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ENVIRONMENTAL-ECONOMIC MODELING WITH SEMANTIC INSUFFICIENCY AND FACTUAL UNCERTAINTY

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ABSTRACT

The present article presents an attempt at modeling an environmental-economic system when neither the semantic knowledge nor the statistical data are sufficient. For these cases the study introduces a new methodology of creating observations based on the knowledge of a selected interdisciplinary group of experts/scientists. This procedure as well as the processing of these "artificial observations" are systematically presented in the article. The application field and the limitations of the method are also discussed, followed by the presentation of an empirical illustration regarding water quality management.

1. INTRODUCTION

Environmental-economic models are nowadays indispensable instruments for effective management and policy design in a wide variety of environmental policy fields [1, 2]. They can be used for both predictive purposes by estimating the ex-ante effects of environmental policy or economic projects, and descriptive purposes by increasing the knowledge base or the communication content regarding interlinked natural and economic processes. Despite this simple and straightforward view, in practice there is considerable methodological difficulty involved in building up such models. In many cases there is incomplete knowledge of the system at hand (insufficient theoretical foundation, lack of a proper specification basis), while solid statistical data are also lacking. Sometimes only qualitative or

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fuzzy information is available. Then the development of a fully specified and operational quantitative model is almost impossible [3, 4].

The present study deals with the above mentioned difficulty. It focuses on environmental-economic models that aim to map, in a formal way, a real world environmental-economic system, and it tries to overcome the above problem of semantic insufficiency and factual uncertainty using expert knowledge and combinational specification methods.

There are two alternative modes for developing environmental-economic models [3]. First, in case the scientific knowledge on the system is fully available, one can formulate proper mathematical relationships (functions) that describe its operation in a reduced form. Second, when one has a sufficient and suitable number of (statistical) observations, one may obtain the relevant mathematical relationships (functions) by processing these data by means of alternative specification tests [2]. Note that also in the first alternative, statistical observations are often used for estimating the coefficients of an abstract mathematical function which had been derived from using the available scientific knowledge; in these cases the model is mainly based on state-of-the-art insight, while statistics are then often of complementary use.

There are however, various cases where one can hardly acquire or access either the necessary complete scientific knowledge of sufficient statistical data. In these cases, it is problematic to specify the mathematical relationships and functions that formally represent the structure and operation of the system under investigation. The present study deals with this particular problem. It aims to combine the two above-mentioned alternatives for those situations in which neither of the two previously mentioned options can be used to solve the problem. Specifically, our study proposes a Delphi type of methodology by using existing interdisciplinary expert knowledge on environmental-economic issues in order to "create observations"; these "created observations" can next be processed by standard statistical methods in order to identify the best specified model.

Clearly, the proposed methodology is not necessarily confined to the field of environmental-economic modeling; it may also be applied in any other modeling experiment characterized by semantic insufficiency or statistical uncertainty.

This article has the following structure. First, the proposed methodology will be presented (Section 2). Then its main elements are discussed in relation to standard statistical-econometrical methods so that its intrinsic merit can be better judged (Section 3). Finally, the scope as well as the limitations of this new approach are reviewed (Section 4), while its potential is assessed on the basis of a simple illustrative application (Section 5).

2. THE PROPOSED METHODOLOGY

In the framework of the present article, the system to be modeled may be any real ecosystem in relation to relevant human activities; for example, it may be the ecosystem of a lake or a river in relation to the human activities in the catchment area. The mathematical representation of such a system will normally consist of the set of all functions (equations) that formally depict the interactions between the components of the system (causal relationships); for instance, between water quality and the fish population, or between intruding economic activities and water quality [3, 4]. Many obstacles however may be encountered in the process of obtaining and specifying relevant mathematical functions. Usually the system is not exactly known, so that we cannot a priori and unambiguously specify the relevant equations, while at the same time there exists only a limited number of statistical observations or data. In our example, we may assume that we wish to delineate a mathematical function that defines the river water quality as a derivative of relevant natural processes (regeneration capacity) and various human activities in the surrounding area. Let us take for granted that for this particular relationship we have neither complete scientific knowledge nor a sufficient number of (statistical) observations. Then the question is how to obtain a satisfactory and operational system's model which can properly replicate the real world [2].

The methodology proposed in the present article serves to overcome these obstacles. In general, this approach concerns the modeling of the causal (cause-effect) relationships between the components of an environmental-economic system. An individual "cause-effect" relationship considers the effects on a single component caused by other components and by external factors as well; the entire system's model, which represents the whole environmental-economic system at hand, consists of the set of all individual "cause-effect" relationships.

