GLOBAL MODELS AND GLOBAL MECHANISMS I: METHODOLOGICAL CONSIDERATIONS

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Introduction

In the view of the increasing significance of global models in the simulation of future developments, the question arises as to whether the scientific basis of these models exist, that is, an adequate knowledge of longer term processes in global development and the corresponding consideration of their complex interrelationships. This question and its methodological aspects will be discussed below and illustrated by means of production functions that are a major factor of global models.

1. Conventional production functions--useful components for global models?

Production functions describe the relationship between the input of production factors and the economic output. They are customarily highly aggregated (i.e. data for a large unit, e.g. a country, is used) and linearly homogenous to avoid scale effects. Conventional production functions with the production factors of capital and labor are a fixed component of many formalized economic theories and most recently also of global models. (Bariloche, Mesarovic-Pestel). From these production functions results (by dividing the function the labor factor) the labor productivity as a function of the capital intensity or, in differentiation over time, the growth rate as a function of the investment

rate. These relationships have been dealt with in innumerable analyses, and comparisons of international cross-sections were employed in the measurements. One of the most comprehensive (cross-sectional) studies was undertaken by the ILO.

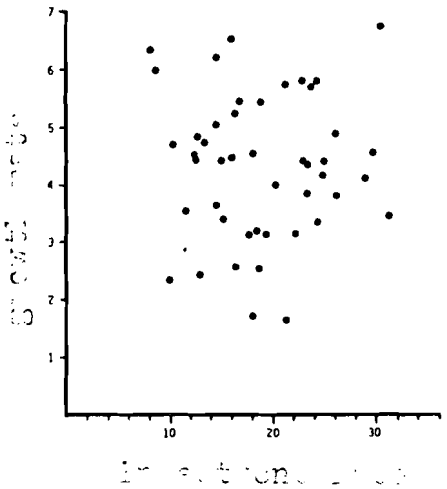


Figure 1,
Investment Rate and Growth Rate (according to a cross-section comparison of the ILO, Galenson, W., & G. Pyalt, "The Quality of Labor and Economic Development in Certain Countries," Geneva, 1964).

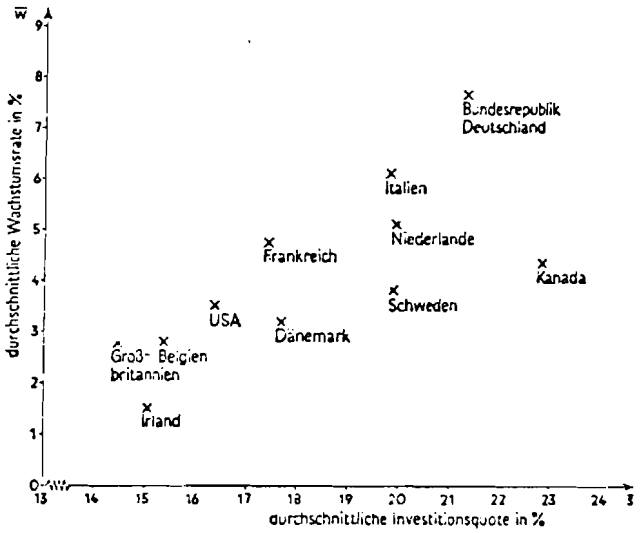
The study showed that as far as the content is concerned differences in national growth could not be explained merely by the growth theoretical assumptions of conventional productional functions that contain only capital and labor, and as far as methodology is concerned that comparisions among countries obviously possess the essential difficulty of the 'ceteris paribus' (the rest remains equal) condition, which is not fulfilled if the great geographical, climatic, historical, cultural and political disparities are not taken into consideration. Evidently connections exist in production which are more complex than the assumptions of

the theory of growth upon which conventional production functions are based. The dubiousness of these assumptions was not in the first instance demonstrated by the proven empirical nonverification but has for a long time been expressed in an immense residual factor comprising up to two-thirds of the value to be explained, which, up to now, has been represented as 'time-dependent' in conventional treatment, where an explanation of decisive progress in productivity has practically been omitted. There is, of course, exhaustive literature concerning the individual factor; however a modification of the production function on the bases of new empirical studies, originally empirically determined by Cobb and Douglas, would serve to explain the residual factor is not to be found.

