SOME METHODOLOGICAL AND EPISTEMOLOGICAL PROBLEMS INVOLVED IN SYSTEM DYNAMICS MODELLING

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ABSTRACT

This paper reviews the application of system dynamics modelling in a variety of substantive studies published between 1961 and 1981. A five-fold typology of system dynamics models is presented and this is followed by a methodological critique of many of these studies. On the basis of this review four fundamental epistemological problems are identified. These problems include the difficulties involved in closing complex, sub-global models, the various behavioural modes exhibited by dynamic models, the distinction between teleological and teleonomic perspectives and, finally, some aspects of the ideology of control are discussed in terms of conservative, reformist and radical uses of system dynamics models. It is argued that the methodological weaknesses and epistemological problems associated with many system dynamics models cast grave doubts on both their scientific content and usefulness to policy makers.

INTRODUCTION

In recent years there has been an increase in the number of publications which have applied system dynamics to a variety of substantive problems. In environmental science, for example, at least eight texts have emphasised the need to examine parts of the environment as dynamic systems. Several of these texts have noted the use of system dynamics as one method which could be applied to these problems (1-8). More generally, however, an examination of the rapidly growing literature concerned specifically with system dynamics reveals that few model builders have considered seriously the methodological and epistemological problems underlying the use of this method. As methodology is primarily concerned with the logic of explanation, that is with ensuring that our arguments are rigorous, that our methods are internally consistent and our inferences and use of data are reasonable, it is important to evaluate the method of system dynamics. Furthermore, as epistemology is concerned fundamentally with the conditions which make knowledge possible it is clear that these basic problems should be given more serious consideration than they have hitherto received (9, 10).

In this paper it will be argued that certain methodological and epistemological considerations which are embedded in any system dynamics model cast doubts upon their scientific content and the potential usefulness of these models to policy makers. In the following section a brief methodological review of various attempts to use system dynamics in substantive studies is undertaken. This review classifies over fifty studies into a five-fold typology, namely economic cycles and innovations; resource use; urban growth; regional and national models and, finally, world models. Whilst this survey is not exhaustive it is clear that very few of the studies would satisfy the methodological norms required by model building in scientific practice. Indeed, only one out of fifty studies have considered necessary an examination of some of the epistemological problems underlying the use of system dynamics. Hence, in section three, four inter-related epistemological problems are considered. These four problems can be identified as follows: the treatment of closure and complexity; steady and unsteady states of behaviour exhibited by some models; the crucial distinction between teleological and teleonomic perspectives in modelling real world systems and, finally, the ideological implications of control and policy options implicit in the use of some system dynamics models. The results of these methodological and epistemological considerations are then summarized in section four. The paper begins, however, with a brief methodological review of system dynamics modelling projects over the past two decades.

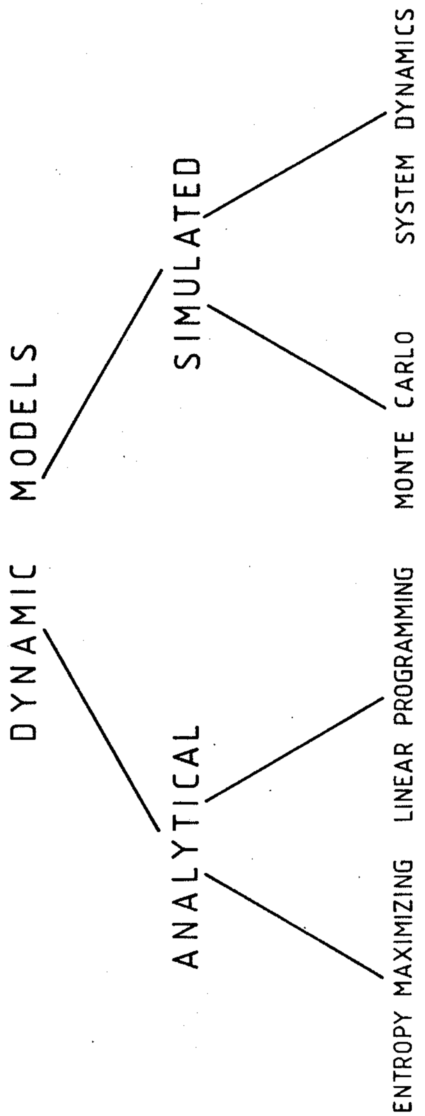
A METHODOLOGICAL REVIEW

Any dynamic model may be defined as a simplication of a real world system of interest which changes through time. With the growth, development and diffusion of computing facilities researchers have been able to produce a whole host of dynamic modelling techniques and the appropriate computer software. Generally, these techniques can be classified as either analytical or simulated models. In an analytical model the system of interest is represented by one or more equations which result in a unique solution to a particular problem. In the case of simulation models, however, the behaviour of a real world system is imitated by a set of deterministic or stochastic equations which are incapable of being solved analytically. A simple typology of dynamic models would include a variety of analytical techniques such as entropy maximizing methods or optimization procedures such as dynamic linear programming. Alternatively, Monte Carlo and system dynamics methods would be classified as simulation techniques (Figure 1).

