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AN ATTEMPT OF LONG-RANGE MACROECONOMIC MODELLING IN VIEW OF STRUCTURAL AND TECHNOLOGICAL CHANGE

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PREFACE

At IIASA consideration is given to the timing of planning if not forecasting. Most of the existing economic models make use of input data such as elasticities and others that are taken from today's and yesterday's situation and thereby suggest that the applicability of such economic models may be of a time span of five to ten years or so. The observation has been made that such models should be used only with such a time frame and with the idea of indicating certain brinks. The analysis of such brinks is then a different matter. At IIASA the attempt has been made to apply the modern methods of differential topology to this brink analysis. This work evolves from the research of the Ecology Project related to resilience. The following papers are illustrative of the work on resilience at the Institute:

Häfele, W., "Objective Functions." Unpublished internal paper.

Holling, C.S., "Resilience and Stability of Ecological Systems." IIASA RR-73-3.

Avenhaus, R., D.E. Bell, H.R. Grümm, W. Häfele, H. Millendorfer, L. Schrattenholzer, C. Winkler, "New Societal Equations." Unpublished internal paper.

Clark, William C., "Notes on Resilience Measures." Unpublished internal paper.

Grümm, H.R., "Stable Manifolds and Separatrices." Unpublished internal paper.

Jones, D.D., "The Application of Catastrophe Theory to Ecological Systems." IIASA RR-75-15.

Grümm, H.R., Ed., "Analysis and Computation of Equilibria and Regions of Stability--with Applications in Chemistry, Climatology, Ecology and Economics--Record of a Workshop." IIASA CP-75-8. Workshop on "Computation of Equilibria and Stability Regions", July 21-August 11, 1975, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Grümm, H.R., "Definitions of Resilience." IIASA RR-76-5.

The present paper is a further step in this sequence. It proposes to consider a macroeconomic model in view of such envisaged brink analysis by differential topological methods.

ABSTRACT

The paper presents an aggregated (five sector) circular flow model of economic development. A key concept, the "societal technology" implicitly, by means of a stratified dynamical system, describes the alternative paths of development that are open to a society. Societal objectives, which determine the actual path, can enter in both a purely descriptive, positive way and as normative "planner's preferences". The aim of the paper is to provide a conceptual basis for the investigation of long-term socioeconomic processes with the tools of dynamical systems theory.

INTRODUCTION

This paper presents an aggregated circular flow model of economic development. It is an extended version of the so-called "New Societal Equations" [1]. The aim of the paper is to provide a tentative basis for the study of long-term economic development and structural change within the framework of dynamical systems theory.

The differential equations model we propose looks oversimplified from the economist's viewpoint. Already from this fact it should be clear that it is not meant to be used as a quantitative planning or forecasting model. On the other hand, once we have decided to analyse global dynamical properties not merely by (heuristic) simulation techniques but also by exact mathematical methods, we have to severely restrict the complexity of the model set-up. The reason is that even "simple looking" nonlinear systems may display an enormous complexity in their dynamical behaviour.

We believe that the much more complex and computer based econometric models, which are very much in vogue now, can be very useful in answering the quantitative planning problems of today and tomorrow, but they are not very convincing when it comes to truly long-run considerations. This is so mainly because structure and technology of the models are estimated from collected data and then kept fixed--an assumption which is often dictated by the high degree of complexity of the model but which seems rather unrealistic when dealing with long-run processes.

Biology teaches us that whether certain species, i.e. living dynamical systems, persist or become extinct is to a large extent determined by their ability for structural change. Carrying this observation over to economic systems, we feel that one should first acquire a thorough qualitative understanding of the process and the structural dynamics of simple socioeconomic models before starting to produce numerical forecasts for the year 2000.

We now proceed to describe the model in detail and then, in a second part, give some thought to the approach in general.

THE MODEL

General

The model economy we will consider is divided into 5 sectors:

- Production and distribution;
- Demographic sector;
- Capital;
- Energy;
- Foreign balance.

We introduce the energy sector in addition to the "traditional" sectors because the model at a later stage should contribute to the qualitative evaluation of long-run technological strategies such as the optimal transition from fuel-constrained to non-fuel-constrained energy technologies.

