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## Chaos Theory and Social Science: A Methodological Analysis

Jan Faber, Henk Koppelaar\*

**Abstract:** This article investigates the relevance of chaos theory for social science. The application of chaos models in the analysis of social phenomena is accompanied by some important scientific problems. First, whether observations of social phenomena are generated by nonlinear dynamics cannot be ascertained beyond considerable doubt, especially when these observations contain measurement errors; i.e., there is a problem of external validity. Secondly, and more important, as a theory of irregular cyclical social behaviour is lacking, inductive-statistical theory-formation about such behaviour, which is based on fitting a mathematical model of chaos to observations of social phenomena, is impossible unless additional information is used concerning the context and circumstances wherein the social phenomena occur; i.e., the internal validity of any theoretical explanation that is derived from only a fitted mathematical model (of chaos) cannot be assessed. So, research into the suggestion derived from mathematical chaos theory that irregular cycles may be present in the development of social phenomena over time requires theory-formation about irregular cyclical social behaviour on the basis of established theoretical insights and empirical evidence instead of fitting sophisticated mathematical models of chaos to observations of social phenomena.

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\* © Kluwer Academic Publishers. Reprinted by permission of Kluwer Academic Publishers. This article was first published in *Quality & Quantity* (1994) 28, 421-433. Address all communications to Jan Faber, Dept. of Science and Policy, Utrecht University, P.O. Box 80083, 3508 TB Utrecht, The Netherlands. Henk Koppelaar, Dept. of Mathematics and Informatics, Delft University of Technology. This article is based on the paper we presented at the *International System Dynamics Conference* 1992 (July 14-17, 1992 in Utrecht, The Netherlands). Acknowledgements go to Willem J. Scheper and Peter G. Swanborn for their comments on an earlier version of this article. Further information can be obtained from the first author.

## 1. Introduction

The growing scientific interest in chaos theory can be traced back to the appealing results obtained by meteorologists (i.e., Lorenz) from their analyses of turbulent flows by means of mathematical models of nonlinear dynamics. The notion that a relative simple deterministic nonlinear dynamical model can produce unpredictable and random-like patterns of data on any possible phenomenon has not remained unnoticed in the social sciences (see, inter alia, Loye & Eisler, 1987). The perspective of chaos theory as a new and unifying paradigm in the interdisciplinary study of social phenomena has even already been suggested (Daneke, 1989). As Loye & Eisler (1987: 53) put it with reference to Laszlo (1984): »... chaos theory ... may also, at a potentially chaotic juncture in human evolution, offer us a much clearer understanding of what happens, can happen, and can be made to happen in a time of mounting social, political, economic, and environmental crises«. In this view, system theory should provide a basis for the integration of various monodisciplinary approaches into an interdisciplinary approach. In this interdisciplinary approach, the concept of self-organization, which is derived from the analysis of »autopoiesis« (Maturana & Varela, 1980), is suggested to possess the capacity to bring (a new) order out of chaos (i.e., the unpredictable and random-like patterns of data on the phenomenon studied).

More cautious statements about the scientific value of chaos theory for the social sciences can also be found in the literature. In their study of the relevance of chaos theory for economics, Baumol & Benhabib (1989: 100) state: »The evidence on whether chaos does or does not occur in economic phenomena so far is only suggestive«. With respect to politics, Saperstein (1984) and Grossmann & Mayer-Kress (1989) end their analyses with the remark that the degree of correspondence between their chaos models of arms races and arms races in reality remains an unanswered question.

