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THE DYNAMICS OF CENTRAL PLACE NETWORKS

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CONTENTS

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1. Aims and objectives: beyond the traditions of central place theory

A major current concern is with patterns of regional development in a variety of contexts and at a variety of spatial scales. Regional science should be able to provide a theoretical basis for this field but it can be argued that it has failed to do so. It is interesting to look back, therefore, at the origins of relevant theory, which we take as central place theory, and assess the progress towards the goal of building an effective theory of what might be called the 'dynamics of central place networks'. This already introduces, in such a phrase, two new emphases: the first on dynamics, which is appropriate both in terms of the interests of theorists but also, more importantly, in the context of rapid structural change; and secondly, on networks, which emphasises the importance of interdependence in contemporary societies.

The basic concerns of traditional central place theory include: the explanation of hierarchy in regional structure; an account of the functioning of regional systems; and perhaps, most importantly, the goal of establishing what amounts to a general and comprehensive theory for regional science. In effect, by choosing to focus on places rather than subsystems involving one or more of the main constituents of places, it becomes necessary to incorporate all the elements and their interactions. To the work of Christaller (1933) and Losch (1940) should be added the contributions of the other 'classical' theorists such as von Thunen (1826), Weber (1909), Burgess (1927) and Hoyt (1939) who all contribute building bricks to the broader goals (though there has been little attempt to integrate these with classical CPT).

Although this provides a starting point, it does not take us very far. The assumptions of classical theory break down, particularly for contemporary times relative to the 1930s; and its methodology does not, and of course could not, take account of recently developed ideas associated with dynamics and evolution. However, it is difficult to replace in a simple way for at least two reasons: the problem it identifies is so huge that it goes beyond our present capacity to integrate the elements of improved theory and method; and in any case, this problem has not been

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effectively formulated. The aim of this paper, therefore, can only be to attempt to write a prescription for a new theory in the light both of the concepts and understanding now available to us and of a critical review of past work. The scale and spirit of these objectives mirrors, on a smaller scale, that of the 'general theory' of Isard et al (1969).

We proceed, therefore as follows with three main objectives: (i) to enumerate basic concepts and ideas which will more effectively expose the nature of the problem; (ii) to make a brief critical review of progress; (iii) to seek a prescription for new models in the light of this argument (but noting that there will not be a universal model for reasons which will emerge). We pursue these objectives in the next three sections in turn and end with some concluding comments in section 5, summarising in relation to a final objective: (iv) to pinpoint the weaknesses in the allocation of modelling effort at the present time.

2. A range of concepts to structure the problem.

It is useful to go back to first principles and begin with a set of concepts which can be used with first-year students; but they are important because they are often neglected and with severe consequences in the present context. This is to argue that the model builder is concerned with three sets of decisions which can be labelled: system articulation, theory and method.

The first of these involves specifying the main elements and relationships of the system of interest (and possibly including formal subsystem definitions), the recognition that this specification has to be at one or more levels of resolution identified as useful by the analyst, and involving some form of spatial representation. None of these issues is trivial: in practise, specification of elements and relationships is usually too partial for the building of effective comprehensive theory; and there is a constant muddling of levels of resolution.

Theorising involves specifying component hypotheses and linking them across scales; making judgements about what is most 'important', because approximation at some stage will be inevitable; combining what is on offer from different disciplines; and learning how to link to key universal theoretical problems, such as the agency-structure problem - to avoid reinventing the wheel, to take some elements of theory 'off the shelf', and to recognise the deep (and perhaps insoluble) difficulty of some aspects of theory building.

There will be a close relationship between theory development at different scales with available methods for operationalising theory. The objective has to be an eclectic assembly of methods for particular theory-building tasks. This is difficult in practise because we are each seriously limited by the skills of our upbringing and experience.

In both theoretical and methodological contexts, it is important to recall Weaver's (1958) classification of problems: simple; of disorganised complexity; of organised comlexity. This both places our own discipline firmly in the context of the theory-building problems of others, but also allows us to recognise the inherent limitations of some approaches and the difficulties of others - for example, we can use the general insights associated with the properties of nonlinear dynamical systems, recognised as systems of organised complexity.

In summary, then, we have to proceed as follows: identify the main elements of a CPN system and group them into subsystems at various scales; this includes a crucial <u>categorisation</u> task; we have to assemble component hypotheses; we have to link subsystems; we have to assemble the methods which will allow us to build operational models. It is worth rehearsing, even though it is only possible in the broadest terms, our responses to these issues because this provides our ongoing agenda.

The key elements are going to be something like: people, organisations, goods, services, transport facilities and land. We are also obviously concerned with the activities and processes associated with them. These elements can be combined together in different ways to form subsystems; for example, if primarily focused on elements, the key subsystems are: demographic, economic, manufacturing sectors, service sectors, transport and land. However, there are alternative and in some circumstances more productive ways of defining subsystems, for example by combining all the elements which make up housing and labour 'markets'. Indeed it is often useful to focus on 'markets', in a broad sense, to represent the sets of adjustment processes which underpin the dynamics of these linked subsystems.

This specification does not include the exploration of different relevant scales or of categorisation. These will be crucial components of theorising.

Component hypotheses can be formulated at different scales. At the micro scale, convention demands a representation of individual and household preferences, probably as some kind of utility function (implicit or explicit) and some theory of the firm or public enterprise, such as the maximisation of profits or the meeting of needs. It is important in principle to be able to articulate all the production possibilities through a full knowledge of production functions for all kinds of organisations, <u>whether currently in existence or not</u>. This is the kind of theorising which can generate insight but not, without tremendous approximation, operational models. At the meso scale, it is possible to theorise directly about, for example, 'most probable states' or the properties of flows in networks. We need to be able to link hypotheses at various scales so that we understand such things as: the organisation possibilities for the production of goods and services, market adjustment processes, political processes, the impacts of technological change and the processes of regional development (the nature of the winners and the losers in the context of a particular national or international economy).