Production and Distribution

The production and sectorial distribution of real output flow (see also Figure 1, p. 9) are described by the equations:

$$Y_t = A_t \cdot L_t^{\alpha} \cdot K_t^{\beta} \cdot E_t^{\gamma} \quad , \tag{1}$$

$$Y_t = C_t + I_{et} + I_{kt} + I_{ft} + I_{it} + F_t \quad , \tag{2}$$

$$C_t = c_t \cdot p_t \quad , \quad C_t = (1-s_t)\, Y_t \quad , \tag{3}$$

where:

Y_t = production output flow (real gross regional product);

L_t = labour input flow;

K_t = capital input flow;

E_t = energy input; and

$E_t = E_{it} + E_{ft}$,

where:

E_{it} = infinite fuel energy flow,

E_{ft} = finite fuel energy flow.

$I_{\cdot t}$ is investment (non-consumption) on:

I_{et} = education (human capital);

I_{kt} = capital;

I_{it} = infinite fuel energy;

I_{ft} = finite fuel energy;

C_t = consumption;

F_t = foreign payments received and paid in terms of real output flow;

A, α, β, γ = technological coefficients of production, $\alpha + \beta + \gamma$ often assumed to equal 1;

c_t = consumption "per capita";

s_t = macroeconomic saving rate; and

P_t = population.

It is often realistic to assume that c_t is fixed for developing regions and s_t is fixed for developed regions.

<u>Demographic Sector</u>

Population P_t and the number of skilled labour L_t are assumed to be determined by:

$$\frac{\dot{P}_t}{P_t} = \frac{a_p}{c_t}\left(1 - \frac{P_t}{P_\infty}\right) - d \quad , \tag{4}$$

with

$$c_t \equiv \frac{C_t}{P_t}$$

and

$$\frac{\dot{L}_t}{L_t} = \frac{1}{P_t}(P_t - L_t)\frac{I_{et}}{p_e} - d \quad , \tag{5}$$

where:

P_t = population ;

p_e = price of education in terms of units of consumption;

d = "death rate";

$\frac{a_p}{c_t}(1 - \frac{P_t}{P_\infty})$ = "birth rate"; and

a, a_p, p_e = coefficients.

Equation (5) means that the evolution of the skilled labour force L_t depends on the population dynamics <u>and</u> on the investment in human capital I_{et}. With high spending on education the ratio L_t/P_t can approach 1. On the other hand a certain positive I_{et} is necessary to maintain an initial or target L_t/P_t ratio over time.

In [1] an equation was used for population growth which is slightly different from (4):

$$\frac{\dot{P}_t}{P_t} = a_p(1 - \frac{P_t}{P_\infty}) - d\, y_t \quad , \tag{6}$$

with

$$y_t \equiv \frac{Y_t}{P_t} \quad .$$

The choice should be made by using statistical evidence, e.g. [4], [5]. One would expect problems with formula (4) for very low c_t values and with (6) for very high values of y_t.

Capital

The capital sector is treated in a standard way by the process equation relating investment, depreciation and capital stock:

$$\lambda_k K_t + \dot{K}_t = \frac{I_{kt}}{p_k} \quad , \tag{7}$$

where:

p_k = price of capital investment in terms of units of consumption;

λ_k = depreciation rate of capital.

Note that $\dot{K}_t$ can be positive or negative according to whether real capital investment surmounts depreciation or not.

Energy

This sector comprises two subsectors itself:

1) E_f = flow of limited resource, but in the short run relatively "cheap" energy.

2) E_i = flow of unlimited resource, but in the short run relatively expensive energy.

The trajectories of E_{ft} and E_{it} satisfy the following equations, which are analogous to (7):

$$p^1_{ft} \cdot E_{ft} + p^o_{ft}(\dot{E}_{ft} + \lambda_f E_{ft}) = I_{ft} \quad , \tag{8}$$

$$p^1_{it} \cdot E_{it} + p^o_{it}(\dot{E}_{it} + \lambda_i E_{it}) = I_{it} \quad , \tag{9}$$

where:

E_i , E_f = energy capacity installed in subsectors i and f respectively, measured in terms of energy flows;

λ_i , λ_f = respective depreciation rates;

p_i , p^1_f = running cost per unit in terms of units of consumption; and

p^o_i , p^o_f = price for newly installed capacity in terms of units of consumption.