From the comments on the scientific value of chaos theory for the social sciences presented above a decisive conclusion cannot be drawn. Some authors argue that chaos theory bears great potentials for catalyzing interdisciplinary theory-formation. Yet, the results from empirical social science research hardly buttress these potentials. In order to investigate the scientific value of chaos theory for the social sciences in greater detail, attention in this article is directed to the question of how chaos theory as a subarea of nonlinear dynamics in mathematics can help to generate theoretical explanations of social phenomena in reality. The answer to this question will be derived from investigations to be presented in the next sections. In Section 2 we start our analysis with a brief outline of chaos, nonlinear dynamics and their assessment from observations of social phenomena in reality. Section 3 is devoted to the explanation of the dynamics of social phenomena in reality that can be derived from a fitted and not falsified nonlinear dynamical model. Some problematic aspects of theory-

formation in social science research on the basis of fitted mathematical models of chaos will be discussed in Section 4. Conclusions to be drawn from these analyses will be presented in the last section of this article.

## 2. Chaos, nonlinear dynamics and their assessment

Chaos theory refers to mathematical models capable of producing chaotic patterns in successive values of the dependent variables. Chaos models are nonlinear in nature, and can be best outlined by comparing them with linear models. For reasons of illustration, two simple deterministic forecasting equations are defined, namely

$$y_{t+1} = \beta y_t \quad (1)$$

$$y_{t+1} = 4\beta y_t(1-y_t) \quad (2)$$

where  $y$  is assumed to take values on the interval  $[0, 1]$  and  $t$  is assumed to take integer values on the interval  $[0, \infty]$ . Equations (1) and (2) represent linear and nonlinear forecasting, respectively. Equation (2) is commonly referred to as the logistic map (see Baker & Golub, 1990). If  $t \rightarrow \infty$  then  $y_{t+1}$  in equation (1) approaches a stable value; for  $\beta < 1$   $y_{t+1} = 0$ , for  $\beta = 1$   $y_{t+1} = y_0$ , and for  $\beta > 1$   $y_{t+1} = 1$ . But if  $t \rightarrow \infty$  then  $y_{t+1}$  in equation (2) does not always approach a stable value; for  $\beta \leq 0.75$   $y_{t+1}$  approaches a stable value, for  $0.75 < \beta < 0.862$   $y_{t+1}$  oscillates back and forth periodically between pairs of stable values, for  $0.862 \leq \beta \leq 0.892$   $y_{t+1}$  oscillates periodically between unstable values due to an ever-increasing number of cycles in the generating process, and for  $\beta > 0.892$   $y_{t+1}$  lies in a chaotic pattern of values (see Saperstein, 1984). So, the forecasts of  $y_{t+1}$  may lie in 4 regimes: (1) stable value, (2) stable bifurcation, (3) unstable bifurcation, and (4) chaos. The chaos regime can be characterized as (Saperstein, 1984: 304): »... orbits do not have definite end points, initially neighbouring orbits diverge exponentially, any flow (of values of  $y_{t+1}$ ) soon fills the entire interval  $[0, 1]$  and prediction is impossible«. Small shifts in the values of  $\beta$  or  $y$  produce entirely different patterns of values of  $y_{t+1}$  in the chaotic regime (see Baumol & Benhabib, 1989).

A more general specification of equation (2), wherein the values of  $y$  are left free to vary between  $-\infty$ , and  $+\infty$ , can be defined as

$$y_{t+1} = \beta_1 y_t + \beta_2 (y_t)^2 \quad (3)$$

Equation (2) is a special case of equation (3);  $\beta_2 = -\beta_1$  and  $\beta_1 = 4\beta$ . The forecasts of  $y_{t+1}$  in equation (3) approach a stable value under the following conditions:  $|\beta_1| < 1$ ,  $|\beta_2| < 1$ ,  $\beta_1 + \beta_2 < 1$  and  $\beta_1 - \beta_2 < 1$  (cf. Johnston, 1984: 374). The last two conditions define a damping oscillator. If this condition is not fulfilled the forecasts of  $y_{t+1}$  explode to the stable values  $-\infty$  or  $+\infty$ . The damping oscillator defined by equation (3) under the conditions imposed above

will produce values of  $y_{t+1}$  in the stable bifurcation regime, the unstable bifurcation regime and the chaos regime when the values of  $\beta_1$  and  $\beta_2$  diverge further from their boundary values, which are the largest values of  $\beta_1$  and  $\beta_2$  that keep the values of  $y_{t+1}$  in the stable value regime. But experimental research into the threshold values of  $\beta_1$  and  $\beta_2$  between the 4 regimes has not been conducted yet