Since the publication of Industrial Dynamics in 1961 (11) system dynamics modelling has been used in a wide variety of substantive studies. More than seven hundred references to system dynamics studies have been noted (12) and these can be conveniently classified into five groups, namely economic cycles and innovations; resource use and pollution; urban growth models; regional and national models and finally world models. Obviously, this typology of system dynamic studies is not exhaustive. In particular the classification excludes many of the applications undertaken by ecologists (13-16). It also excludes technical monographs concerned with DYNAMO and DYSMAP computer simulation languages as well as pedagogic publications using system dynamics (17-23). Despite these limitations it is instructive to examine these widely published studies in order to uncover important methodological and epistemological problems involved in using system dynamics as a technique for building dynamic simulation models.

ECONOMIC CYCLES AND INNOVATIONS

The cyclical behaviour of the capitalist economic system has fascinated economists and economic historians for many decades. By the

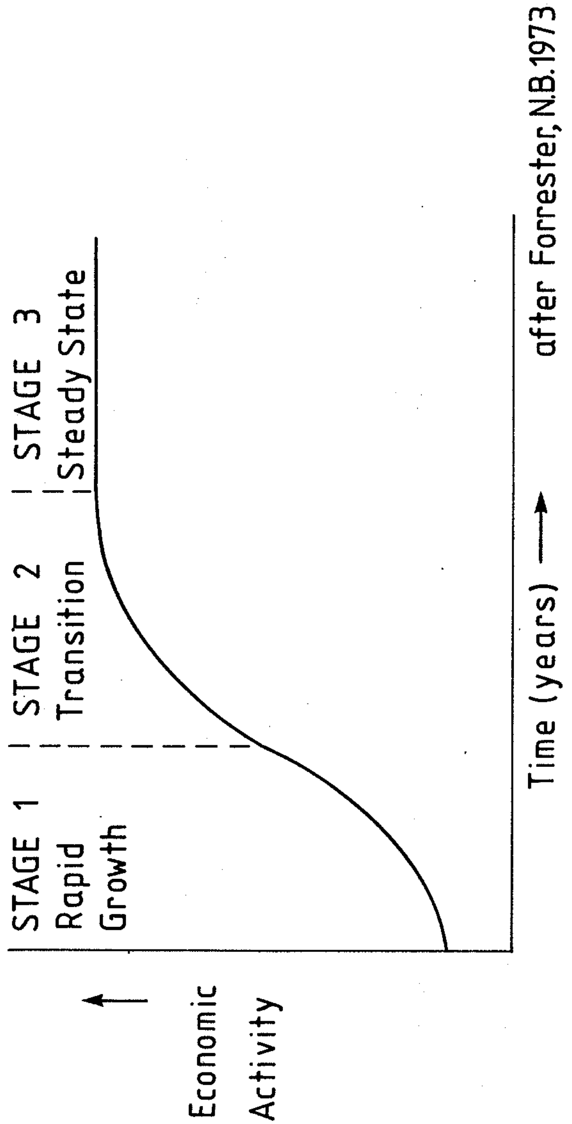


A simple typology of dynamic models

Figure 1

1970s several system dynamic model builders were examining the cyclical nature of commodity production (24), Keyne's General Theory as a disequilibrium model (25) and the 'life cycle' of economic growth (26). Two other related papers used system dynamics to model market penetration and technological substitution, which are intimately related to cyclical economic behaviour (27, 28). The interaction of the trade, Kuznets and Krondratieff cycles had by 1979 been explained as cases of over expansion and collapse of capital producing sectors of a hypothetical market economy (29-31).

Whilst it is difficult to explain the various non-seasonal temporal fluctuations in economic behaviour within market economies it is clear that the system dynamic models do not clarify an already complex debate. Out of the eight system dynamic models which have examined various forms of cyclical economic behaviour only the output of one of the models has been tested with real world data. This makes it impossible to judge the empirical content of these models. Furthermore, there is an acute danger that a spurious three-stage life-cycle of economic growth will be introduced into this debate. This three stage life-cycle is characterized by exponential growth followed by a transition stage which finally reaches a state of dynamic equilibrium (32). Whilst Forrester notes that the life cycle of economic growth must not be confused with other economic cycles, it cannot be overstated that this hypothetical three stage life-cycle is not a matter of fact (Figure 2). Indeed, if we examine any of the relevant long time series data it becomes apparent that economic historians have not even



after Forrester, N.B.1973

The hypothetical three-stage life cycle

Figure 2

recorded this so-called cycle (33, 34). Despite the doubts concerning the existence of this life-cycle, its validity has been assumed in many of the system dynamic models. This problem will be re-examined below (c.f. section 3).