Coefficients p^1_{it} , p^1_{ft} , p^o_{it} , p^o_{ft} can vary over time. In [1] it is assumed that the p_i , p_f quantities include a fraction due to safety expenditure, the fraction depends, of course, on public risk adversity to and risk assessment for the technologies involved.

Häfele [6] proposes that risk adversity, and with it safety expenditures increase rapidly with a growing standard of living, as measured by per capita GRP. Consequently, effective prices are assumed to be the product of prices not including risk expenditures and a risk correction factor, depending on per capita GRP.

$$p_{it}^{1} , p_{it}^{o} \sim \gamma_{it} \quad p_{ft}^{1} , p_{ft}^{o} \sim \gamma_{ft} \quad , \tag{10}$$

and one may assume for instance:

$$\gamma_{it} = \left(\frac{c_t}{c_o}\right)^{\delta_i} \quad , \quad \gamma_{ft} = \left(\frac{c_t}{c_o}\right)^{\delta_f} \quad . \tag{11}$$

The coefficients δ_i , δ_f are, of course, the most likely candidates for a sensitivity analysis, with δ_i , $\delta_f \varepsilon$ [0,2] being a reasonable range of variation.

Any rigid assumption to be made on the form of equation (11) to quantify subjective risk assessment would be based on little more than pure speculation.[1]

Note also that the dependance of safety expenditures on per capita GRP and hence on consumption adds a new aspect to the problem of how to share output between consumption and investment. The point made by (10) and (11) is simply that it is necessary to incorporate the dependencies of the coefficients of our equations into the model to take care of the qualitative change of societal behaviour in the long run. The actual identification of such dependencies, including subjective societal perceptions, is a problem of its own but can be left aside for the considerations of this paper.

Resources

As our primary concern is with energy, for the time being only fuel resources are considered. However, other primary commodities could be introduced in much the same way. Also, resources do not enter the production function explicitly. We specify the following resource restrictions:

$$\int_{o}^{t} E_{ft}\, dt \leq R_{ft} \quad ; \tag{12}$$

$$(1 - b_t) \int_{o}^{t} E_{it}\, dt \geq R_{it} \quad ; \tag{13}$$

[1] See also [6] on related matters.

and

$$\bar{R}_{ft} \geq R_{ft} = \int_{o}^{t} \dot{R}_{ft}\, dt + R_{fo} \geq 0 \quad ; \tag{14}$$

where:

R_{ft} = total fuel available in the region up to time t (equals fuel available at time O plus variations in stock $\dot{R}_{ft}$ due to buying, selling, new explorations, etc.);

R_{fo} = fuel available at time O;

$\bar{R}_{it}$, $\bar{R}_{ft}$ = recoverable world resources at time t; and

$[0,1] \ni b_t$ = coefficient to allow for the reduction in primary fuel requirement by the reproduction of fuel (e.g. breeder technology).

Foreign Payments

We assume that all fuel stock variations are caused by buying and selling, i.e. that there are no new explorations.

$$F_t = p_{ft} \cdot \dot{R}_{ft} + p_{it} \cdot \dot{R}_{it} + F_o \quad ; \tag{15}$$

where:

F_t = interregional balance of payments. Note: Payments are, like prices, in units of consumption; and

F_o = payments to other regions without immediate compensation.

Generality of the Model

The model as shown above can be used equally well for industrialized resource-importing regions and developing regions. The respective parameters have to be chosen, of course.

One could argue that there should be an explicit agricultural sector at least for developing countries. This would certainly be true for a policy oriented model, whereas for the present model we are more concerned with the morphological redundancy this might bring about.

Once we consider two models with different coefficients, say for developed and developing regions, the question immediately arises as to how these models interact (via their foreign sectors). Unfortunately, the process of conflict resolution on world market is, by and large, not well understood by economic theory, and this is the sore point of many "world-trade" models.