Equation (3) is thus a very general nonlinear model with the capacity to produce values of  $y_{t+1}$  in one of the 4 regimes mentioned before. But the parameters  $\beta_1$  and  $\beta_2$  in equation (3) represent autoregressive effects in  $y$ . Such effects provide only information about *how*  $y$  develops over time and no informal ton about *why*  $y$  exhibits its development over time. According to Cohen & Nagel (1961: 246), a causal interpretation can only be given to an invariant relationship that exists between two by definition different variables, in which the explanatory variable precedes the variable to be explained. So, in order to give a causal interpretation to  $\beta_1$  and  $\beta_2$ ,  $y$ , inequation (3) must be replaced by another variable  $x_t$ . This is done, for example by Saperstein (1984) and Grossmann & Maier-Kress (1989) in their specifications of a chaos model of arms races.

Estimation of the values of  $\beta_1$  and  $\beta_2$  from observed data on  $y$  and  $x$  can be accomplished by applying econometric methods (see, among others, Johnston, 1984)<sup>1</sup>. But before such estimation is carried out it should be assessed whether or not the specification of a nonlinear relationship between  $y$  and  $x$  is correct. This means that the time series data on  $y$  and  $x$  must be analyzed in order to decide whether these data are generated by a deterministic nonlinear process or by a stochastic nonlinear or linear process. In case it is a deterministic nonlinear process all combinations of  $(y_{t+1}, y_t)$ ,  $(x_{t+1}, x_t)$  and/or  $(y_{t+1}, x_t)$  lie on parabolic curves (Baumol & Benhabib, 1989: 102). But in case it is a stochastic process these combinations of  $y$  and  $x$  are shattered around parabolic curves. The choice between a stochastic linear process and a stochastic nonlinear process may then become rather difficult. If one further adds that most data on social phenomena contain measurement errors, which are due to various kinds of theoretical, methodological and/or instrumental imperfections (see for more details, among others, Blalock, 1969 and 1982), this choice becomes even more complicated. One of the tests that seems useful in order to decide between a linear and a nonlinear specification is the following one. After having estimated a stochastic nonlinear process from the observed data, the estimated regression

<sup>1</sup> Econometric methods are mostly used to estimate relationships among phenomena of which the values over time lie in the stable value regime (linear regression analysis) or in the stable bifurcation regime (multivariate time series analysis). In the latter case various tests and filters have to be applied before an estimated causal relationship can be conceived as Granger-causality, that is, free of effects of spurious correlations (see Johnston, 1984: 371-381). So, the problems connected with the estimation of relationships among phenomena, which take values over time in the unstable bifurcation regime or in the chaos regime, will be even larger.

coefficients and random disturbances are used to forecast the observed data from initial values of the independent variables that differ only slightly from their observed initial values. If the temporal trajectory of the forecasts runs parallel to the temporal trajectory of the observed data then the stochastic nonlinear process is inherent stable and the question arises whether or not a stochastic linear process might provide a better fit to the observed data. If the temporal trajectory of the forecasts diverges from the temporal trajectory of the observed data then the stochastic nonlinear process is inherent unstable or, in other words, strange attractors may be present (Baumol & Benhabib, 1989: 103).

The conclusion to be drawn is that it requires various tests to be applied to time series of observed data before one can decide whether or not the observed phenomena are induced by a nonlinear process. Furthermore, if these observations also contain considerable random disturbances then such a decision cannot be made beyond doubt. So, a problem of external validity shows up. Additionally, the question arises whether fitted nonlinear processes (including chaos) can be a basis for the derivation of an explanation of the investigated phenomena. This issue will be addressed in the next section.