The main problem is then to establish a function f representing formally each individual causal ("cause-effect") relationship, when neither the semantic knowledge nor the existing statistical observations alone suffice to do so. For these cases, our approach will use the limited available scientific knowledge of the system at hand, in order to "create" acceptable and relevant observations. In the following we will systematically present the steps of the proposed methodology in order to derive a proper mathematical function of an individual causal (cause-effect) relationship; in our example, this is the river water quality determined by the natural assimilation capacity and relevant human activities in the catchment area.

Step 1: Composing an Interdisciplinary Scientific Expert Group

A properly selected interdisciplinary group of experts with expertise on a broad range of environmental-economic issues is composed as the first step in our approach. The suitability of this group stems from the prerequisite that the members of the group should have the maximum possible scientific knowledge of the system under investigation and are supposed to be knowledgeable in the area concerned.

This interdisciplinary group gathers and considers all existing information for the individual pertinent causal relationship in relation to the phenomenon studied. So, besides any other information, the existing statistical information will be accessed by the group. Clearly, we assume that this information is not sufficient for deriving the relevant mathematical function by means of standard mathematical-statistical methods.

Next, within certain limits of time and money, the group—once composed—may take initiatives or actions which may augment the scientific knowledge on the relationship or phenomenon at hand. Even experiments—if possible—can be used for obtaining more statistical information. Evidently, if a statistically sufficient number of observations is obtained from these experiments, then modeling activity may proceed immediately with the application of standard statistical/econometric methods; in our case however, we assume that such experiments do not generate a sufficient number of observations.

As a result, all available information is accessed by the members of the group, including even an extensive discussion on the underling relationships so that all members share a common knowledge base.

Step 2: Creating Observations

This step is the most crucial one for the accomplishment of the methodology. It aims at "creating" observations or artificial data for the relationship examined; these newly created observations will also be called "hypothetical observations" throughout the article. The creation of these observations is done on the basis of the "common knowledge" established in the previous step. How can this be achieved?

The pertinent "cause-effect" relationship can formally be represented by an abstract function in the following way:

$$y = f(x_1, x_2, x_3) \qquad (1)$$

The problem now is how to create artificial observations, each one describing a specific instance of the relationship or phenomenon under investigation. Actually, each observation consists of numerical values of both the dependent and the independent variables incorporated in (1).

This method works as follows. The interdisciplinary experts group creates a hypothetical combination for the independent variables of (1) (x_1, x_2, x_3) by attaching random values to each one. Obviously, the random value of each variable is restricted to the range given by its real world definition; moreover, these values could be selected according to the purposes of the model. Then, the value of the dependent variable y should be defined for this combination of independent variables in order that the created combination be complete. This task is performed on the basis of the established "common knowledge" concerning the relationship/phenomenon at hand. In this context, the members of the group define the value of the dependent variable y, so that the complete combination (y, x_1, x_2, x_3) describes an arbitrary, but feasible instance of the phenomenon at hand. At this point, it is assumed that the group identifies only one value for y for the given combination of x_n's. However, there may clearly be a disagreement among the members of the group, so that more than one value may be proposed for y. Consequently, the members of the expert group are exposed to a Delphi-type of negotiation via a further scientific discussion and an exchange of experience, so that ultimately they may agree on one common value based on scientific criteria; if at the end disagreement still prevails, this combination of independent variables is rejected. As a result, an observation based on consensus can finally be created for the phenomenon examined.

Evidently, other options to deal with potential disagreements are available. For instance, all different opinions may be accepted and then a weighting model could be used for including them in the data set; or instead of a unique value a range of y's values may be indicated by the expert group for the given combination of the independent variables x_n's. In this respect, our choice to use only "consensus" artificial observations originates from our decision to "create" observations similar with the actual observations, which are based on measurements of the relevant physical entities and so are uniquely determined. Therefore, the exclusive use of "consensus" artificial observations is a principal characteristic of our study.

The whole procedure is repeated until a statistically sufficient number of observations has been created. Attention should also be paid to the fact that the artificially created observations correspond to all possible aspects or phases of the phenomenon examined. Therefore, a suitably selected set of combinations for the independent variables should be created. In this respect, the purposes of the model should be taken into account.