The issues of method can be reviewed briefly using Weaver's categories mentioned earlier. For simple systems, characterised in terms of a small number of variables, the methods of conventional algebra and calculus can be used. The economic base theory is of this type. Again, insights can be gained, but usually major approximations are involved in representing any aspect of a CPN system as 'simple' when the reality is complex. The danger is that some researchers will make these approximations because they are limited to essentially 'simple' methods in their own background.

Systems of disorganised complexity involve large numbers of components and weak interactions between them. Some kind of statistical averaging methods can then be applied: average rates with <u>accounting</u> models (cf. Wilson, 1981-A, Chapter 4)and entropy maximising methods (under whatever guise) are good examples. Accounts, in particular, play a potentially very important general rule as the 'cement' of comprehensive models.

Weaver argued that the problems of organised complexity - large numbers of components and strong interactions, were the key problems of modern science - and he has been proved right. What he did not see was the methodological contribution to this problem which would come from the mathematics of dynamical systems - from catastophe theory ('simple' dynamics) via the bifurcation properties of large systems of differential equations to the relationships between structural change and 'chaos'. (Master equations provide an explicit dynamic treatment of the sets of probabilities involved in this kind of modelling - in the urban context, see Weidlich and Haag, 1981; Haag and Wilson, 1985). All this has generated some operational models, considerable general insight, and in particular, a recognition of the real difficulties of understanding organised complexity.

3. A critical review of progress.

The beginning of the age of contemporary modelling as it potentially contributes to the CPN problem can be taken, roughly, as dating from Lowry's (1964) Model of Metrolpolis. We are then talking about almost 25 years of dramatic progress, initially with the tools for modelling disorganised complexity (and hence with limited application, though it was not always argued in those terms at the time) and, for the most recent decade, with the tools of nonlinear systems dynamics at our disposal. This is not the place to attempt to review the vast range and diversity of contributions in this period, but to try to draw some broad conclusions as a starting point for the next step in the argument. (But for some reviews, see Wilson, 1974, Paelink and Nijkamp, 1975, Batty, 1976, Wilson, Rees and Leigh (eds), 1977, Wilson, 1981-B, Wilson and Bennett, 1985, Bertuglia, Leonardi, Occelli, Rabino, Tadei and Wilson (eds), 1987, Nijkamp (ed), 1987, Bertuglia, Leonardi and Wilson (eds), forthcoming.)

We can summarise the key elements of progress under a number of headings: progress within subsystems; general insights from the theory of dynamical systems; whether we have focused on the right questions or not; and the influence of fashion.

There has been progress with virtually every major modelling subsystem. At an aggregate scale, this is true of demographic and regional input-output modelling. This is important in the context of this paper but beyond its scope to review these developments here (though in the context of this conference, the work of Artle, 1959, on Stockholm remains seminal). What is of more immediate importance is the attempts to link these models and to extend them, e.g. to household sectors, within regional contexts (cf. Schinnar, 1976, Gordon and Ledent, 1980, Batey and Madden, 1981, Batey, Madden and Weeks, 1987 and Batey and Weeks, 1987). It is also worth noting the tremendous level of expertise which is available in integrating the concepts of account-based input-output modelling with spatial modelling - though to an extent, possibly because of problems of data availability, or inability to formulate problems and make approximations in the right way, this expertise has run ahead of practical model building. For a review, see Wilson, Coelho, Macgill and Williams(1981).

Progress has been made in the direction of explicitly dynamic modelling in the main sectoral subsystems: agriculture (e.g. Wilson and Birkin, 1987), industry (e.g. Birkin and Wilson, 1987-A,1987-B, in this case building on other work on the combining of spatial flow modelling with input-output modelling, usually within an entropy-maximising contexxt - Wilson, 1970, Chapter 3, Cripps, Macgill and Wilson, 1974, Macgill, 1977, Boyce and Hewings, 1980), private services (beginning with Harris and Wilson, 1978), public services (e.g. Leonardi, 1981), residential and housing (cf. Clarke and Wilson, 1983-A), the labour market (e.g Birkin and Clarke, 1987) and the land market (cf. Anas, forthcoming). This progress has been at a variety of scales which do not, on the whole, integrate well. The models which have been made fully operational tend to be improved versions of previously operational models, in fields like retailing. In areas where the problems of organised complexity are greater, less progress has been made (beyond valuable theoretical formulations) - agriculture and industry are examples. In some of these cases, the data is inherently more difficult to get and this has also hindered progress. There has also been tremendous progress at the micro scale (e.g. Lloyd, forthcoming), but typically this is not integrated into modelling in the sense of this paper.

The main recent modelling advances may be considered to come from the general insights of dynamical systems theory. At first, the progress was in terms of 'simple' models of catastrophic structural change (e.g. in the work of Amson, 1974, Papageorgiou, 1980 and Dendrinos and Mullally, 1985). This was extended in various ways to more explicitly spatial systems, this bringing techniques for handling organised complexity explicitly into regional science and geography (cf. Wilson, 1981). The key insights are that nonlinear systems are governed by (large numbers of) underlying multiple equilibria, and by criticality of parameters and sudden structural change. There is also another kind of structural instability - a more dynamic one. This arises when adjustment parameters in dynamic models become too large. May (1976) was one of the first to show that, even in quite simple models, there are critical values of parameters above which oscillatory behaviour can set in followed by something fundamentally <u>chaotic</u>. This has spawned a large recent literature. All this has provided a better broad understanding of the old 'uniqueness vs. general' debate: that there may be general laws, but the richness of possible specific outcomes is immense. This last feature, coupled with its attractiveness as an alternative method for handling complexity in large systems, has led to an increased interest in micro-simulation methods (cf. Clarke, Keys and Williams, 1981 and Clarke and Wilson, 1986). One of the reasons for developing such models is to use them on a simulation basis to explore the range of possible futures which are consistent with a given set of assumptions.