RESOURCE USE AND POLLUTION

Since the mid-seventies western advanced industrial nations have had to pay increasing attention to the twin problems associated with increased resource use, namely finding sustainable energy sources and effectively dealing with pollution. In 1975 two studies examined the role of coal in bridging a possible energy gap in the United States of America. Using a four sector model incorporating energy demand, oil and gas supply, electricity generation and coal production it was argued that a series of policy changes could be made in order to ensure a smooth transition from the exponential growth in non-renewable energy resource use to the use of renewable and potentially sustainable forms of energy. Whilst this study does use real world data to calibrate the model it is again predicated in the assumption that energy use in the United State of America will follow a three stage life-cycle similar to that assumed in the studies concerned with economic development (35, 36).

Whilst the researchers into the use of coal as an energy option for the United States of America may have faith in their models it is by no means certain that renewable sources of energy can provide sufficient energy for consumption in this century, let alone the next one. In 1982, for example, a system dynamics model of solar enhanced energy scenarios were produced based on an earlier energy study (37, 38). This study makes rather gloomy reading, since it concludes that, assuming no new energy technologies are introduced, by 2010 non-renewable reserves of oil and gas will be depleted. Furthermore, assuming that no breeder reactors are in operation then uranium will be exhausted by 2030. Twenty years later the reserves of coal will be depleted by 60%. Even if solar energy is introduced into the national energy budget of the United States of America, it is argued that this source of power will only postpone the day of inevitable collapse in energy requirements and ultimately economic power by about one century (39).

One of the difficult problems in examining the movement of a pollutant in the environment is being able to collect the relevant data in a consistent and scientific manner. In 1972 an attempt was made to simulate the movement of DDT in the global ecosystem. Owing to the incomplete evidence of these movements of DDT in various compartments of the ecosphere it was noted that model builders were unable to make exact quantitative predictions of the levels of accumulation of DDT in the system (40). Similarly, in modelling sulphur dioxide in an urban area the absence of good data can only indicate areas where further detailed quantitative research are needed(41).

URBAN GROWTH

In 1969 Forrester published another pioneering computer simulation model describing the growth and development of an hypothetical urban area (100,000 acres), consisting essentially of a male labour force, housing and industry (42). Forrester's model received a great deal of criticism since he ignored almost all of the immense literature concerned with urban growth and development. Furthermore, the original model was not subjected to empirical testing and was therefore unable to prove its mettle. Nevertheless, several researchers have attempted to modify the original model or build their own models in order to subject these models to the hazard of empirical refutation (43). These researchers have demonstrated that the original model of urban dynamics is a reasonable simulation of some patterns of urban growth in the western world. There are, however, some reservations about the structure of the model and the degree of fit between the model and the real world data (44).

In 1972, for example, the original model of urban dynamics was applied to Harris County, Texas, based presumably on the town of Houston (45). Similarly, the pattern of urban growth of Lowell, Massachusetts was simulated using the model of urban dynamics for the period 1801 to 1970 (46). In both cases many of the parameters in the original model had to be changed so that it could simulate the pattern of growth of these two towns. In the Harris County study it was claimed that the major variables were reasonably close to the actual data although many of the minor variables often showed large deviations from the data. This weakness in the model was thought to be a function of the assumptions used to define the sub variables in order to match them with the actual statistical data. In the Lowell study nine parameters were changed in Forrester's original model in order to produce a reasonable fit both in terms of the magnitude and timing of the peaks and decay of the main state variables recorded in statistical sources. Superficially, the empirical success of the original model of urban dynamics has to be tempered by the criticisms that in the Lowell study the minor variables demonstrated an extremely poor fit with the observed Lowell minor variables (47, 48).

Whilst the original model of urban dynamics attempted to simulate a single, hypothetical urban area several researchers have attempted to interconnect a series of 'urban dynamics' models to form a system of cities. In Britain, for example, three hypothetical cities were inter-connected using various migration equations based on a variety of different assumptions (49). A more ambitious effort has been undertaken in the United States of America when a set of central city areas and suburbs were inter-connected to form a national metropolitan model (50). This latter model has not, as yet, been calibrated to simulate the actual patterns of urban growth in the United States, but it does point a direction for future research in urban modelling at the regional and national scale.