A FEW GENERAL THOUGHTS ON THE "NEW SOCIETAL EQUATIONS" APPROACH

Societal Technology

We will find it convenient to look at the New Societal Equations as describing the Societal Technology[2] available to the society (or region) considered. Then in analogy to the micro-economical notion of a technology, we think of a Societal Technology (ST) as (implicitly) describing the set of attainable economic states. Thus ST sets the frame for the various paths of economic development that are open to a society or region.[3] It is important to note that the problem of choosing one over the other paths of economic development can arise only after the objective or objectives within a society have been specified. Obviously this has not been done so far. As with models in the natural sciences like the nerve impulse (e.g. [7]) where the nerve's behaviour cannot be explained by its organic structure only, we have to know, at least qualitatively, what the form of the stimulus will be. No more can we possibly understand the behaviour of an economy in an economic model without knowing its driving forces.

More will be said about objectives in a later sub-section; now we will take a closer look at the conceptual structure of ST.

We can think of ST as a stratified dynamical system, differentiated by the three strata:

1) Structural pattern,

2) Set of coefficients, and

3) State variables,

and we will try to categorize the features of ST with respect to them.

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[2] Technology means "the systematic applications of scientific or other organized knowledge to practical tasks", J.K. Galbraith, "The New Industrial State", 2nd edition.

[3] In the following, society and region are used interchangeably.

Structural Pattern

The structural pattern of an ST relates to the network of economic, i.e. physical and informational flows. A prominent feature of the network as shown in Figure 1 is the connectedness of the

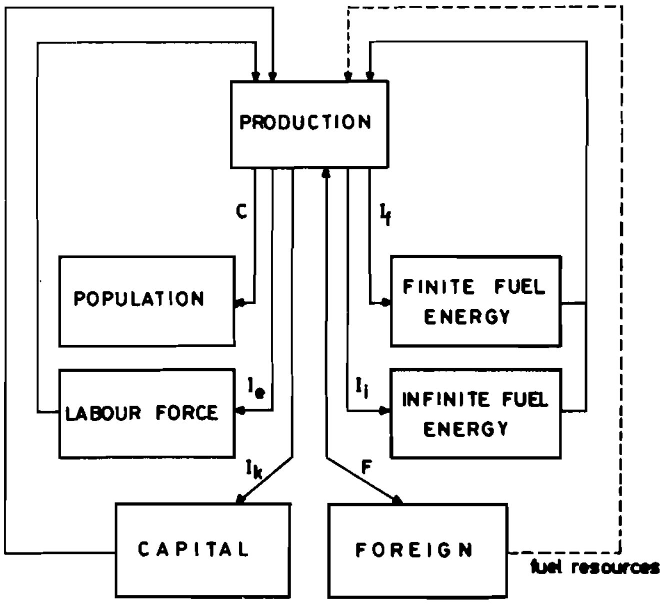

Figure 1. Production and Distribution Network

network of physical flows. This expresses the belief that in modern economic systems

1) the consequences of a taken decision--to change the energy technology for example--are felt economy-wide, so that

2) it makes sense to speak of an economic decision center.

It is important to note that the existence of a decision center does not imply that decisions are taken in an authoritarian manner; it means that decisions have to be agreed upon as they are of an essentially public nature. This would certainly not be so with an adequate model of an economy in the Middle Ages or the Roman Empire, what they have in common, however, is a rather rigid basic network pattern that usually changes only in the very long run, perhaps over centuries. In present economies we observe an increasing degree of connectedness which seems to go along with the importance of publicly provided goods and services.

There is a great similarity among several of the components of the ST network (morphological repetition) but only little morphological redundancy; to omit any one of them would mean to destroy the model's organism as a whole.

Set of Coefficients

Coefficients describe the internal functioning of the different sectors; in contrast to societal technology we could call them "local" technologies[4], examples are: production output given input; population growth given ... etc. At the present aggregation level, local technologies can be seen as being basically throughput-oriented whereas ST is feedback-oriented.