There are also some tremendous technical difficulties: the 'backcloth problem', which arises because 'everything depends on everything else' - in practise, some approximation has to be made to make problems tractable (explored in the urban systems context in Clarke and Wilson, 1983-B); and the difficulty that it is necessary to be able to anticipate and articulate possible new production functions or other system features which are not observed, nor in some cases can even be imagined, in contemporary systems. This is one of the fundamental problems of modelling any kind of evolutionary process (Wilson, forthcoming-A). These kinds of difficulties have taught us that there is a limit to the kind of progress which can be expected - for instance, we have no more chance of building deterministic long-term predictive models than the equivalent weather forecasters (and for the same reasons). But we can make new kinds of progress in understanding and insight.

This progress can be summarised, by showing how different kinds of models have been generated through three stages of increasing complexity and ambition - and this is done in Figure 1. The interaction models, particularly through the calculations of revenues (or some other measure of total useage) provide crucial inputs to the dynamic structural models. The third stage identifies the evolutionary models on which very little progress has been made. In some senses, some of the dynamic models of the second stage are evoolutionary; but the definition used here is that a new form of organisation should appear - a new r - with a new kind of production function and possibly a new kind of product altogether. So what cab be seen from Figure 1 is the important interaction basis for synamic modelling - in some senses a 'network' basis - and then the two kinds of parameters which appear in stage 2: the alphas and betas which affect structural change and the epsilons which can generate 'chaos' if they are too large. We should also recognise that all otgher variables which are exogenous to any particular model function as parameters, and in particular, the transport cost terms, c(i,j). It is through this key connection that we seek to model transport land-use relationships.

There is also a negative side to the longer term record which we need to be aware of to begin to respond to in the future. Some wrong judgements have undoubtedly been made: not focusing on the right questions for example (such as economic development, technological change, welfare in a realistic sense' or even on concepts such as 'hierarchy' or 'agglomeration'). There have been poor system definitions which have not encouraged researchers to focus on the right questions. There has been disciplinary myopia; difficulties of integrating non-operational theoretical insights with the traditions of operational modelling; and very little integration across scales. There is always a temptation to use the kind of theory which is <u>convenient</u> for operational modelling. We return to these issues in section 5.

The whole period has been complicated by swings of fashion and cutbacks in higher education and research programmes. There was certainly a swing against modelling and particularly against large-scale modelling. In one sense, this climate is now changing, if only because a much wider range of 'clients' for modellers have now been discovered - beyond government planning agencies (cf. Clarke and Wilson, 1987). This trend combines with that of computing continuing to get cheaper at a rapid rate and the possibilities of developing much improved geographical information systems - though in this context there are some difficult problems (cf. Birkin, Clarke, Clarke and Wilson, 1987).

4. Prescription for new models.

Any prescription must be properly connected to the kinds of basic concepts outlined in section 2 and discussed briefly, in the light of experience, in section 3. Because of the order of complexity of CPN systems, and the present state of the art of theory building and associated methodology, we also recognise at the outset that imperfections and approximation will be crucial to developing any operational model; and that because there will be a variety of ways of doing this, there will be a considerable variety of possible models, each of which will be more or less useful in different contexts. What we need to do here, therefore, is to state some general principles briefly, to note but largely to ignore the wide class of models which have been developed which make some existing contribution to the CPN task and to go on to explore by example what new kinds of model might look like.

We must be prepared to operate at a variety of spatial scales and, in particular, for a variety of spatial systems. Indeed one characteristic we will look for is an attempt to build <u>general</u> CPN models which operate at a variety of spatial scales. We should also note a difficulty here: for both methodological reasons and practical reasons, spatial systems which form the basis for modelling are likely to be discrete zone systems. Ideally, at the micro scale, they should reflect the parcels of land which contain buildings or some relatively homogeneous land use. <u>But these parcels change their shape over time</u>. We have to resolve this problem as best we can and then try to make CPN theory applicable whether the zones are neighbourhoods, cities, regions or countries. The kind of nested system which we are likely to end up with is shown as Figure 2.

We must define sectors (or other subsystems), investigating in depth their origins, structures, functions and dynamics - starting at the level of the establishment and enterprise and building up in the development of component hypotheses.

In order to find a way of classifying the types of models we would like to be able to develop, it is useful to think of subsystems which are either <u>sectoral</u> or have some different <u>focus</u> (such as the labour market). The spatial units, as noted earlier, will be finite zones, and <u>centres should be thought of as zones with certain kinds of properties</u>, such as a high density of the presence of certain elements or actvities. It is likely to be more productive to attempt to build a general model in terms of spatial systems of finite zones and then to derive centre features as properties of these zones than to try to explain 'centres' directly. Recall also that we want to develop models and theory which, as far as is possible, is <u>general</u> with respect to zone size.

We can then usefully distinguish between the following classes of models:

* single zone/single sector or focus
* single zone/multi sector-focus
* multi zone/single sector-focus
* multi zone/multi sector-focus

Of course, the last of these is the comprehensive general model, and the ideal; but it has rarely proved practical.