Thus, if the description of production in several global models rests on such production functions, then this means an oversimplified--i.e. in terms of reality, an insufficiently complex--view of the relationships in production in these global models. The same is true for other longer term interrelated developments, the knowledge of which is crucial in the construction of realistic world models, as for example between the level of education and economic growth, technological progress and productivity, progress in medical knowledge and health development, etc. Global processes which extend over a large chronological and spatial range of societal development demonstrate a multi-

dimensional quality that encompasses the most varied spheres of society, a quality not fully grasped by the previous, over-simplified model assumptions. Thus, one of the fundamental prerequisites for global models would seem to be the investigation of the complexity of global processes. The following delineates the methodology of such an investigation, using the production function as an example. The next working paper will describe first results.

A starting point for reflections on the treatment of these qualities is given by an observation by Krelle:



(Figure 2, Investment Quota and Rate of Growth) by Krelle, "Investment and Growth," Jahrbuch f. Nat.Ök. u. Statistik Bd.176/1964, p.21.

As the expected positive correlation between investment and rate of growth when limiting the observation to the western industrialized countries was proved right, we can assume that the aggregation problem plays a decisive role. Obviously all kinds of relationships could be drawn from the cluster of dots in Figure 1, if similar arbitrary

groups of countries were formed. The question now arises as to whether the group of countries in Figure 2 is plausible and not arbitrary according tc objective criteria. One objective criterion is the demand for fulfillment of the 'ceteris paribus' condition, i.e. of equality of the relevant variables not included in the calculation. An appropriate approach would thus be to form groups of countries, in which the influence of non-observed by relevant variables is fairly constant. The task of forming groups of countries so as to fulfill the 'ceteris paribus' condition includes, however, much more than the narrower field of economics. Further, the question arises as to whether, in the above cited survey performed by the ILO on the economic effects of schooling which provided only very general conclusions, could be refined by introducing such groups of countries, or vice versa, if the residuals of Figure 2 could be explained by introducing the variable 'training'. These questions concerning the multi-dimensional interdependencies with non-economic areas necessitate methods of research that allow one to represent such complex relationships in reality with complext abstract structures. This question of methodology will be dealt with in the following:

2. Methodological Questions: the iteration of alternative strategies in the investigation of multi-dimensional interrelationships.

2.1 Iterative collaboration of generalists and specialists in interdisciplinary research problems.

The multi-dimensional quality of those global mechanisms relevant to longer term development leads to the conclusion that they cannot be comprehended by means of analyses that are limited to such specific fields as economics, education, health, etc. Rather, global systems studies are necessary, in which specific areas, which are otherwise dealt with by different disciplines, should be examined simultaneously. Thus, it seems to be necessary that various disciplines should collaborate in the investigation of global processes; the difficulties of interdisciplinary collaboration be above all in the interface of these disciplines, more specifically in the functional relationships between the fields as the various disciplines are dealt with. These difficulties could be overcome, if a framework of these relationships are produced by "generalists", i.e. experts in the survey, within which the specialists would work within their fields of specialization under consideration of their functional relationships to other fields and simultaneously would assist the generalists in improving this framework, who in turn would improve interdisciplinary collaboration, etc., such that through an iterative process, a state of constantly improving interdisciplinary collaboration would be achieved.

The decisive factor in this process is the initial framework of the generalists that must encompass all those aspects of society which are relevant to longer term development. Thus, the data upon which such a framework is based must also include all areas of society. These data, from the most varied areas of specialisation are to be organized by the generalists in such a manner that, knowledge on the causal relationships between various areas can be gained which are relevant to longer term social development. In the following an iterative method for this task is described which is based on the cybernetic model concept.