Note that extreme coefficient constellations may well influence the structural pattern--a drastic increase in the death rate could have catastrophic consequences upon the rest of the system. Coefficients such as productivity, depreciation rates for example, are intuitively thought of as showing much less inertness and rigidity than the structural pattern.

State Variables

State variables characterize the momentary state of the economy in a very short term perspective, i.e. they characterize consumption flow, capital stock, energy production and also policy variables such as I_{et}, I_{kt} etc. They all are quantities which, as everybody knows from his personal experience, can vary substantially from day to day. In general usage the term "economic policy" mostly refers to decisions whose aim it is to influence these economic state variables.

The decision, what is to be regarded as a state variable and what is a coefficient, has to be made according to the aspects under investigation, and it would not be wise hereto seek once-and-for-all definitions.

If we drew a (rather soft) analogy from operating an ST to a theatrical performance, the matching could be the following:

α = structural patterns = choice of play,

β = set of coefficients = actors ability, stage design,

γ = state variables = positions of actors on the stage.

What the analogy illustrates rather well is the fact that each stratum has, within bounds, some autonomy and variability, with a variability that is greater the lower the stratum.

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[4]Not in a spatial sense, of course, but local with respect to the network structure.

One could immediately object that the structural pattern of an ST cannot, if at all, be chosen as easily as a theater play, and so the analogy appears much less convincing. This argument really is at the heart of the matter; it is taken up again in a later subsection on optimization. Generally speaking, coefficients of real economies are not directly observable quantities but must be estimated from sequential observations of the state variables. In fact everything we possibly know about a real ST is known from observations of the state variables. This indicates that particularly for long-term investigations, it could be misleading to consider the upper strata of the ST as fixed independently of the trajectories of the state variables.

Variables - Fast and Slow

It is clear by now that elements of different strata could in general be differentiated by their degree of inertness rather than in terms of state variables, coefficients or structural pattern. In a more rigorous approach one could in fact define a stratum as the set of system components with the same or a "similar" degree of inertness.

Therefore, in a more general systems view we come to consider variables only and categorize them as fast and slow variables with respect to a certain stratum. The coefficients above then are fast variables with respect to stratum β but slow variables with respect to stratum γ (see our earlier analogy).

Clearly, the greater the separation in inertness, the sharper the distinction between the strata. In general, however, the categorization of the variables will not be straightforward. One should always keep in mind that, unlike variables in multilevel planning models, variables of different strata are different in nature: The variables of the upper stratum can be thought of as representing "stable" relationships between the variables of the lower stratum.

Optimization and Objectives

In view of what was said in the preceding discussion of fast and slow variables, let us now think of a system with strata indexed $1,\ldots,i,\ldots,L$. Each stratum comprises a set of variables with the values of the variables on stratum i determining the relationships between the variables on stratum $i + 1$. For example, stratum i variables could as parameters[5] enter functional relationships of stratum $i + 1$ variables.

Optimization on the i-th stratum means to influence the variables on strata i, $i + 1,\ldots,L$ in such a way that a given performance

[5] A parameter need not be a real number or anything alike.

index[6] is extremal, given fixed values of the variables on strata 1,2,...,i - 1.

The idea of optimizing the relatively lower strata, while keeping the upper relatively inert strata fixed comes from engineering practice, of course. In engineering problems the less inert variables are usually also the more controllable ones. In socioeconomic systems, however, the variables on the lowest stratum might not be controllable at all.[7] Take the case of "regional planning" where one might be able to provide infrastructure, technology etc. but not to plan day-to-day operations, i.e. the fast variables.

As a simple and at the same time rather general example of a system which belongs to the above described family and which comprises only two strata γ and β, consider the following optimal control problem for the time period [0,T] to maximize $x_o(T)$:

$$\dot{x}(t) = f_y(t,x,u) \quad , \tag{16}$$

where:

$$f_y = (f_{yo},\dots,f_{yn}) \quad ,$$

$$x = (x_o,\dots,x_n) \quad .$$

Here the stratum γ variables are state variable x and control variable u, whereas the stratum β variable is y, which can be conceived as indexing a suitable class of functions f_y. With more than two strata we can formulate an equation that governs stratum β:

$$\dot{y} = f_z(t,y,v) \quad , \tag{17}$$

$$f_z = (f_{zo},\dots,f_{zm}) \quad ,$$

$$y = (y_1,\dots,y_m) \quad ,$$

[6] Which could be a stratum i variable and which would usually be a functional that is defined on the set of all attainable trajectories of stratum i + 1,...,L variables. .