An example of a class 1 model would be a demographic model of a country, a region or a town; or perhaps a model of one service sector in a town - such as the education system. The economic base model might be put in this category because it takes such a simple view of economic sectors. This class of models will in many cases be 'simple' in Weaver's sense.

The second class of models is important and helps to point the way ahead for CPN modelling. A good example is the modelling of an economy for a single spatial unit. This could be, as noted earlier in our search for generality, a neighbourhood, a CBD, a town, a region or a country. Some of these problems have to an extent been 'solved', for example with input-output modelling, but not in a way which operates with sufficiently small units to serve as effective building bricks for improved CPN models - nor with sufficient endogenous sectors. (We need to be able to produce 'neighbourhood' input-output models for instance.) So this is one of the major examples we pursue below.

The third class incorporates the set of models where the most dramatic progress has been made in the last decade. The methods of dynamical systems analysis have been grafted on to interaction-based subsystem modelling with considerable success. This has been done most sucessfully with the retail system and this has the advantage that it has shown, for one service system, that it is possible to build dynamic CPN models which revolutionise and extend the Christallerian or Loschian models for such systems. There is a much richer variety of spatial patterns which can be generated and the basis of the dynamics of structural change can be understood. What is more, the theory can be matched against reality. This approach has been extended to include agriculture, industry and housing as 'single sector' models - though the industry model does incorporate inter-industry relationships.

Some progress has been made with the fourth class of model, but usually by making massive approximations which, in effect, mean that settlement systems in general behave like slightly more complicated retail systems (cf. Allen and Sanglier, 1981). As noted earlier, more effective modelling in this class represents the goal.

What is the most productive strategy for making progress? <u>Either</u>, the integration of single sector submodels into a comprehensive model, which has been the most common strategy; <u>or</u>, the development of single-zone models to the extent where they can provide alternative building bricks. Because there is a lot of experience of the first strategy, in this paper we concentrate on the second.

The first point to note is that the notion of a single zone model is infeasible as such. It is necessary to set such a zone in a regional context, perhaps a national one and an international one. Here we make the approximation that we can deal with a local unit (L) and a regional context (R) without specifying the relative sizes of these regions, and recognising that the outer region will usually have to be further subdivided. The reason, of course, why this is such a fundamental step for a single zone model is simply that the flows across the boundary, in both directions, are crucial to the description, functioning and modelling of that zone.

There is one particular advantage in trying to take a single spatial unit as a building block: that is, it forces us to consider the interdependence of elements, activities and processes - as in a land market model, but more broadly. We can also characterise the zone by the presence, absence or quantity of each of these and pose interesting questions like: 'How many zone types can we usefully identify?'.

We have to summarise the main subsystems (elements, activities, processes) - bearing in mind that there are different ways of doing this, but that we will select one which is plausible and will form the basis for a reasonable state description.

STOCKS

Population: demographic, individual and household activities:

* birth
* death
* migration
* residential decisions and mobility
* economic activity rate
* skills (occupations)
* incomes
* demand for goods and services

Production - public and private:

* objectives (profit, meeting needs etc)
* production functions
* organisation of production ('factors')
* pricing decisions
* ongoing review of locational structures (the 'migration' of establishments and organisations)
* activity measures - e.g. related to employment: earnings per employee etc
* NB1 this section should all be categorised by SECTOR - at least primary to quaternary, but in many cases down to a fine level of detail. (It is also necessary to note the complex input-output relationships - e.g of quaternary inputs to the other sectors.) We also need to be able to find ways of representing, e.g. information processing or 'knowledge handling' sectors.

* NB2 when sectors are specified in detail, there are crucial links to the population subsystem - e.g. through training

Land and buildings markets:

* e.g. housing
* 'rent' setting
* adjustment processes of land use
* physical development and redevelopment

Transport and communications

* evolution of networks

INTERACTIONS AND LINKAGES

Labour market:

* choice and adjustment processes linking workers and jobs
* pattern of income flows
* links to migration models

Use of private services:

* choice of service supply units by consumers
  - e.g. retail
* attraction of consumers from outside the zone

Use of public services:

* choice of, or allocation to, service supply
  - e.g. education and training
  - health
  - social security
* supply of services outside the zone

Inter-industry relationships:

* decisions on suppliers of all inputs
* marketing and selling

Interaction summaries

* it is useful to try to find zonal summaries of interaction patterns, especially

  - various import-export balances:

    - commuting
    - retail
    - other services
    - industry

because these are the basis of dynamic adjustment processes and are also important factors in developing zonal typlogies - as discussed below

- and it is also possible to use such concepts as:

  - catchments (which needs a system map for each zone) or
  - catchment populations
  - resource, market or intermediary orientation (cf. Johansson, 1987)

INTERVENTIONS

Government regulation:

* e.g. on land use control (planning permissions)

Government taxation and expenditure:

* taxes on individuals
* taxes on organisations
* payments to individuals and households
* payments to organisations
* expenditure decisions on public services

For a single zone (plus outer region) system, we can begin to spell out the full set of accounting relationships - a task which is too intimidating for a multi-zone system. This process then begins to point out what is missing in existing models. Some formal state variable definitions and equations for this system are set out in a separate paper (Wilson, forthcoming-B). Implicit in this is the need to spell out production functions - and it is here that we see the full difficulty of the exercise, and why economic modelling has been neglected in the urban and regional spatial context. The way forward has almost certainly to be through the use of 'activity variables' which stand as proxies for a range of production function variables. The most obvious fallback position is to use employment in this way (because it is available) - but there are drawbacks, because it will not do all the work required of it in a model (cf. Baumol, 1958, Broadbent, 1973, 1977).