2.2 Iteration between the theoretical and empirical approach.

The iterative process to organise empirical data which is to be described rests mainly upon the cybernetic concept of model building, as is shown

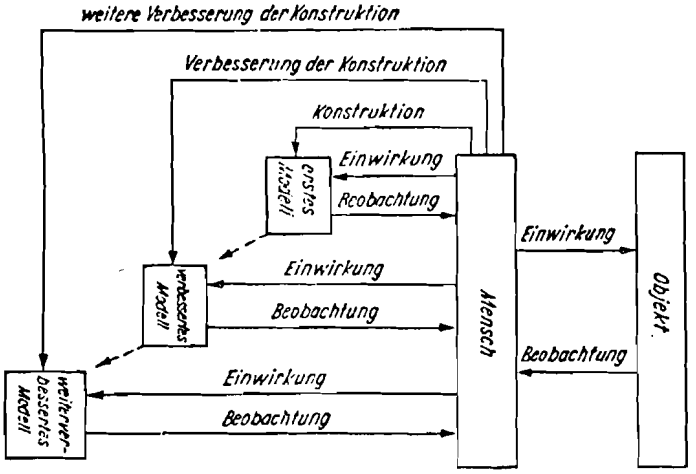


Figure 3

Pattern of a Knowledge Acquisition Model in 3 Phases.

Starting with a "pragmatic decision"[1] concerning the aims of gaining information and with an initial heuristic temporary hypothesis established by the model subject [(i.e. creator)], empirical observation and theoretical hypothesising constitute in iterative reciprocal effect, as the model step-by-step describes the model-object better and better. Empirical observations, elicited by the initial hypotheses, lead through their current interpretation to improved hypotheses. These lead to new empirical observations, the interpretation of which corrects or improves the original hypotheses, etc. This iterative process continues until the theoretical interpretation of empirical observations can no longer be changed by further empirical observation. The purpose of the described method is thus to discover information patterns in a determined uncontradictory system of information and to interpret these theoretically--in certain circumstances using already existing theories--such that further empirical observation does not force a change in the theory.

A major principle in the application of this method in statistical, social-scientific investigations is not to attempt any premature interpretations, for instance in the nature of the familiar frequency of storks--frequency of births, for example, not to make assertations about one area without examining neighbouring or superimposed areas.

Thus, one proceeds from the investigation of a single relationship to that of a whole complex field. The goal, starting with a certain question, is to discover as many relationships as possible by examining as many variables

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(1) Re:"pragmatic decision" in the sense of neopragmatic modelling, see H. Stachowiak, "Algemeine Modelltheorie".

as possible. Their interpretation is postponed until a sufficiently consistent network of relationships is obtained (which could partially represent predetermined system) in which a relationship is controlled by others.

2.3 Heuristic hypotheses, organization of empirical data and experienced, scientific cognition.

Of course it is also useful and economical for this empirically based approach to have temporary hypotheses, which lead to meaningful questions, i.e. for example in the selection of variables, through which the discovery of relationships relevant to the examined question is actually attained. The hypotheses, though, are of merely heuristic value in this case. In other words, the structure of the problem to be studied is not determined by the heuristic hypotheses, which can be abandoned and replaced by others on the basis of empricial analysis. The structure of the investigated problem, i.e. the kind of aggregation of various populations, the selection of variables, the form of the regression functions, etc., as well as their interpretation is rather derived from a large amount of data in a repetitive reciprocal interaction between empirical studies and theory-forming hypotheses.

The quantity of data is understood to be an overdetermined noncontradictory information system. After reducing the overdetermination by extricating redundancies, the data may be organized in a certain noncontradictory way in view of

the question to be analyzed. The heuristic hypotheses thus understood are aids in finding, on the one hand, redundancies and on the other hand, relevant information patterns in empirical data.

In the method described, the relationship to one existing theory deserves special attention which was first understood only as one of many heuristic hypotheses. It can, however, enjoy special significance, for example if the additional information obtained in the application of the iterative method should lead to a new view of the existing theory.

This will be shown in principle by the example of the general production function[2] which can be understood as the generalization of the well known Cobb-Douglas production function. The residual factor of the Cobb-Douglas production function can now be explained: this function, frequently used in economic theory, can be freshly understood as a special case of the general production function for constant education and structure.

