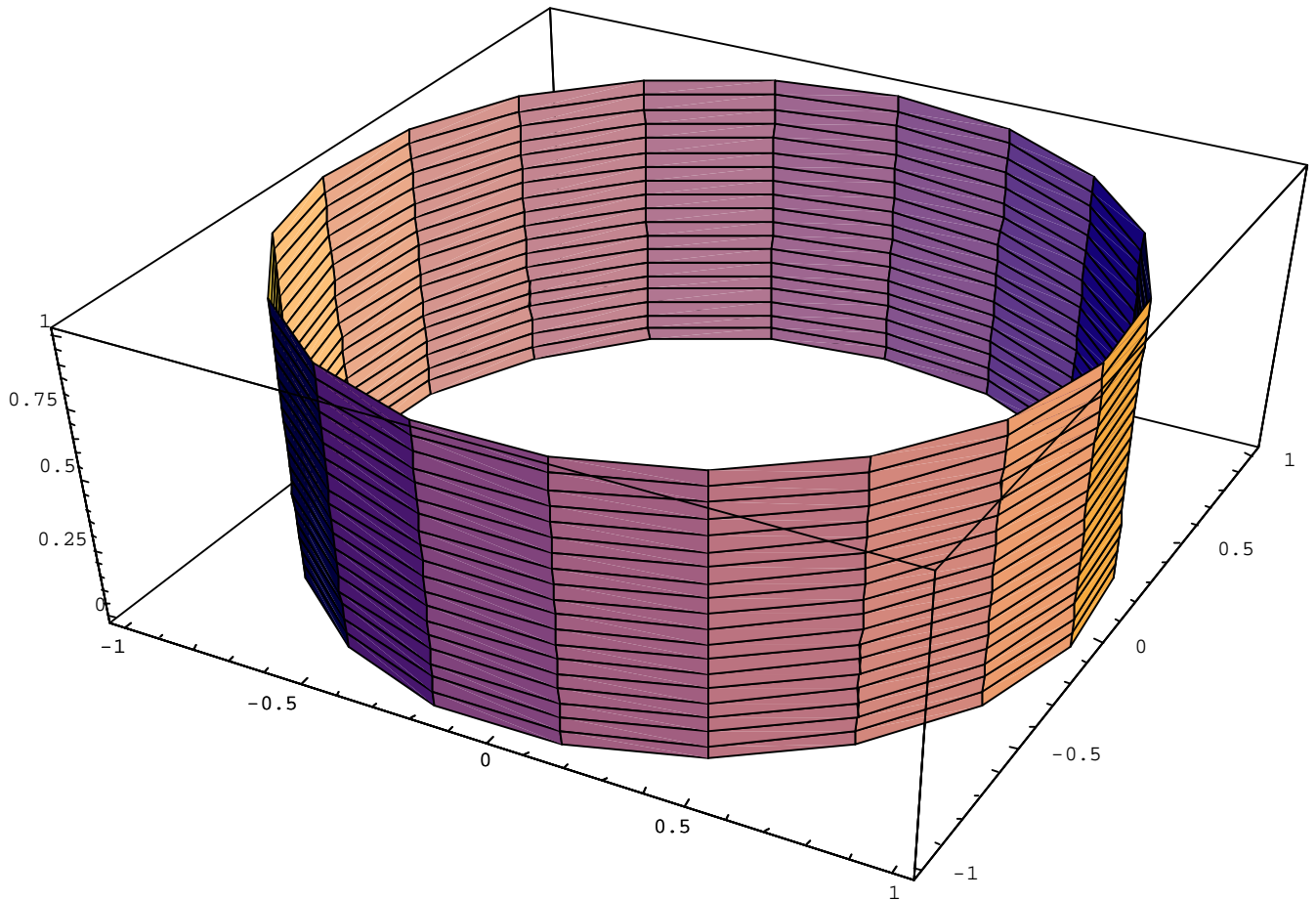


Figure 2
Total Land Space Conceived as a Torus

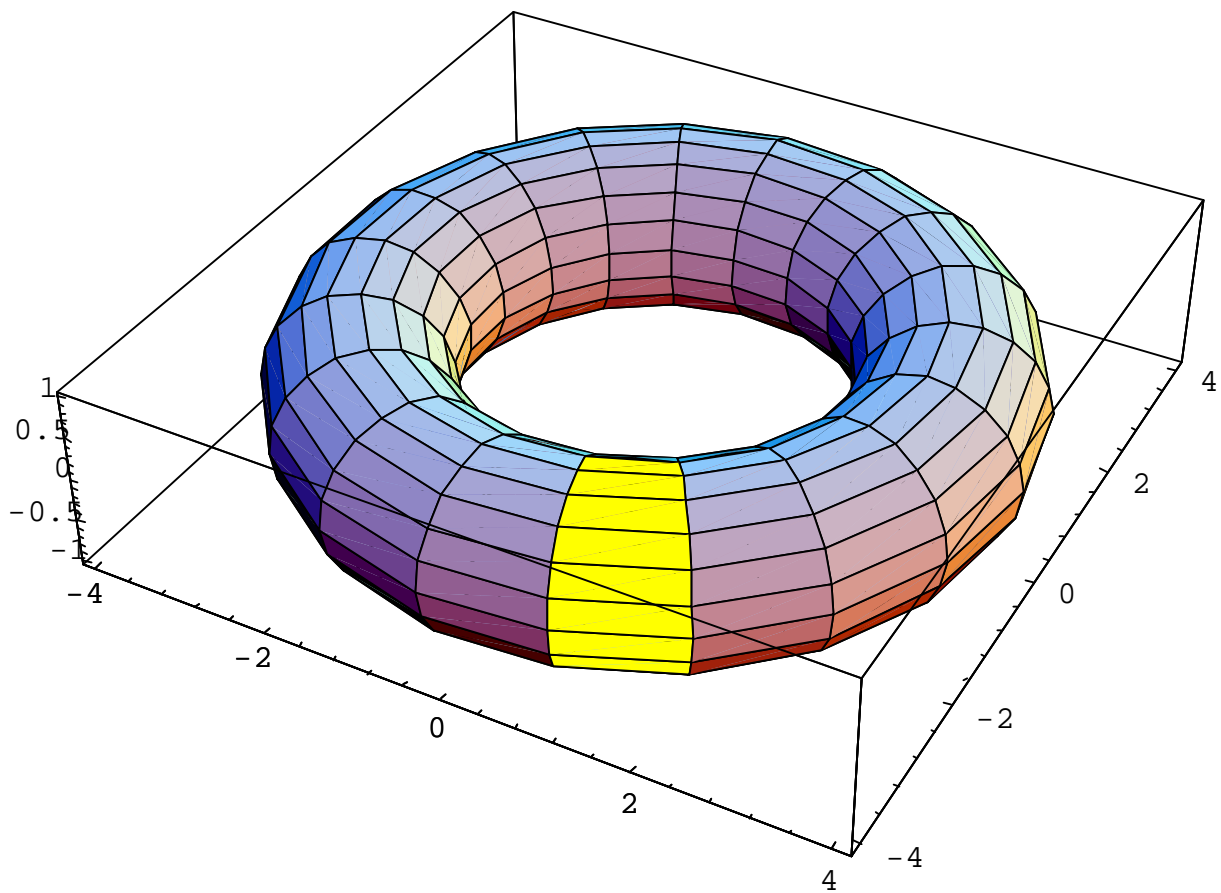