### 3. Explaining nonlinear dynamics

The empirical finding of nonlinear processes generating values in the unstable bifurcation regime or in the chaos regime taken by the phenomena studied leads to the question whether or not such processes represent scientific explanations of these phenomena. In order to answer this question it should be noted that a mathematical model of nonlinear dynamics is estimated from observed data. Such a mathematical model can be found as the best fitting member of a whole set of mathematical models fitted to the observed data. Subsequently, a theoretical explanation must be derived to underpin the best fitting mathematical model as its operationalization. Such a theoretical explanation can be derived via either deduction or induction. Following the deductive approach, a theoretical explanation of social phenomena is deduced from a more general theory of social behaviour or even better from a set of axioms concerning social behaviour. But a theoretical explanation of irregular cyclical social behaviour, which is deduced from a more general established theory of social behaviour, has not been formulated yet (Loye & Eisler, 1987: 57).

Following the inductive approach, a theoretical explanation of the social phenomena, which are contained as variables in the best fitting mathematical model, is inferred from the estimated mathematical relationships between the variables. But various equally plausible theoretical explanations may compete for being the theoretical ground of the fitted mathematical model. And repeatedly fitting of the same mathematical model to different samples with

data on the phenomena studied does not solve this problem when the model is not falsified<sup>2</sup>. Consequently, nothing can be said about the explanatory power of the theoretical interpretation derived from the fitted mathematical model of nonlinear dynamics. This is due to the fact that the mathematical model may be argued afterwards on equally plausible grounds to be the »valid« operationalization of different theoretical models. For example, a fitted and not falsified arms race model (see Richardson, 1960: 16) contains mutual positive effects between the (yearly) defense expenditures of two nations *i* and *j*. But from these empirically assessed effects at least two different theoretical explanations can be inferred: each nation strives for (1) military power domination over the other, or (2) offsetting military power domination by the other. The first interpretation may be labeled »rational power theory« while the second interpretation may be labeled »threat reduction theory«. Without extra information about the context and circumstances wherein the expenditures on national defense are done both interpretations are equally valid.<sup>3</sup> This implies that the fitted mathematical model does not represent an empirical test of a theoretical explanation. Consequently, a problem of internal validity is present concerning the correspondence between the fitted mathematical model and its theoretical explanation. This implies that fitting a mathematical model of nonlinear dynamics to data on the phenomena of interest produces no clues concerning the choice between a better and a worse theoretical explanation of that phenomenon or, in other words, contributes nothing to theory-formation about the development of the observed phenomena over time.

The conclusion to be drawn is that fitting mathematical models of nonlinear dynamics to time series of observed data on social phenomena adds nothing to our knowledge of why these social phenomena develop over time; i.e., only a mathematical description of the social phenomena is given and not an explanation. It becomes impossible then to imagine how the values of a social phenomenon exhibiting a chaotic pattern return to a pattern of stable bifurcation or to a stable value. Such a shift would require a change in the values of the parameters inserted in the model. The implications of such a shift in parameter values and the scientific problems connected with them in terms of mathematics, philosophy of science and social theory must be added to the

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<sup>2</sup> Fitting a mathematical model to just one sample creates the problem of verification by induction.

<sup>3</sup> The logically consistent deduction or inference of a theoretical explanation of any observed phenomenon from a more general theory or a fitted and not falsified mathematical model, respectively, has been criticized from a philosophy of science perspective. A theoretical explanation of an observable phenomenon contains not only logically derived concepts but also extralogical concepts, which can only be defined in observable terms. These extra-logical concepts are included in the theoretical explanation in order to limit the number of why-questions, which are connected with a logically consistent derivation of a theoretical explanation, and to answer the remaining why-question(s). (See Stegmüller, 1983: 1-10 and 940-978.)

problems of empirical assessment and theory-formation identified before. And the various problems related to a shift in parameter values do not disappear with the introduction of the system-theoretic notion of selforganization. As system theory like mathematics is empirically empty its concepts cannot provide any explanation of such a shift. Self-organization should be given meaning by defining it in terms of the disciplines that study the social phenomenon concerned (see Scheper, 1991). This will be difficult to realize because of the (rudimentary) state of theory-formation; a theory of irregular cyclical social behaviour is lacking. Nevertheless, the term »theory« is notoriously often used in the social sciences although only a few theoretical insights are demonstrated to be valid across more than one sample. The discrepancy between the lack of theory-formation and the use of ad hoc »theoretical« (or suggestive) arguments to justify the specification and estimation of (nonlinear) mathematical models in the social sciences will be discussed in the next section.