REGIONAL AND NATIONAL MODELS

System dynamics was first used to simulate regional systems in 1969 with the study of the Susquehanna River basin (51). Although in that pilot

study the drainage basin was subdivided into eight sub-regions each area had the same model structure with interaction only limited to the water sector, employment and demography. As the model was commissioned by ten electric power companies the interest focused upon the adequacy of water resources under a range of assumptions for economic growth, water consumption and the impact of pollution. It was concluded that water was not a constraint to regional development in the drainage basin. One year later, a system dynamics model of Kent County was produced (52). This model also attempted to link economic and demographic variables into a dynamic model. The result of this model, however, reveals large discrepancies in the 'professional/technical' sector of the population when compared with the real world. This result was due either to a poorly specified set of migration equations or to deficiencies in the actual migration data.

By 1973 Lowry's famous model of the metropolis was given a system dynamics interpretation set in an hypothetical regional setting (53). In the same year the performance of the United Kingdom's Northern Economic Region was modelled as REG 2 (54). Like the Susquehanna River basin model the objectives of this pilot study were to evaluate the impact of proposed major regional development policies on the area. One of the model's characteristic behavioural modes was to forecast massive out-migration of the unemployed from the region which gradually reached a state of dynamic equilibrium. Later, in 1976, a revised model REG 3 was built in order to make the model's behaviour more credible (55). In particular REG 3 was able to simulate an endogenously generated business or trade cycle which would, of course, have an impact on industry and employment. Despite this methodological improvement the problem of massive out-migration of the unemployed was not resolved. In fact REG 3 is more akin to a macro-economic model than a demographic-economic model.

At the national scale several system dynamics models have been produced (56). For example, in Britain it has been argued that it is naive to model a single urban area or region on the assumption that the outside environment forms a limitless source or sink for migrants. The unusual behaviour of both REG 2 and the original model of Urban Dynamics is partly the result of incorporating poorly specified migration equations into the models structure. Hence, some research has been directed towards integrating all ten economic regions in Britain so that the migration equations simulating the movement of people between the different regions can be carefully constructed, constrained and calibrated (57). More recent research has produced a set of migration equations for a national system of urban and regional units based on the twin assumptions that inter-regional or inter-urban moves are determined by employment opportunities whereas short distance moves are determined by the state of the housing market. The results of this dynamic modelling research using a four-fold then a ten-fold age cohort have indicated empirically that the general bases of the migration equations embedded in the models are sound (58). Perhaps the

most ambitious national model currently being developed is the System Dynamics National Model (59). This model consists of six basic sectors: production, finance, household, demography, labour and government. These sectors interact to simulate various types of endogenously generated economic cycles, including the trade or business cycle, the Kuznets and Kondratieff cycles. At present the model is not calibrated to simulate the real world behaviour of an advanced industrial nation so it remains a set of interesting, plausible hypotheses. The model does, however, have the potential to explain the complex socio-economic behaviour of a country's economy in the copilatent system.

WORLD MODELS

Whilst migration equations are very important in inter-connected national models composed of cities or regions the pattern of migration can be temporarily suspended in aggregate models of the world. In 1971, Forrester produced a preliminary model of world dynamics (6). Later, this system dynamics approach to world modelling was extended in the poorly documented 'Limits to Growth' text and in the more serious academic study of the dynamics of growth in a finite world (61, 62). Yet even this latter text depended heavily upon the suspect Malthusian argument (63, 64). Meadows et al. note that in a finite world system society will attain a more favourable and sustainable equilibrium state the sooner it begins to manage the transition to global equilibrium (65).

It is not necessary to re-iterate all the methodological criticisms which have been made of these models. Nevertheless, it is important to focus attention on some of the most important methodological errors. First, it has been argued that the structure of these world models necessarily leads to a gloomy future for mankind or, at best, a state of dynamic equilibrium if draconian policies are immediately implemented (66-70). Some research has, however, shown that by introducing social feedbacks into this class of world models the gloomy predictions or forecasts evaporate (71). Next, the level of aggregation has been criticised as too simple, especially in the case of subsuming all the various types of pollutants and non-renewable resources into two state variables. Whilst any model has to have a certain degree of aggregation it is rather meaningless to assume that all non-renewable resources and pollutants have the same impact on the ecosphere. Third, it has been argued that in some cases the functional relationships are spurious. In the pollution sector, for example, it can be demonstrated that the structure of the model will inevitably cause massive amounts of pollution in the ecosphere (72). An even more crucial point is that very few of the relationships or variables in the early world models have been drawn from actual data or empirical studies. In the world models and in many of the system dynamic models reviewed above, the reader is presented with measurement without data (73). Even when empirical relationships are used, as in the most recent World 3 model, it can be shown that the relationships are incorrect. Witness, for example, the relationship between

the cost of exploration and the fraction of unproven reserves remaining which are shown as a curve which misses all the data points rather than a simple linear regression line. Similarly, if the constant parameters life expectancy normal in World 3 is set at the real world value of 56 years and not 28 years, then the global population does not reach crisis proportions and the spectre of Malthus in laid to rest.