[7] A non-controllable variable on all levels is <u>time</u>.

where z belongs to the additional upper stratum α; y and v are the state and control variables of stratum β.

In traditional terminology we would call the choice of z (on the highest stratum) systems design[8], as opposed to systems control for then choosing u $(\cdot)$ and v $(\cdot)$.

Instead, we are arguing that optimization in stratified systems could be a more general and more fruitful way of thinking about the development of socioeconomic systems.

Two remarks should be made her:

1) There is obviously no intrinsic distinction between state variables x and control variables u. The latter are thought of as directly controllable variables. Also the partitioning of the vector (x,u) may vary over time, and, as we have seen, there may be a strata where u is empty.

2) There is a conceptual difficulty with the "optimization on level 1" because it is hard, especially for socioeconomic systems, to specify objectives unless at least a basic scenario of the (model) universe we want to live in is created. Coming to that one feels that in socioeconomic systems one should allow for some feedback from the technological strata to the strata of norms and objectives, because human objectives can best be understood and quantified in the context of human environment. In this paper, however, we shall not elaborate on this in order to keep matters simple.

Suppose now that in the course of an optimization procedure for problem (16) we have chosen control functions $u(\cdot)$ and v $(\cdot)$ for levels γ and β respectively. Then the differential equation in (17) is a closed system in the sense that, given the value of z, it produces[9] unique trajectories, say $\hat{x}(t)$, $\hat{y}(t)$ of the state variables on strata β and γ, for any initial condition $\hat{x}(0) = x^o$, $\hat{y}(0) = y^o$. If we keep stratum α, variable z and y fixed but vary x^o, we obtain a (stratum γ) state-variable phase-space. The phase portrait depends, of course, on the variables y of stratum β. Again the dynamical behaviour of y, i.e. its phase portrait depends on the variable z of the highest strata, which we assumed to be fixed.

Note that in our example above (16), variable y also determines an objective functional for stratum γ if a particular function f_{yo} is "chosen":

$$\dot{x}_o(t) = f_{yo}(t,x,u) \quad , \tag{18}$$

[8]Often thought of as being fixed once and for all.

[9]Under regularity conditions.

and so

$$x_o(T) = \int_o^T f_{yo}(t, x(t) \quad , \quad u(t))\, dt + x_o^o \quad . \tag{18}$$

This shows that, by determining the objective of stratum y, the dynamics of variable y on the higher stratum is crucial for the morphogenesis of the phase portrait for variable x.

Reversing this argument, one could in fact think of comparing different objective functionals by their respective phase-portraits i.e. the topology they induce on the phase space.

As we know from static mathematical programming, different objectives may conflict for one set of constraints but not for another. The same situation can occur with dynamical systems, but there it is much more difficult to analyze. A simple case of determining via the morphology of the state space that two objectives are conflicting occurs if the initial state lies within different domains of attraction, depending on which objective is chosen.

In order to <u>close</u>[10] an indeterminate system we can also specify an additional equation other than a control function, for example a growth target for a state variable which is not directly controllable.

<u>Policies, Objectives and the Societal Technology</u>

What has all that got to do with our Societal Technology? Clearly ST is, and deliberately so, not a closed[11] dynamical system. That is to say that in the system of New Societal Equations there are "free" variables; reference [1] discusses two approaches to close the ST dynamical system:

1) To specify additional restrictions such as
   a) differential constraint of a <u>local</u> nature; and
   b) global constraints on the variables, thus restricting the evolution of the system to hypersurfaces.

2) To specify the time path of control variables, thus adding as many differential equations to the system as there are "free" controllable variables.

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[10] Note that the term <u>closed</u> has a different (though not entirely independent) meaning in economics and mathematical systems theory.