#### 4. Chaos theory applied in social science research: an example

In the previous section it was stated that from the perspective of philosophy of science established theories of social phenomena are rare. In our opinion, it is precisely this lack of established theories in the social sciences that has stimulated ad hoc reasoning about social phenomena. And with the aid of information technology explanatory models of social phenomena based on ad hoc arguments can be easily translated into mathematical models and tested for their validity. This has happened, for example, in the study of arms races in international relations. The central hypothesis in this field of social research is that arms races increase the risk of outbreaks of war. But this hypothesis has never been put to an empirical test in arms race research. Furthermore, a theoretical explanation of the relationship between arms races and outbreaks of war that is based on theoretical notions derived from empirical evidence on individual and group information processing and decision making within governments is lacking. In such a situation of poor empirical evidence and shallow theory-formation it is not surprising that mathematical models of chaos are applied in the study of arms races. The argument on which these applications are based is that when arms races become unpredictable war will get inevitable. These aspects of the study of arms races in international relations will be described in further detail in the rest of this section.

Scientific research into arms races in international relations has accelerated after the publication of Richardson's book 'Arms and Insecurity' (Richardson, 1960). The central hypothesis of the research published in this book is that outbreaks of war among nations are preceded by arms races. In order to test this hypothesis Richardson formulated his famous arms race model, translated it



into a mathematical model consisting of two first-order differential equations, and estimated the unknown parameters in the mathematical model from pre-World War I data. Furthermore, the mathematical model was tested for its validity. The empirical results obtained by Richardson do not falsify his central hypothesis. Estimation of Richardson's arms race model has been replicated many times by other scientists using different samples of data on defense expenditures and other empirical indicators of military power. Their results increased the reliability of the arms race model.

Consequently, one might conclude that arms races increase the risk of outbreaks of war. However, research into the general question whether or not occurrences of arms races precede outbreaks of war has not been conducted by Richardson and other arms race specialists. They only investigated the existence of arms races. Richardson (1960) only demonstrated that World War I was preceded by arms races. The relationship between occurrences of arms races and outbreaks of war among powerful nations involved in serious disputes during the period 1820-1965 has been empirically investigated by Wallace (1979). His confirmation of the existence of this relationship is disapproved by the empirical results obtained by Houweling & Siccama (1981). Their results demonstrate only a negative influence of arms races on the escalation of serious disputes into war among nations. Later they have provided empirical evidence of a positive effect of power transitions on outbreaks of war among powerful nations (Houweling & Siccama, 1988 and 1991). But in these studies the power of nations is not strictly defined as military power but as a mixture of manpower, economic power and military power. So, the question whether or not arms races increase the risk of outbreaks of war cannot be answered yet.

But let us assume that the question can be answered positively. From a prediction point of view this result would be very satisfactory because arms races can then be conceived as an early warning indicator of war, but from an explanatory point of view the positive answer only generates more questions concerning why arms races increase the risk of outbreaks of war. So, the predictive power of a mathematical model should not be confused with the explanatory power of its theoretical foundation. As outbreaks of war result from governmental decision making the question of why and how arms races increase the risk of outbreaks of war represents a very complex subject of research; it touches upon the areas of individual information processing by members of governments, of group processes within governments that lead to choosing the war option out of a set of alternatives, of political, cultural, economic and demographic constraints on the decision process itself as well as on the selection of the set of behavioural options considered, etc. In other words, an interdisciplinary explanation is required and must be constructed from at least those theoretical insights prevailing within the various disciplines of social science that bear resemblance to reality.\* Only then meaning can be