Given this obvious lack of methodological rigour in many of the system dynamic models it is clear that policy recommendations emanating from many of these models must carry little or no conviction. Yet this has not prevented many of the system dynamic model builders from offering policy recommendations. According to Naill, 'the ultimate measure of the validity of a model lies in its utility to real world policy makers' (74); the implications of this stance are awesome. Whilst this methodological review has highlighted some of the major weaknesses inherent in many of the system dynamics models, it is still necessary to consider some epistemological problems in this class of dynamic models.

SOME EPISTEMOLOGICAL PROBLEMS

So far in this review we have avoided any coherent examination of the epistemological problems underlying the use of system dynamics. Yet, as epistemology is concerned with the conditions which make knowledge possible it is clear that this fundamental problem must be considered. Hence, in this third section, four related epistemological problems are examined: the problem of closure and complexity; steady and unsteady states; teleological and teleonomic views and finally the ideology of control.

THE PROBLEM OF CLOSURE AND COMPLEXITY

At the outset it is obvious that any system can be defined as a set of functionally related units. The word set implies that the units have common properties which are functionally inter-connected by flows of energy, materials (including money) and information. The state of a unit or level is constrained by or conditioned by or dependent on the state of other units in the system of interest. Obviously, in many substantive studies it is difficult to define the boundaries of a system of interest. Only at the global scale is the task made relatively easy since the world can be conceptualized as a closed system with the exception of the vital inflow of solar energy.

In the analysis of any sub-global system it is useful to construct a model of the system by defining its boundaries which provisionally or a priori exclude units which are either of no or little importance to the substantive problem under investigation. This immediately poses a major epistemological problem as the researcher has to define his/her system in an arbitrary manner. Obviously, subsequent research may often mean that the boundaries have to be modified from the original a priori delineation. This may, however, involve incorporating a previously exogenous unit into the structure of the model. It was noted in the previous section that in many of the urban and regional/national models failure to account for extra regional linkages have resulted in unusual migration behaviour, especially in the case of Urban Dynamics and REG 2.

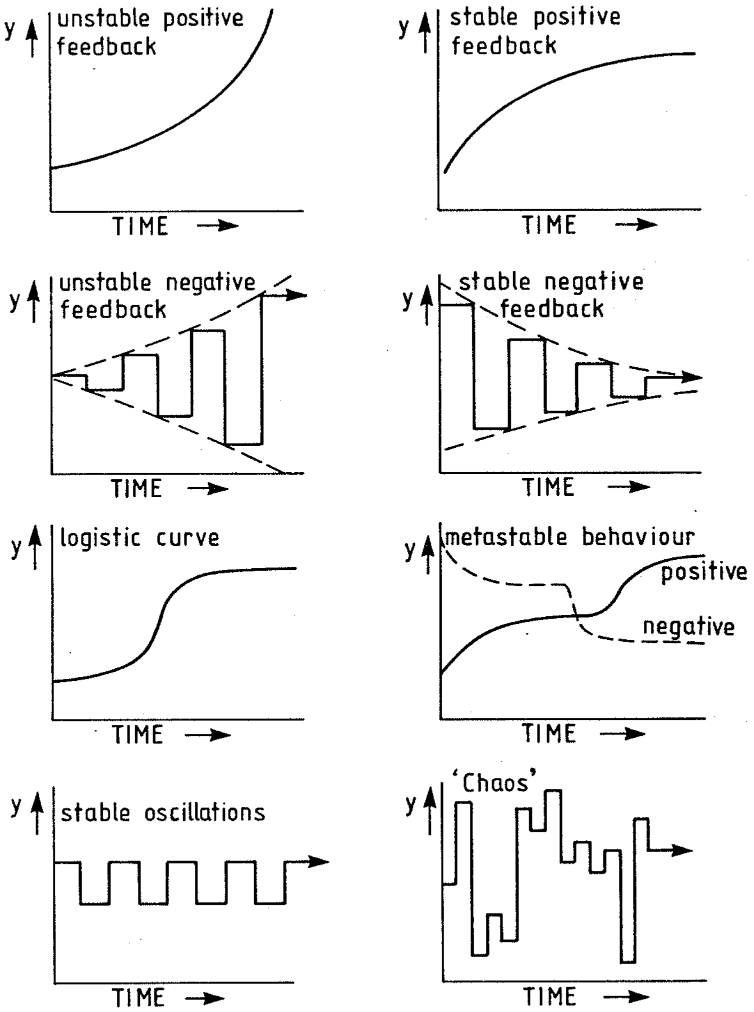
Once the problem of analytical closure has been satisfactorily resolved then the model builder must construct a causal diagram which shows the functional relationships between the state variables or levels. As many of the systems of interest are complex it is essential to simplify the causal flow diagram so that the hypothesised major inter-connections are still retained. In this creative act of simplification, however, it is possible that one or more major links are ignored. In the case of 'World Dynamics', for example, an important social feedback loop is omitted having serious consequences for the subsequent behaviour of the model (75).