Figure 3
Total Land Space Conceived as a Sphere

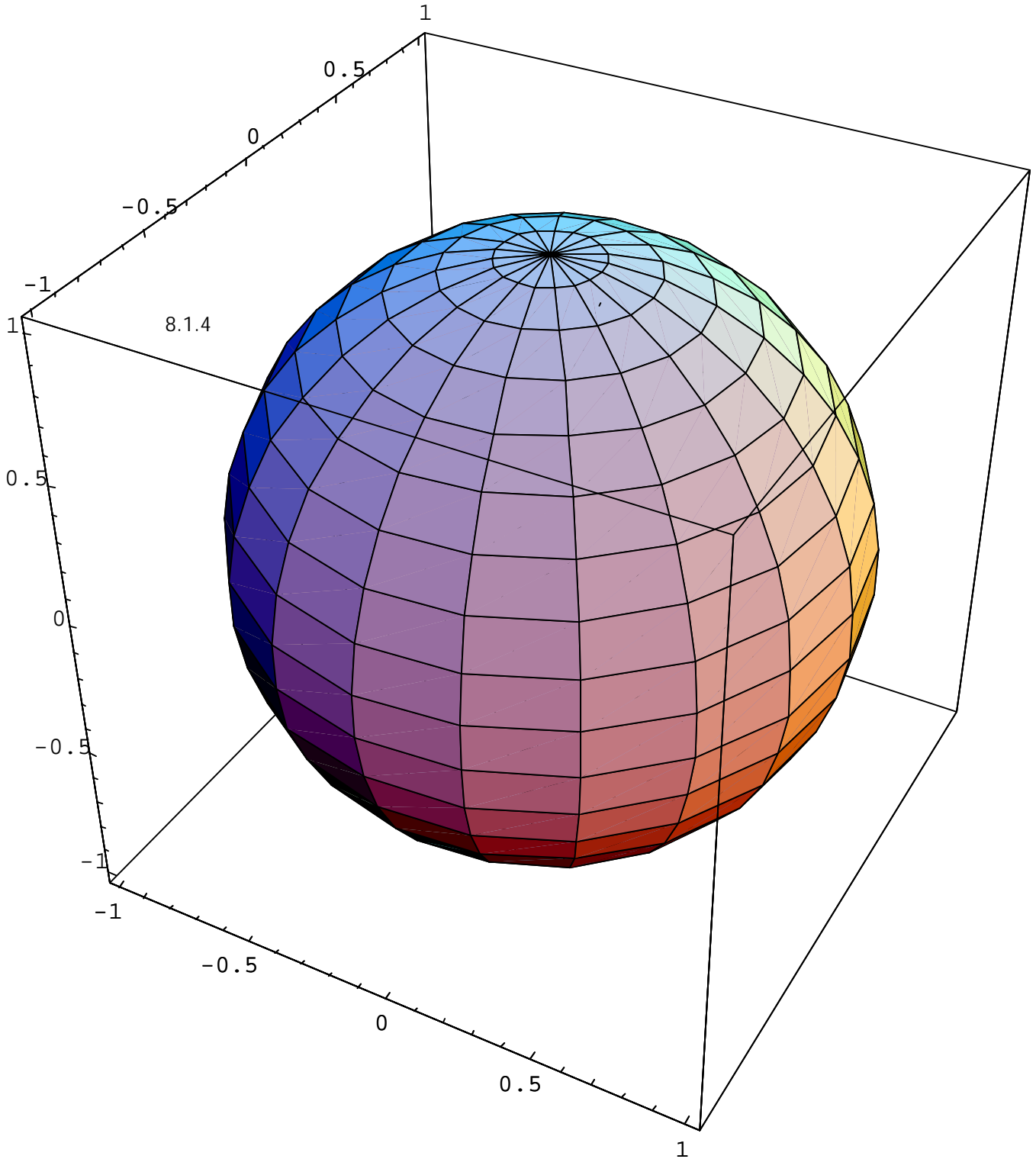


Figure 4 Asymmetric Housing Quantity Adjustment Between Booms and Slumps Due to Interaction with the Commercial Sector