A statement of the model consists of first, the initial conditions and secondly, the dynamics. The main steps of account-based dynamic modelling for a single zone can then be summarised in two phases, therefore, as follows.

Phase 1: comparative statics

* describe the initial population
* calculate the local workforce, making some assumption about the economic activity rate
* calculate local production, taking the 'initial condition'

of the local economy as a starting point

* calculate local labour requirements
* use a labour market model to calculate the extent to which local requirements for labour are met from the local workforce or from workers commuting in; calculate the numbers of local workers commuting out. (For the zone, these can be seen as the IMPORTS and EXPORTS of labour)
* local unemployment can be calculated as a residual
* specify all initial prices
* calculate local service demand
* calculate the pattern of service useage (which determines, for the zone in conjunction with the demand figure the extent of service IMPORTS; at the same time, estimate service EXPORTS
* calculate the factor inputs needed for the production schedules NB this should include the goods needed by service sectors, including retailers and wholesalers
* calculate the set of inter-industry flows between L and R (which determines the pattern of IMPORTS and EXPORTS of goods)
* calculate the pattern of money flows associated with flows of labour, services and goods noted above, including local INCOMES and PROFITS (and note the L- and R-shares of the latter) - in effect, develop zonal accounts, concepts of 'balances of payments' and so on

* calculate transport and communications flows, and hence congestion levels in networks; and hence generalised costs of transport and communication

This is basically an account of stocks and steady-state flows. Note, however, that this phase of the model includes some Lowry-like iterative features: the demand for services will be a function of local incomes, for example - and yet these cannot be known until a later stage of the calculation because they are calculated from the employment schedules which depend (among other things) on the level of service demand. These kinds of circularities are well known and can be handled.

In practice, there will be also be imbalances and departures from equilibrium, and so Phase 2 of the model is to make the adjustments which are the basis of the dynamics. One of the inherent complexities of this kind of modelling involves both unravelling (in terms of understanding) and then properly meshing together the mechanisms represented by the iterations of the phase 1 part with the time sequence of adjustments and their consequences in Phase 2. (Recall that Lowry always denied that his iterative scheme had anything to do with dynamics - that it was merely a scheme for solving the equations - though others treated it as dynamic.)

Phase 2: dynamics.

The next step is to connect the imbalances identified in the phase 1 model with the associated adjustment processes and hence to specify the dynamics. There are three main (longer-term?) markets and associated adjustment processes:

* housing
* labour
* land

together with the usual

* economic markets

in goods and services. And perhaps we should consider separately

* transport systems and infrastructure

This last case points to the very complicated feedbacks between these markets. Development in transport systems will obviously respond to indicators like congestion, as implied by this scheme. But a large number of the component submodels in other markets and subsystems involve transport terms (e.g. as generalised costs) and we are far from fully understanding the impacts of these in the dynamics of development in these other sectors. We should also recognise that there are different time scales operating and that these need to be understood. (The relative magnitudes of these are represented by the epsilon-parameters introduced illustratively earlier in Figure 1.) When this understanding has been achieved, the mnodels can be <u>nested</u> appropriately.

In each case, the markets take the system nearer to one of the available equilibria via a series of adjustments which could be in terms of

* price
* quantity produced (where possible)
* land rents (when they are primarily determined by the associated activity.
* innovation (components of system evolution)

There is a need for deeper understanding of the relative strengths, in different circumstances, of these possibilities (cf. Wilson, 1985-A, Birkin and Wilson, 1985). This emphasis on adjustments via imbalances was emphasised in a different way in a recent paper by Batten and Johansson, 1987.

This dynamical part of the model is also spelled out in the asssociated paper (Wilson, forthcoming-B). It is here where there are inherent nonlinearities and so all the general insights of nonlinear systems dynamics apply.

The set of state variables specified above for the single zone system can be considered to be a ZONE PROFILE: essentially stocks and steady state flows which describe the existing situation, together with a specification of the dynamics, mainly through variables which represent IMBALANCES which are the inputs to sets of adjustment processes. A key part of the profile is the set of IMPORTS and EXPORTS which have been articulated. These are steady state flows when the system is in equilibrium, but will be crucial parts of the dynamics when the 'balance of payments' departs from an acceptable steady state. They also indicate how a single zone model depends critically on connections to the rest of the system - in effect, to all other zones. It should be emphasised that it will not be possible to build up zone profiles from data: too many key elements are missing. In effect, we are recommending the use of a model system to estimate these missing elements. In the longer run, variables from both single-zone and multi-zone models will contribute to these profiles.

This profile will also be very much a function of past dynamics, of 'histories'; and the possible futures will be very much dependent on the present state, the 'initial conditions'. We should also note that we can enhance the quality of the profile by drawing it not simply in terms of 'raw' state variables - even from models - but in terms of 'performance indicators' which are constructed from these (cf. Clarke and Wilson, 1987).

For each zone, its profile (both equilibrium and dynamic tendencies) will give us the basis for describing it and its function within the system, for describing possible trends and as a basis for planning.

In terms of zone profiles, <u>central places</u> can then be seen as zones with certain kinds of properties: high densities of certain kinds of elements and associated activities. The notion can now be generalised, however: not simply a concern with centrality but with the <u>distinctiveness</u> of places which we are trying to capture through these profiles.