In order to know if a link is of major or minor importance it is very clear that some measure of the strengths of associations between various state variables is determined. This requires that the relationships are stated quantitatively or, if put into a model as a qualitative estimate, that rigorous parameter sensitivity tests on these relationships are performed. Unfortunately, very few of the system dynamic models reviewed in the previous section actually use empirical data or detailed parameter sensitivity tests. Hence, it is impossible to judge whether or not the linkages are of major or minor importance. It must of course, be noted that parameter sensitivity tests and calibration of a model are irrelevant if the structure of the model is wrong. This leads us to consider the epistemological problems associated with the behavioural modes of many system dynamic models.

STEADY AND UNSTEADY STATES

One of the characteristics of many system dynamic models is the complex way in which the internal positive and negative feedback loops interact. In a positive feedback loop a change in one element in the loop reinforces another change in the same element and thus drives the entire loop on a trajectory of growth or decline. In a negative feedback loop, however, the model of the system is capable of reaching some goal or steady state. Whilst the interaction of negative and positive feedback loops may give the system a greater flexibility to respond to exogenous changes it is clear that a very strong endogenous positive or negative loop can dominate the behaviour of the entire system. Obviously, it is important to identify these dominant loops in any system dynamics model.

The ways in which systems change have been noted by several researchers (76, 77). Even in the case of a simple system composed of only two deterministic equations, chaotic behaviour can be observed in computer simulation work (78, 79). At least eight modes of behaviour can be noted, namely unstable and stable positive feedback; stable and unstable negative feedback; stable oscillations; metastable systems; logistic curves and feedback; stable oscillations; metastable systems; logistic curves and chaos (Figure 3). As noted earlier, out of the eight theoretically possible modes of dynamic behaviour in systems models the preferred mode of many system dynamics model builders is a form of logistic curve. In several



Eight modes of systems behaviour
Figure 3

publications the so-called life-cycle of economic growth has been assumed to be a steady state goal to which many systems would try and achieve. The vision of a steady state economy assumes a world in which sufficient wealth is efficiently maintained and allocated in an equitable manner. This utopian vision has appealed to many economists ranging from Mills to Daly (80, 81). Whilst this may be one desirable vision of the future it is abundantly clear that these arguments are often used to justify different conceptions of how to manage the same socio-economic system and not about radically different socio-economic systems (82).

In several of the models reviewed earlier, the steady state solution is achieved by massive outmigration of the unemployed. Whilst this apparent solution may be one policy option available for a single city or regional administration, it is very difficult to justify the same policies at the national level although forced migration has recently been effected in Nigeria. Even more serious is the fact that the steady state solution predicted in the World 3 model is achieved by exterminating 25% of the labour force.