Step 3: Determining the Mathematical Function for the Phenomenon

The next step aims at determining the quantitative form of the abstract representation (1). The hypotheses, underlying this step, are the following:

a. The functional relationship (1) is assumed to exist in a structural sense; it relates y to the independent variables, so that (1) forms the statistical model of our problem [5]. Specifically, (1) is the abstract mapping relationship for the real-world phenomenon examined. However, an important remark is in order at this point. The phenomenon under consideration should concern a physical/technical process of a deterministic nature and not socio-economic behavior that involves social stochastic factors [2, 6]. This does not imply that we should confine our research to the domain of natural phenomena alone; physical-technical interactions involved in economic and social phenomena can also be examined, if they do not involve stochastic elements of socioeconomic behavior [2]. In our example, the population size in the catchment area may influence the quality of the river; the relationship between the population and river quality can be studied by the above discussed methodology, since what matters is the physical aspect of the population. On the other hand, the relationship between the income level and the consumption of agricultural products cannot be examined this way, since it involves socioeconomic behavior and inherent stochastic factors.

b. It is assumed that the interdisciplinary group has sufficient knowledge of the phenomenon, so that all relevant factors are included in (1). Moreover, it is assumed that there is no factor contained in (1) that is not really involved in the phenomenon at hand.
c. It is also assumed that the used set of the newly created (hypothetical) observations will determine the same equation (function) f for (1) with every other possible set of created observations. This ensures that this equation (function) f obeys any set of observations (created or real) of the phenomenon at hand and not only the given one that is used for determining f.
d. The created observations are randomly distributed. This indispensable prerequisite can be fulfilled, since we are able to create the observations by a random selection of values for the independent variables.

Subsequently, the statistical problem is a rather simple one. In fact, the problem consists of determining a function f by making use of a given set of observations (hypothetical observations in our case). In other words, we should fit a curve (surface) to given points, determined by the set of observations, in the n-dimensional space. This problem is extensively studied by statistical mathematics under the title of "mathematical fitting." There are several statistical mathematical methods for fitting a curve to a given set of observations; among them the standard regression method usually prevails [2, 5, 6].

In the proposed methodology for the set of observations to be used for defining the mathematical expression of function f we may face two alternatives. Either we use only the set of the created (hypothetical) observations, while keeping the real ones for testing the function f, or we can also make use of the really existing statistical observations.

Step 4: Test against Reality

The estimation of the mathematical expression for the function f of (1) bears some arbitrary elements which stems from the use of the created observations. Indeed, they do not necessarily depict real instances of the relevant phenomenon. Rather, they originate from the relevant scientific knowledge.

Therefore, some kind of testing is indispensable part of the methodology. Specifically, when we compose the set of observations that will be used for defining f, a number of real observations should not be included in this set. They will be used for testing the function f, once it is estimated. For this test several methods may be applied depending on the particular characteristics of each case study. If f fits sufficiently these real observations, it should be accepted; otherwise, it should be rejected. If it is rejected, the whole process should be repeated (creation of new observations etc.), until a better function f is estimated.

Finally, a function f is established which can be accepted as a reliable formal representation of the examined relationship/phenomenon. Evidently, the function f is estimated on the basis of the hypothetical observations created by the interdisciplinary group. The basis of this estimation is that the scientific knowledge of the group substitutes the lack of actual observations.

As a result of the whole process we obtain the formal representation of the examined individual interaction/phenomenon that takes place within the environmental-economic system under investigation. Referring to our example, we obtain the function f that depicts the river water quality as the effect of the human activities in the catchment area and of the relevant natural regeneration process. For modeling the entire system of our example we should repeat the methodology for all individual relationships/phenomena involved in the system. Once all causal relationships have been quantified, we obtain the mathematical model representing the whole system. Then, a test of the entire model reliability can only be performed if suitable statistical data are available. Some corrective actions can of course be undertaken in this step.

Finally, a mathematical model that represents formally the system at hand can be developed in this way. Evidently, this model is based on the assumed scientific knowledge of the experts composing the interdisciplinary group. This knowledge leads to creating observations for each individual causal relationship of the system under investigation. Based on the created observations we then obtain the mathematical expression describing formally each causal relationship.

The uses of the model and the respective limitations will be discussed in Section 4. We shall first confront this new approach with conventional approaches.

3. THE PROPOSED METHODOLOGY IN RELATION TO CONVENTIONAL STATISTICAL/ECONOMETRIC APPROACHES

The present section aims at relating the properties of the proposed methodology to the properties of the standard statistical/econometric approach. Both methodologies aim at determining a formal mathematical representation for a real-world phenomenon by making use of statistical observations. However, they are fundamentally different in the way they perform this task. Let us describe the differences by delineating briefly the steps and characteristics of each one.