Key elements of zone profiles, in certain combinations, can then be sought as a basis for defining zone <u>typologies</u>. A next step in the argument, therefore, is to try to pick out from the long state description what might be the crucial variables in such typologies. We have to start with the obvious state variables:

* population
* primary economic activity, say
* manufacturing
* private services
* public services

(and, of course, all the interesting disaggregations of these). But we might then go on to look at six ratios which relate to the import-export flows discussed earlier. These are:

* proportion of local labour requirements met locally
* proportion of the local workforce taking jobs outside the area
* proportion of service needs met locally
* proportion of services produced taken up by people outside the area
* proportion of factor inputs produced locally
* proportion of total product 'exported'

These six ratios are single-zone approximations to what we might expect to gert out of a full-blown inter-zonal input-output model. Again, it will be important to disaggregate each of the six by category in some appropriate way.

To focus the issue in a different and interesting way, we might pose the question: what makes successful places? A speculative list is:

* an appropriate historical legacy (e.g. in terms of economic mix - measured in terms of activity variables)
* an available workforce with a diverse range of skills
* training facilities; a creative environment (universities etc?)
* some good residential environments (or, at least, access to these)
* good consumer services
* land availability for developing work environments
* good links to other factor input (e.g. producer services - finance, advice, developers etc)
* good links to markets at different scales
* 'good links' in the above lists implies good transport facilities and telecommunications (e.g. cheap trunk lines)

This is an important list, partly in relation to practical economic development issues, but also, from a modelling point of view, because something like this should constitute the elements of the 'profit functions' of locational decision makers. An important subsidiary question in relation to economic development is: what is a robust combination of variables?

The formal structure of a system within which zone profiles and typologies are constructed at different scales is shown in Figure 3.

Within this framework, for different kinds of places at different scales, there is a very rich variety of possible mixtures of these various ingredients (whichever list is chosen), and we need to be able to understand this distribution. It is interesting to consider that (again up to inertia and historical constraints) there should be a market in a bundle of 'goods' which might be grouped together under the label of 'locational advantage', and what we might then expect to see is dynamics which aims to equalise this over time. Against this, and given imperfections in markets, a successful 'place' at any one time might be considered as a nexus of profit and high utility relative to other places. We have to learn how to measure these properties and to write our dynamic models in these terms.

Whatever basis we use for drawing zone profiles, we can begin to see how, in at least some obvious ways and perhaps ultimately, less obvious ones, typologies of zones can be developed which relate back to the traditions of central place theory. It is easy to imagine vectors of variables on either of the schemes noted above which distinguish:

* CBDs
* inner city residential areas
* suburbs
* ex-urbs

and so on. What we can then see is the possibility of mapping and explaining a much richer variety of spatial structures than traditional CPT. Andersson (1988) has used a different kind of categorisation of regions - as R-regions, I-regions and C-regions - and has argued that in modern economies, the C-regions are the most important and fastest growing and that other reiobns have to convert themselves. There are some interesting ideas here. However, this broad analysis offered in this paper suggests the possibility of seeking richer categorisations: what kinds of C-regions can we find in different kinds of situations?

Two broad conclusions can be drawn at the end of this analysis. First, the full set of interactions provides a crucial basis for understanding even with 'single zone' models; secondly, to build effective dynamic models, some of these interactions need to be valued in money terms, much more than is evident in current models - for it is only then that the profit functions can be calculated which form the basis of the dynamics.

We can then argue that if this basis can be established, then it can be incorporated fairly easily into multi-zone models: to an extent it becomes a matter of adding explicit interaction models and computation; though in terms of dynamic modelling, we will then be taken back to some difficult issues such as the 'backcloth' problem. We discuss the strategies for these steps in the concluding section.

5. Concluding comments.

The key argument of the paper is that in order to produce an adequate CPN model, it is necessary to take a broader view and to seek to build a general and comprehensive model which includes all interacting sectors. The nature of this task is explored by considering in detail the single-zone building bricks of such a model. It is also argued that generality in this context implies that the model should, in principle, be capable of working at any (particularly spatial) scale. What can then be seen is that, while dramatic progress has been made in modelling, there are vital gaps, particularly in economic modelling. In this case, models exist at some scales - such as the input-output model, but not at a sufficiently fine scale for CPN purposes. And yet to make progress, it is essential to grapple with this problem. There is a tremendous amount of research in both regional science and economic geography which has a bearing on this issue, but it typically falls short of formal modelling - and we should recognise, through the argument of Weaver or otherwise, that one of the reasons for this is that the problem, one of organised complexity, is inherently very difficult - made more so by the spatial extent of MNEs (multi-national enterprises).

To make progress, we will have to put more effort into the modelling task, emphasising the concepts which are likely to turn out to be important for understanding the issues of economic development at a fine scale (in terms of 'imports and exports'); and also to find new ways of making approximations. One recent paper which attempts to do this (while also acknowledging the immense difficulty of the problem) is that by Johansson (1987) mentioned in another context earlier. We have to find ways of relating the tremendous amount of qualitative knowledge about economic development to the scales which are relevant for CPN theory (e.g Hall, 1987 - and many others). This is a major intellectual challenge, one which is likely to, or ought to, represent a major shift in the efforts of modellers in the coming decade.

The advantage of taking a zonal or place perspective is that it forces us to consider the complex of elements, activities, processes and relationships at that place, and the ways in which they contribute to the wider spatial system. We already know from research on single-sector dynamic modelling that the spatial structures which evolve can be very sensitive functions of key parameters. What this analysis shows - though this is of course a conjecture, is that there are potentially other important interdependencies which help to determine the character and role of particular places.

We can summarise the shifts which are therefore needed and make some judgements about strategies to be adopted by modellers. Some of the possibilities are as follows.

(i) To articulate and recognise the full complexities of the modelling task; to use improved economic modelling with single zone building bricks to help to accomplish this.

(ii) To be prepared to work with e.g. money flows more explicitly, at least to seek to achieve the understanding of dynamics which this would facilitate.