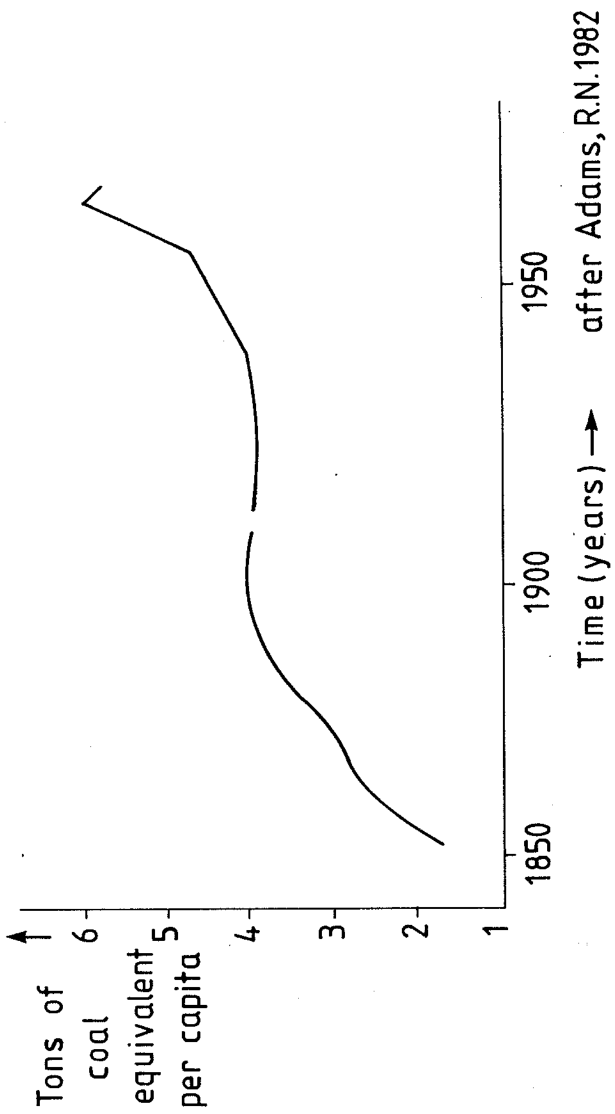
TELEOLOGICAL AND TELEONOMIC PERSPECTIVES

In many system dynamic models it is assumed that the real world system could be manipulated in order to achieve a steady state or condition of dynamic equilibrium. In the World models, Urban Dynamics and several energy studies it has been assumed that rapid growth of resource use must pass through a period of transition and finally reach a state of dynamic

equilibrium. If this behaviour is actually observed in the real world then it could be argued that some processes of dynamic homeostasis are in operation which may be likened to a model of the real world system dominated by a goal seeking loop. It is, however, vitally important for modellers not to confuse their models of the real world system with reality (83).

If we are not to mislead ourselves, policy makers or the public, it is important to distinguish the differences between teleological and teleonomic perspectives. In the former case, if a system of interest appears to reach a certain final state of behaviour then it may be inferred that the philosophical doctrine of final causes has been in operation. A teleonomic perspective, however, ensures that a model of a system reaches a desired goal because of the instructions in the computer program and not because of teleological suppositions. The following example will clarify this crucial epistemological distinction.

In a recent study of energy and economic history in Britain it has been shown that Britain reached a steady state in terms of energy consumption per capita by 1890 (84). This steady state lasted for about sixty years until the actual pattern of energy consumption again began to grow rapidly (Figure 4). From the graph it is clear that the actual pattern of British energy consumption per capita does not conform to the so-called life-cycle of economic growth or the logistic curve beloved by so many system dynamic



after Adams, R.N. 1982

United Kingdom energy consumption per capita, 1850–1972.

Figure 4

model builders. If a model builder attempted to simulate this growth in energy consumption it is clear that a teleonomic model would offer only a pale reflection of the actual events. Furthermore, policies designed to stabilize energy consumption per capita between 1900 and 1950 would only result in retaining low levels of energy consumption whereas, in fact, much higher levels have been achieved. Clearly, the use of a teleonomic system dynamic model would seriously underestimate the capacity for real socio-economic systems to adapt and change to new and higher levels of production and consumption of energy. In short, more research effort ought to go into understanding the dynamics of meta-stable models which have the potential to replicate the real world rather than prematurely trying to control it.

THE IDEOLOGY OF PLANNING AND CONTROL

One of the features of system dynamic model building is the emphasis placed upon planning and control options available to decision makers. Meadows, for example, notes that the purpose of World 3 is to identify future policies that may lead to a stable rather than unstable form of behaviour in the global pattern of population growth and material output (85). Similarly, other system dynamic model builders have advocated policies on urban, regional and resource use despite the serious weaknesses of their models. Underlying these various policy presumptions is the important epistemological problem concerned with the ideology of planning and control (86).

In the early applications of system dynamics modelling it was argued that more efficient and profitable management of an individual industrial plant could be achieved by modelling the system of production (87, 88). Once the model of the system was understood it is a relatively simple task in systems modelling to maximize a particular objective function subject to certain constraints. In the case of a motor car factory, for example, the number of vehicles produced could be increased if the management and work force could agree on ways in which to implement changes predicted in the model of the system. Translating the policy or control options from a computer model to the real world is, however, fraught with difficulties. In the case of a simple industrial plant it is assumed that every employee agrees with the aims and proposed changes to maximize a particular objective function. Often, however, not all employees agree with the proposed changes. One result of the proposed change to established patterns of work practice is in industrial disputes; alternatively, the employers may alter the work schedules in order to achieve the new production targets at the expense of the work force and hence create unemployment in order to preserve and accumulate capital.