\* See Scheper (1991: 67-72) for a detailed discussion of interdisciplinary scientific explanations.

given to what is meant by self-organization in the interdisciplinary approach to complex social phenomena that is based on system theory as advocated by Laszlo (1984). But such an interdisciplinary explanation has not been formulated yet

The state of social science research into the arms race-war relationship with respect to the empirical evidence obtained and its theoretical explanation has been discussed above. These discussions form the background of an evaluation of research into arms races utilizing mathematical models of chaos. The studies of Saperstein (1984) and Grossmann & Mayer-Kress (1989) referred to before both contain specifications and analyses of chaos models of arms races. But only Saperstein has put his model to empirical tests. Therefore, our evaluation concentrates on Saperstein's research. The study of Grossmann & Mayer-Kress is built on Saperstein's chaos model and presents a small refinement of that model in terms of operational definitions of the variables specified. Furthermore, they present results of simulations with the model. These results show that the transition of predicted values of the proportional defense expenditures from the stable value regime to the chaotic regime is much sharper and occurs at lower values of  $\beta$  in their explanatory chaos model than in the autoregressive chaos model (see Section 2).

Saperstein (1984) starts his article with the suggestion that war outbreaks occur when the predictability of arms races vanishes or, in other words, when the predictions of future armaments leave the stable value regime and move successively into the stable bifurcation, the unstable bifurcation and ultimately the chaos regimes. One would expect then an analysis of the relationship between the types of regime characterizing the natures of arms races and the subsequent occurrences of war. This analysis has not been conducted by Saperstein. He has only estimated his arms race model in order to detect in what regime a particular arms race lies. The investigated arms races are those between France, the United Kingdom, and the USSR at one side and Germany and Italy at the other side during a 2-years period preceding World War II (1934-35 or 1936-37). The estimates of the parameters in each arms race equation are derived from only two observations, which implies that the reliability of the results obtained tends to zero. Only 2 of the 12 estimated arms race equations lie outside the stable value regime; the predicted values of proportional defense expenditures of the USSR due to the values attained by Germany lie in the chaotic regime, and the predicted values of proportional defense expenditures of the USSR due to the values attained by Italy lie in the stable bifurcation regime. The finding of 2 relevant cases out of 12 does, however, not make up a good result concerning the validity of the proposed relationship between the breakdown of the predictability of arms races and the outbreak of wars. Consequently, the external validity of chaos in arms races as the explanation of outbreaks of war tends to zero. The internal validity of the theoretical explanation that outbreaks of war are caused by chaos in arms races needs not to be disapproved anymore.

What is needed in the study of arms races in international relations are better theoretical notions about the necessary and sufficient conditions under which arms races stimulate and deter outbreaks of war among nations. Furthermore, not only the empirical assessment of arms races is required but also additional empirical research into their relationship with outbreaks of war. This implies that better mathematical models are not most desired, but that better theories should be developed.<sup>5</sup>

One might argue that our analyses of the relevance of new mathematical models for theory-formation in the social sciences and of the state of theory-formation in the social sciences are rather thin. Obviously, we have only analyzed a very small segment of the social science domain. But let us give another example of the immature state of theory-formation in the social sciences that refers implicitly or explicitly to the basics of all social science. Collective behavior of a group of individuals consists of composite individual behavior. And individual behavior is rooted in individual information processing and decision making. A recent overview of the state of theory-formation concerning these latter subjects can be found in Bell et al. (1988). From this overview it can be concluded that a comprehensive theory of information processing and decision making by individuals has not been reached yet; or, as Einhorn & Hogarth (1988: 150) put it »The challenging task for future research is to improve our normative models [i.e., models derived from a set of axioms] by enlarging the context in which they have been used. This will involve incorporating better descriptions of what people are doing and why they are doing it«. The analyses of the state of theory-formation concerning the relationship between arms races and outbreaks of war and of the relevance of mathematical models of chaos for this theory-formation were never intended to provide valid results for all social science research. The only purpose of our analyses is to stimulate social scientists to ask themselves: »Have we in our field of interest arrived in the same situation as the study of arms races in international relations?« And if the answer is positive you have arrived in a chaotic scientific situation, in which »theories« based on suggestive ad hoc reasoning and fancy mathematical models prevail.