(iii) This will demand new skills for making approximations to operationalise models in a realistic way; these in part can be developed from an understanding of the likely relative contributions of the large numbers of parameters which help to determine system form.

(iv) Part of making approximations will involve refusing to back away from building in variables (imports and exports again) which we feel to be crucial but for which data is typically not available; in the first instance, we will have to build more complete 'toy' models to complete our understanding and help to force the process of improving data availability where necessary.

(v) Part of the route to achieving this understanding will come from a large amount of running of (even 'toy') models in simulation form as the nearest we can get to an analytical approach to understanding the range of structures and behaviours which can be generated by the models now available to us.

(vi) Considerable additional insight should come from developing models and theories which are independent of scale.

(vii) This programme should generate new insights into the basic areas of urban modelling - where the zones are relatively small and represent 'urban' structure; but should also encourage the development of models at a scale where a new intellectual input is very much needed: whwre the zones are cities and subregions within larger regional and national systems: and this input is needed to facilitate the understanding and planning of economic development in a variety of contexts.

(ix) The programme should provide a framework for integrating currently very diverse styles of research.

The outcome of this discussion can be summarised diagrammatically, as in Figure 4. The main spatial scales and ther single-multi sector decision are depicted on one dimension and the main broad modelling areas on the other - these progressing, in part from the interaction to the evolutionary as depicted on Figure 1, but preceded by the demographic and economic modelling systems which are (in some respects) simpler.

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FIGURE 1 A scheme to review model development

3 phases of modelling:

(1) Interaction (disorganised) (steady state flows)

	flows	totals
work:	$T_{ij}^{mr}(\alpha,\beta,c_{ij})$	
services:	$S_{ij}^{mk}(\alpha,^1\beta,^1c_{ij})$	$D_j^k = \sum_{im} S_{ij}^{mk}$
goods:	$Z_{ij}^{rsg}(\cdot\cdot)$	$D_j^{sg} = \sum_{ir} Z_{ij}^{rsg}$

(2) Dynamics (organised, disorganised)

labour market: $\dot{T}_{ij}^{mr} = \varepsilon^{(1)} [\ldots]$

services: $\dot{W}_j^k = \varepsilon^{(2)k}[D_j^k - C_j^k] \ldots$

economy: $\dot{X}_j^{rg} = \varepsilon^{(3)r}[D_j^{rg} - C_j^{rg}] \ldots$

C_j^g, C_j^{rg}: specification of cost functions, essentially production functions

NB: structural dynamics and comparative static shifts via

α,β,c_{ij} in D_j^k, D_j^{rg} ...

temporal dynamic (chaos?) via epsilons

(3) Evolution

creation of new (r,g)'s or C_j^{rg}'s

then D_j^{rg}'s; then X_j^{rg}'s ...