With advances in systems modelling the problems involved in maximizing industrial production in one factory have been dwarfed by attempts to model and control urban, regional, national and global systems. Several writers have noted these changes with alarm as the control and manipulation of nature entails a domination of people by the techniques of domination (89, 90). As Kennedy notes, the major aim of some environmental scientists and geographers is to achieve world domination in the most complete and efficient fashion using systems models (91). Clearly, if this is the goal which many system dynamic model builders are working towards then, as Gregory points out, such systems models, if put into practice are ideological as they secure the reproduction of specific structures of domination (92).

It could, of course, be argued that the goals which several system dynamic model builders cherish are not inhumane or unjust even if they are somewhat utopian. Meadows, for example, suggests that changes in economic, political and social structures may be required in order to create a decent and sustainable standard of living for all (93). Unfortunately, the ways to achieve this aim are not mentioned, although in the World 3 model several draconian policies are implemented in order to achieve a state of dynamic equilibrium. Similarly, in a recent paper concerned with a global new economic and political order it has been noted that any world model which stresses the concept of equity as an overriding goal will require a substantial effort in addition to formal mathematical modelling (94). Clearly, to define the aims and methods required to achieve such goals immediately raises ideological problems.

At least three distinct ideological alternatives concerning the basic requirements for ensuring the conditions of survival of the human race in harmony with the natural world can be discerned in the literature. The first approach of conservative orthodoxy stresses the need for cosmetic changes which do not radically alter the economic and social system of capitalism or state socialism. Hence, in the West several writers have stressed the fact that the market mechanism can solve the problems which it creates, such as resource scarcities, massive unemployment and large scale pollution (95). A somewhat similar conservative orthodoxy is found in the ideologies of the East who argue that 'only under socialism .... under central planning carried out in the interests of the whole society and on a long term basis, can an exchange of matter between people and nature be established that would be adequate to the nature of man' (96). A more liberal ideological approach has been proposed which stresses the need for a world view based on sharing and co-operation (97, 98). Unfortunately, this liberal position has quickly degenerated either into clothing capitalist underdevelopment in a cloud of respectability, as in Brandt's North-South Report, or into a search for some new environmental ethic which underpins the World Conservation Strategy (99, 100). In contrast, the radical perspective is opposed to the status quo, offering a real attempt to dislocate the elites who control the multi-national capitalist corporations and the centrally planned state bureaucracies so that a rational, equitable, ecologically sound and socially just production and distribution of the world's resources can be achieved (101, 102). Whether this radical goal can be achieved by peaceful or violent means is, of course, the real problem. In

human history peaceful tactics have rarely achieved these goals. If, however, a violent course of action is pursued then there is a grave danger of a new era of totalitarianism under the guise of planned capitalism or planned socialism (103). There is also the real danger of a nuclear apocalypse which would, of course, render any discussions about the world's future obsolete. Clearly, in discussing fundamental questions concerned with human survival the three ideological perspectives need very deep thought as a guide to action.

CONCLUSION

This paper has examined some of the major methodological and epistemological problems involved in system dynamics modelling. Whilst the review is not exhaustive it has highlighted severe methodological weaknesses in this class of simulation models. In particular, the following conclusions can be noted. First, in any simulation model it is important to ensure that the simulation is related to a body of theory; that the functional relationships are carefully specified and tested; that the parameters in the model ought to be carefully scrutinized in order to reveal sensitive parameters. Wherever possible the simulated output of the major and minor variables ought to be checked with the relevant historical time series data in order to verify the model. As Naylor and Finger have noted, 'simulation models based on purely hypothetical functional relationships and contrived data which have not been subjected to empirical validation are void of meaning..... and such a model contributes nothing to our understanding of the system being simulated' (102). Until these methodological problems are resolved the value of system dynamic models is decidedly suspect.

Underlying these important methodological issues are several fundamental epistemological problems which also need careful consideration. It has been argued that in several system dynamic studies the problem of closure and complexity has been handled in an inadequate fashion often leading to a steady state by massive outmigration of the unemployed. Furthermore, it has been noted that several influential system dynamic studies prefer a logistic mode of behaviour as the final state whereas several modes of behaviour are possible. Indeed, meta-stable behaviour is often recorded in real world systems. Whilst the ideals of a steady-state may be a desirable normative goal many of the computer programs used in system dynamics models would inevitably result in this mode of behaviour. There is, of course, a large discrepancy between the instructions in a computer program and the mischievous way the real world behaves. It is quite clear that many of the system dynamic models are neither methodologically sound nor epistemologically valid. With these failings, it becomes academic to propose policy changes emanating from such models. If, however, the conservative policy presumptions were actively pursued they would simply reinforce the politics of repression which support wealthy minorities at the expense of the rest of mankind. But, perhaps, that was the ideological purpose of these models all along.

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