This example of the general production function and the Cobb-Douglas production function demonstrates a methodological axiom: the empirical studies have to be performed in cognition of, though not based on or dependant upon, the existing theory. In this latter, customary approach lies the danger of immunization, i.e. due to a prejudiced view

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(2) See H. Millendorfer and C. Gaspari, "Immaterielle und materielle Faktoren der Entwicklung: Ansätze zu einer allgemeinen Produktionsfunktion". (Non-economic and Economic Factors in Societal Development: the General Production Function)· An IIASA Working Paper on the General Production Function will follow.

one is not open to relevant new information. Thus, the existing theory did not form a starting point, but rather the predetermined network of information gained from empirical investigation led back to the existing theory, though on a higher level, by which the existing theory became the special case of a new, more general theory.

This result shows, as will be more explicitly described in 2.5, that in interpreting research as a learning process, the danger of "negative immunization" is avoided, which consists not in the prejudice of an unquestioning clinging to a specific theory, but in the prejudice of absolute denial thereof. A special case of this negative immunization will be described in paragraph 2.7.

2.4 Pluralism of formal instruments.

In the method described, those formal instruments, otherwise customary in the social sciences, such as cluster-analysis, development profile, factor analysis, simple and multiple regression analyses, are applicable in a meaningful pluralism. A meaningful pluralism of formal instruments allows for the fact that various formal instruments are differently suited to different questions. This means that not every formal instrument can be equally well employed for every question. This statement seems trivial, but an attempt has actually been made to deny, with the help of a factor analysis that possessed 65% of the explanatory value, a production function arrived at by means of a multiple regression analysis and explanatory value of 99% of the variance.

The failure is not so much in the great disparity in explanatory value, but in the ignorance of the variety of possibilities of different formal instruments. Factor analysis, which reduces the n-dimensional space of characteristics to $m \leq n$ main axes on which it projects the n characteristics, is an outstanding instrument in extricating redundancies from a large quantity of data when the examined relationships are linear. More sophisticated aspects of the relevant information pattern, such as nonlinear causal relationships, as represented by production functions, cannot be adequately dealt with by factor analysis. For this a technique is necessary that not only analyzes the relation between the simple correlation coefficients, but among other things the connection between deviations from simple correlation relationships, in other words, residuals. This is done by means of the multiple regression analysis, which also allows for adjustment to nonlinear relationships. Because of the great differences between the comprehended area of complexity, factor analysis cannot be employed to test a multiple regression analysis--much less so in view of the above mentioned difference in explanatory value. Other combined kinds of application of both formal instruments exist. Thus, for instance, factor analysis can be used to advantage in a rough going-over of a large amount of data, so as to discover heuristic hypotheses for a multiple regression analysis or for a detailed analysis of a highly

aggregated subsection as derived by the multiple regression analysis. In the latter sense, for example, a factor analysis that is concerned with the factors of the development level with regard to political structures contains information about the factor 'structure' of the general production function.

The example used shows that, despite a basic consensus on the necessity of the pluralism of formal instruments in research, there exists something like an immunization against unfamiliar formal instruments and methods and not only against perturbations of one's own theory. This may be due to the fact that the interrelationships between various formal instruments and methods are not well enough elaborated in the usual representation. An elaboration of these connections would facilitate the discussion of methods, which sometimes employs thoughtless arguments, even when said immunization does not exist. One of these arguments states, for example, that in social development "parallel trends" appear in the most disparate variables and thus a high correlation between the variables is trivial. This argument is in principle related to the problem discussed in the previous paragraph. It neglects the difference between multi-dimensional, regression analysis and the sum of several single regression analyses. In a multiple regression analysis, not only "trends" are analyzed, it is extended beyond the analysis of "trends". It can be shown that the simultaneous analyses of several variables is formally identical to analyses of those deviations from "trends", in other words, residuals.

If, for instance, the residuals of variable Z in the relation to X and the residuals of variable Z in relation to variable Y are in negative correlation, then Z depends on the sum of X and Y (rated with regression coefficients). If the correlation between the residuals is small compared to the "parallelism of trends", there exists the multi-colinearity implied by this expression. The presence, or absence of this multi-colinearity can, however, be perceived from the significance of the contribution of the explanatory variables.