FIGURE 2 Nested zonal systems

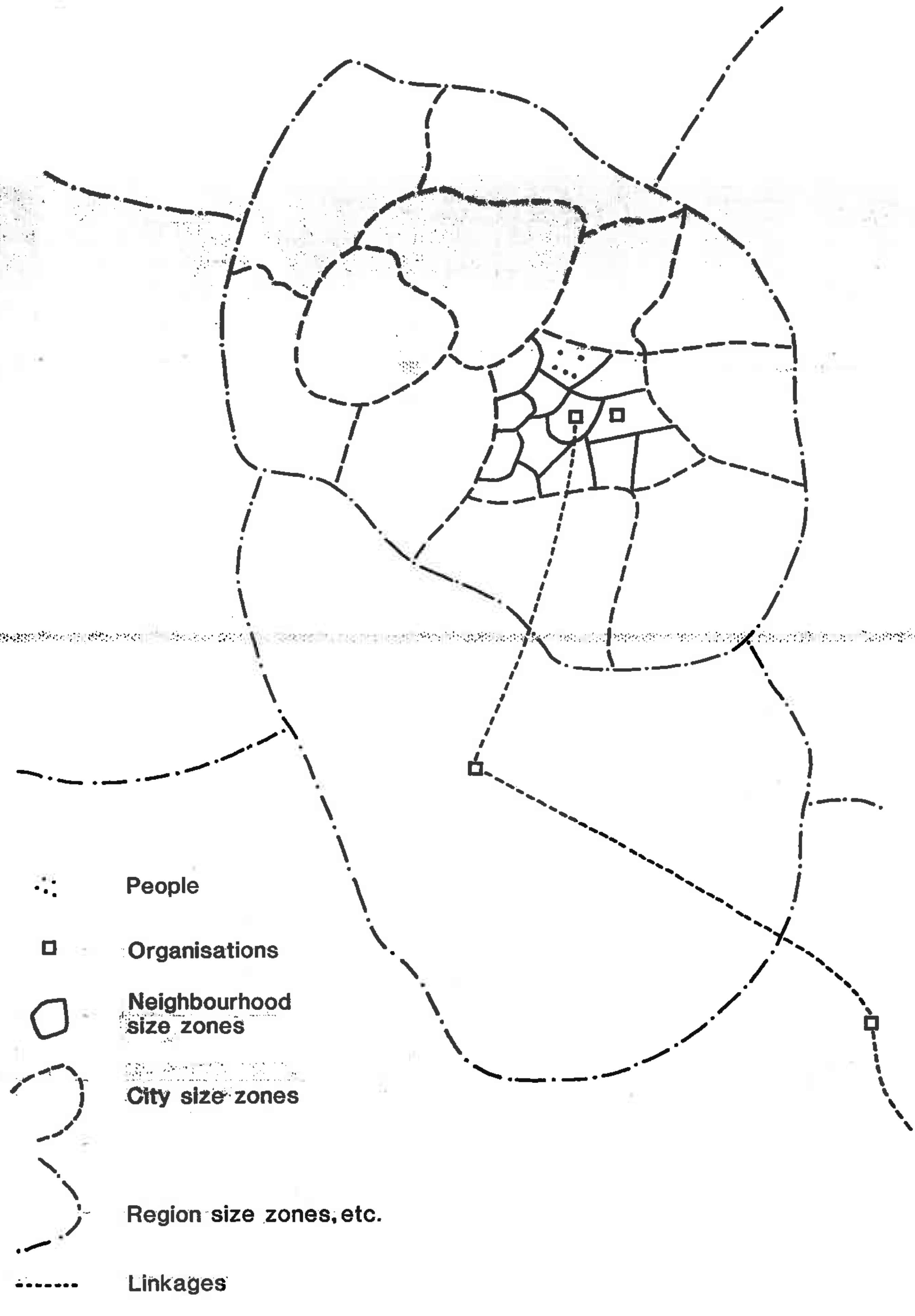

FIGURE 3 Zone profiles and typologies at different spatial scales

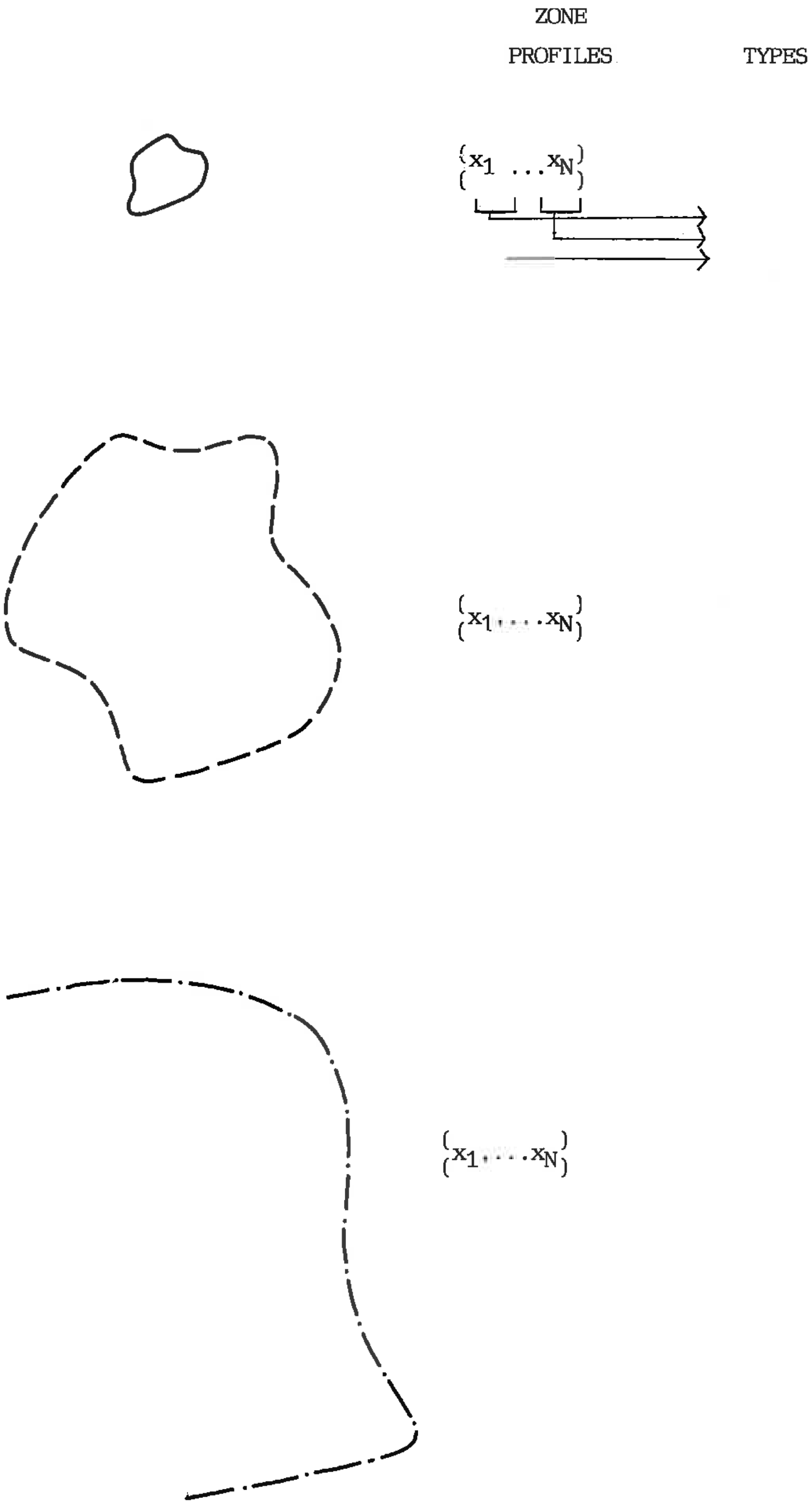

FIGURE 4 The opportunities for new modelling styles

		Dem	Ec (i-0)	Interaction (single sector)	Interaction (multi sector)	Dyncs	Evol
nhbd	single	√?	☐	√	☐	☐	. .
	multi	√?	☐	√	√	√?	. .
city	single	√	√?	√	☐	☐	. .
	multi	√	☐	√	☐	√?	. .
region	single	√	√	√	☐	☐	. .
	multi	√	√	√	☐	?	. .
country	single	√	√	√	☐	☐	. .
	multi	√	√	√	☐	?	. .

√ : possible in various degrees

☐ : modelling opportunities via single-zone building brick

Nested spatial scales