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<sup>5</sup> Better theories should be understood as follows. Theory refers to the status that a theoretical model acquires if its mathematical representation is not falsified in the course of repeated empirical testing. And a theoretical model is better than another if its empirical content is better specified (see Popper, 1975: 112-123). Furthermore if a theoretical model is better then the choice of the mathematical model representing the theoretical model for the purpose of testing follows less ambiguously from the specification of the theoretical model although some operationalization problems may exist (see, *inter alia*, Kaplan, 1946).

## 5. Conclusions

Chaos models are nonlinear models. The finding that such models are capable of producing outcomes with a chaotic pattern may be considered as a novel scientific result. But it should be noticed that by definition chaos models belong to the scientific domain of mathematics. Using chaos models as mathematical descriptions of irregular cyclical phenomena within the empirical sciences (for example, physics or social science) requires then the stipulation of the correspondence between chaos in mathematics and irregular cyclical behaviour in another scientific domain. If that correspondence results from a theory of irregular cyclical phenomena within the latter domain then no scientific problem with the application of mathematical chaos models shows up. But if that correspondence is not derived from such a theory of irregular cyclical phenomena then several problems of philosophy of science show up and add to each other. This occurs if mathematical chaos theory is embraced as a new paradigm to the interdisciplinary study of social science. Sooner or later this will lead to fitting chaos models to time series of observed data on social phenomena (see, among others, Saperstein, 1984). The problems that arise then from a philosophy of science perspective are the following:

- (1) fitting a chaos model to observed data on social phenomena gives rise to the problem of external validity. This problem stems from the difficulties involved before a decision can be made concerning whether or not the observed data on a social phenomenon are generated by a nonlinear process capable of producing chaotic patterns of data. These difficulties appear as a result of the existence of a stochastic component in the estimated process. The choice between a stochastic linear process and a stochastic nonlinear process becomes even more problematic when the random disturbances in the observed data are relatively large. As observed data on social phenomena are mostly subject to measurement errors for a variety of reasons (see Section 2), the assessment of the data generating process is not beyond considerable doubt; and
- (2) as a theoretical explanation of irregular cyclical behaviour by (groups of) individuals, which draws upon established scientific insights, is lacking, the degree of correspondence between the mathematical chaos model and its interpreted underlying theoretical model of group or individual behaviour becomes zero; i.e., the problem of any interpreted theoretical explanation derived from a mathematical chaos model that it possesses no internal validity cannot be solved.

The temptation to ignore these correspondence problems in the application of the mathematical model of chaos to the social science domain has been argued in Section 4 to exist due to the immature state of theory-formation in the social sciences. The lack of established theories has stimulated the creation of

»theories« based on suggestive ad hoc reasoning. The relevance of chaos theory for social science is made plausible via suggestive ad hoc arguments like: »the unpredictability of an arms race may lead to an outbreak of war« (cf. Saperstein, 1984), which is a probabilistic statement about an invariant relationship; or »chaos theory bears resemblance with selforganization in system theory« (cf. Laszlo, 1984; Loye & Eisler, 1987), which is remarkable because the scientific areas of mathematics and system theory are both empirically empty. In our analysis of the study of arms races in international relations it was demonstrated that research based on such ad hoc »theories« may even leave the central assumption in such theories uninvestigated.

Our conclusion is very short. Social science is not helped by the trendy application of sophisticated mathematical models. To improve knowledge and understanding of social phenomena in reality better theories of their existence and dynamics are necessary prerequisites. And only when these prerequisites are fulfilled the scientific value of chaos theory for the social sciences can be properly investigated.

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