Such formal methodological questions necessarily arise with pluralism of formal instruments. They could be multiplied in any way, e.g. in the question of clustering in multi-hierarchically structured population, resulting from the development of the general production funtion. In view of the complexity of these questions, it seems advisable to discuss them in an open, scientific manner without the polemic attitude likely to occur in the question of values. In the following example of the iterative method of gaining information the most varied formal instruments were used. Questions of aggregation, i.e. the division into various populations (or groups of countries) were dealt with in a kind of simple cluster analysis. Rough development profiles produced information about possibly applicable variables. Then simple and multiple regression analyses, partly in a non-linear assessment procedure, were undertaken in cross-section analyses and in the process various populations were

linked together by dummy variables. Single questions were treated partially with the help of detailed development profiles. Finally, the chronological development of dummy variables was examined in a time series of cross-sections in the various populations. The selection criterion for the variables was their contribution toward the improvement of the model, i.e. for example, in the case of the multiple correlation the statistical significance of the explanatory contribution, measured with appropriate significance tests built into the computer (e.g. F-test). At this time, studies are being run in which attempts are made to apply principles of factor analysis to non-linear relationships and dynamic processes.

Despite this pluralism of formal instruments, unified basic principles were maintained. Thus, in every step of the described iterative processes, the results of the previous step were understood only as heuristic hypotheses. Therefore, for instance, special attention was paid to the residuals and particularly to large deviations. Thus, it was useful to not only have the computer print-out as the usual residuals of the respective formal calculations, but also to represent them graphically, to gain a general view of new regularities possibly leading to new heuristic hypotheses.

Thus, in the pluralism of formal instruments, the basic principle of the method remained unchanged; namely, that in regard to a particular question the model comes closer to

observed reality step-by-step, namely in an iteration of empirical observations from as broad a data base as possible and of theory-forming hypotheses.

2.5 Research as a specific learning process.

The aim of the method described is to reduce the abundance of empirical data to relevant information patterns and to present the structure of the reality to be observed as an abstract structure following certain logical formal regularities that correspond to the regularities of the reality to be described with respect to the questions posed.

While it is the task of formal sciences to develop logical formal structures, the reflections of reality in such structures is the task of experimental science which tries by this reflection to explain certain phenomenon of reality or to allow for prognoses. "Explanations by expermental science may refer to the past (explanation in the narrower sense) or to the future (prognosis). In logistics there is no difference between explanation and prognosis (H. Giersch: Explanation is Retrospective Prognosis)".(3)

The aim of prognosis according to the method described --which is nothing but the feasible formulation of the research strategy practised or at least theoretically required experimental sciences for a long time--is not reached by a single step of theory formation (possibly followed by empirical testing): "the progress in knowledge as such is the result of constant searching for fertile hypotheses,

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(3) Handwörterbuch für Sozialwissenschaft, Vol.12, p.310.

difficult theoretical inferences and a follow-up selection by verification and/or falsification, whereby the knowledge gained is slowly aggregated into a formalized system".[4]

This eventual progress of knowledge in the laborious process decribed can be justly called a learning process. If this way of knowledge acquisition is understood as a learning process, and is consciously seen as the step-by-step incorporation of new information to extend and, if necessary, modify the knowledge gained, then a conscious readiness for innovation is present and the danger of immunization of theories and knowledge thus gained is minimized.

Though the acquisition of knowledge through such a step-by-step process is rarely used in single studies of social science, they have been generally used throughout the hisotory of various sciences, that show constant interaction between the development of logically formed abstract structures, empirical assessment of reality and theory formation of experimental sciences.[5] Thereby alternate turns in stressing one component in the course of developing the science are replaced by attempts to come to a synthesis

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(4) See above, Handwörterbuch, p. 311.