[11] Note that the term <u>closed</u> has different (though not entirely independent) meanings in economics and mathematical systems theory.

The first approach originates from the physical sciences where inanimate natural systems are the object of investigation. These systems are thought to be closed and non-purposeful.

However, by the Lyapunow theory or others one is always able to ascribe an objective X to a fixed-point-stable dynamical system, that is to say it is assured that the system behaves as if it were optimized with respect to X.[12] Physicists call X a potential function. We should note, however, that a potential function is a rather special kind of objective function as it is defined on states and not on trajectories of states. Note that the stability concept also exists for non-differentiable (even non-numerical, structural) processes and that a corresponding, generalized Lyapunow theory is available.[13]

The second approach is historically related to the analysis and design of man-made systems, namely the decision sciences. The systems considered are thought of as being purposeful, driven by one or several, even conflicting, objectives. As opposed to physics, where natural laws are identified, the aim of this approach is to identify control variables and to determine their optimal control law.

To decide which approach is more promising depends on the aim of investigation:

1) If we wish to find out the effects of proposed long-range economic and energy policies (and the objectives they imply) one would employ the first (the physicist's) approach.

2) If we want to synthesize control policies for stratified systems which are optimal with respect to a given performance index, then we would favor the second (the economist's) approach.

CONCLUSION

We suggest that the stratified systems approach could be a useful way of thinking about the long-range development of socio-economic systems. Not only is it a natural approach in the sense that the strata of the model have identifiable counterparts in real economic systems; but also in that it suggests a methodology of mathematical analysis. Obviously enough, identifying slow and fast variables suggests to regard the slow variables as fixed coefficients at first and to only analyze the dynamical behaviour of

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[12] A similar problem is known as the inverse problem of optimal control, see [8].

[13] See [9]. Stable structural processes are processes displaying a movement toward greater order, symmetry or form and are also called morphic.

the fast variables, and then also vary the slow variables, in order to trace out the behaviour of an entire stratum. Here the recently developed tools of catastrophe theory (see [10] and [11]) can be of great help. The explanatory success of a model depends, of course, on whether one has found the "right" categorization into different strata.

References

[1] Avenhaus, R., D. Bell, H.R. Grümm, W. Häfele, J. Millendorfer, L. Schrattenholzer and C. Winkler, "New Societal Equations." Unpublished internal paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

[2] Rogner, H.H., "Übergang von Öl und Kohle zur Kernenergie," Thesis at University of Karlsruhe, Federal Republic of Germany, 1975.

[3] Häfele, W. and A.S. Manne, "Strategies for a Transition from Fossil to Nuclear Fuels." IIASA RR-74-7, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1974.

[4] _Population Policies and Economic Development_, Ed., King, T. John Hopkins University Press, Baltimore, Maryland, 1974.

[5] _United Nations Statistical Yearbook 1973_, United Nations Statistical Office, New York, 1974, p. 8.

[6] Häfele, W., "Hypotheticality and the New Challenges: The Pathfinder Role of Nuclear Energy." IIASA RR-73-14, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1973.

[7] Zeemann, E.C., "Differential Equations for the Heartbeat and the Nerve Impulse," in _Towards a Theoretical Biology_, 4, Ed., C.H. Waddington, University of Edinburgh Press, 1972, pp. 8-67.

[8] Casti, J., "A Note on the General Inverse Problem of Optimal Control Theory," IIASA RM-74-8, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1974.

[9] Mesarovic, M.D. and E. Pestel, "A Non-Numerical Systems Theory for the Large Scale Systems Problems," in _Systems Approaches and Environmental Problems_, Ed., H.W. Gottinger, Vandenhoek u. Ruprecht, 1974.

[10] Thom, R., _Stabilité Structurelle et Morphogénèse: Essai D'une Théorie Générale Des Modèles_, W.A. Benjamin, Inc., Reading, Mass., 1973.

[11] Isnard, C.A. and E.C. Zeemann, "Some Models from Catastrophe Theory in the Social Sciences," in _Use of Models in the Social Sciences_, Ed., L. Collins, Tavistock, London, 1974.