(5) One example is the development of trigonometry through the need for remeasuring the land after the flooding of the Nile. Another example is the further development of modern mathematics by problems from physis, which helped to formulate new theories (e.g. partial differential equations for the mathematical field theory).

between them.(6) This can also be observed in the social sciences: in the present situation more and more outstanding social scientists advocate catching-up with the back leg of empirical foundation,(7) and/or practice this research strategy.(8)

This does not mean that the methodological argument between Schmoller and Menger is decided in favor of Schmoller, but that the extreme position of both viewpoints is overcome by recognizing the need for a synthesis of the empirical and the theoretical approach--even though the related problem of "theoretical assumptions and non-observed facts", has not been fully solved in social science research.

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(6) For example, the history of medicine where, since the emphasis on empirical thinking of the primitive races and the boom of speculative thinking of the early civilized nations, a constant change of foci occurred until speculative thinking was abandoned in the "rational empirism" of the 18th centry, which now is replaced by an attempt for synthesis.

(7) "We need new theories which however abstract are more realistic in that sense that they are more adequate to the facts" (Myrdal "Value and Social Theory", p.236, New York, 1958).

W. Leontieff comments upon this in his article with the characteristic title, "Theoretical Assumptions and Nonobserved Facts" (Am.Ec.Rev. Vol. LXI No. 1, p. 2, March, 1971): "What is really needed, in most cases, is a very difficult and seldom very neat assessment and verification of these assumptions in terms of observed facts". On the same topic, "Handwörterbuch f. Sozialwissenschaft," Vol.12, p.321, says under methodology: "While apriorism (Ludwig von Mises, Lionel Robins) considers these model assumptions as evident and not subject to proof, the majory of methodologists today require some kind of empirical support for hypotheses through a test equivalent to an experiment (e.g. a prognosis)".

(8) Such as C.S. Holling, who said during a presentation of his work at the IIASA 1974 Seminar, that an abundance of empirical data is the best prerequisite for good methodology.

This viewpoint, which requires a "pragmatic decision" on research intentions, corresponds to the cybernetic concept of a model on which Figure 3 is based and where the conscious use of the concept of the model subject implies that the model is related to the intentions of the model subject. This viewpoint can also be described by using the term learning process as "learning for what purpose".

It seems to be necessary to add one restriction: "The neopragmatic model pattern of knowledge acquisition requires a discussion on ethics which has to protect itself against the special absolutisms of exclusive objective determination."(11) Therefore, this concept is left facing two evils: between Scylla and Charybdis, between the "undifferentiated total reality and dogmatic misuse of the argument of inter-subjectivity leading to determination by experts as to what is real science and what is truth".(12)

2.7 Rules of scientific argument and immunization.

Stachowiak demands "rules for fair disputes"(13) for scientifically dealing with difficult scientific questions. Here we have reached a decisive stage which causes a serious problem in the present--as well as in former scientific arguments--for a useful scientific learning process: by distorting fair scientific rules of the game, immunization

(11) H. Stachowiak, see above, p.62.

(12) H. Stachowiak, see above, p.60.

(13) H. Stachowiak, see above, p.61.

against innovations, ensures which blocks the process of learning. A description of this distortion by Goethe is still today, 150 years later, highly applicable: "Sciences consider as their property what is passed on, preserved and taught at academies. If someone brings something new that is in contradiction to our creed that we have been repeating and passing on for years or even threatens to overthrow it, we arise all passions against him and try to suppress him in any way. One tries to resist as much as possible, one pretends to be deaf or not to understand, one talks about it in a derogatory manner, as if it were not worth looking at or studying; and truth takes a long time to emerge".(14)

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(14) Geothe, "Gespräche mit Eckermann".

Concluding Remark:

A relatively small number of social scientists in the world still use the described iterative method for investigations of long-term societal development. A collection of their results could be a first step to extending the knowledge of global mechanisms. This increased knowledge would provide a substitution of non-verified "theoretical assumptions" by "observed facts"--not only in world models but also in models in the different special fields, like energy, food and agriculture, etc. Further research should eventually lead to a consistent network of quantitatively described processes, a framework for a better understanding of long-term societal development, linking together the different fields where IIASA teams are involved. A step towards such a framework will be described in the next Working Paper: "Global Mechanisms and Global Models II: The General Production Function".