Conventional Econometric/Statistical Methodology

a. The target is the establishment of a quantitative function that delineates a real-world phenomenon. The scientific knowledge and the factual experience establish a set of abstract functions which, by assumption, describe the phenomenon at hand. They form the theoretical model of the study [2]. This theoretical model will be numerically defined in the following steps. It either can be proven valid or it is rejected, and in the latter case another theoretical model is proposed. Note that if sometimes a theoretical model cannot be established, the quantitative function f should be interpreted by taking into account the relevant restrictions as well as the nature of the phenomenon at hand [5]. In this respect, the theoretical model encloses the scientific knowledge which takes a formal representation via the use of a random data set. Therefore, the existence of a theoretical model gives the necessary generality to the function f, so that it can be perceived as a "law" [2].

   This constraint holds less in the case of natural sciences phenomena where a suitable number of statistical observations suffices to establish the "quantitative law" of the phenomenon, because such physical phenomena lack usually the stochastic social elements that are to be handled by the theoretical model. In the case of a physical phenomenon, each random set of observations is expected to lead to the same function f with any other set of data. Therefore, the function f forms the relevant "quantitative law," even if there is no theoretical model.

b. The existing statistical observations are processed by established statistical-mathematical methods through which the function f can be estimated.

c. Once f is defined, it should be tested. More precisely, it should be examined whether f is actually the "quantitative law" of the phenomenon examined. In this framework, usual tests of misspecification (homoscedasticity, autocorrelation, and multicolinearity) should be carried out. Indeed, if the defined law is not sufficient, the above tests may lead to establishing a better one [5, 7].

The Proposed Methodology

The proposed methodology aims at representing formally a physical-technical relationship or mapping out a phenomenon. The specific problem here is the lack of a sufficient set of statistical observations. On the other hand, there may exist, to a considerable extent, scientific knowledge concerning the relationship at hand. However, this knowledge does not suffice to establish directly the mathematical representation of the phenomenon. The proposed methodology utilizes the available scientific knowledge in order to create a set of observations. The essence of this process is the following: the members of the interdisciplinary group create observations describing specific instances of the phenomenon; this data creation activity is based on the expert perception of the "logical law" that underlines the phenomena, although the expert does not know unambiguously the precise quantitative specification of this law (the quantitative law of the phenomenon). So, the experts create "hypothetical observations" according to the rationale behind the logical law.

Briefly, the steps of the proposed methodology are the following:

- the assembly of the interdisciplinary group whose members establish a "common knowledge pool" that can be perceived as a mapping of a "logical law" governing the phenomenon;
- in the light of the above logical law, the members of the group create artificial but feasible observations;
- by processing the created observations, a function f, which describes them, is defined. It is assumed that f represents formally the logical law, so it may be perceived as the quantitative law of the phenomenon;
- once f is defined, any test such as on homoscedasticity, autocorrelation, or multicolinearity may only play a marginal role. All these tests aim at establishing a proper quantitative law, once we have a set of statistical observations. On the contrary, the proposed methodology presumes the existence of this law; indeed it is the logical law that leads to the creation of observations.

The main steps both of the proposed methodology and of the statistical one are systematically presented in Table 1.

4. THE SCOPE OF THE PROPOSED METHODOLOGY

The above analysis reveals the application field of the proposed methodology. It can be applied when either physical-technical phenomena or the physical-material basis or consequences of social phenomena are investigated. In these cases it can be assumed that a group of qualified scientists knows the determinant factors of the phenomena examined, and moreover, that to some extent they know the "logical law" underlying them. On the contrary, if socioeconomic phenomena are examined, we can hardly expect a group of scientists to know all interesting background factors involved and their functioning, as this would assume a complete knowledge of human behavior which is the main question in the social sciences. For phenomena related to human behavior the use of statistical observations may confirm or reject our theoretical assumptions about human behavior; this permits us to investigate it, and therefore statistical observations are necessary. Nevertheless, it may be possible that in some particular cases a highly qualified experts group may "create" artificial observations concerning social phenomena.

Table 1. The Focal Points of the Proposed Methodology in Relation to Those of the Statistical/Econometric One

The Statistical/Econometric Methodology	The Proposed Methodology
It aims at establishing the quantitative law of a natural phenomenon or of a socioeconomic relationship	The target is the establishment of a quantitative law that describes a technical/natural phenomenon
A theoretical model is assumed that describes the phenomenon examined. The target is the numerical estimation of the model. (This step is often skipped)	A suitably selected interdisciplinary scientific group is established. It is assumed that this group is able to perceive the "logical law" underlying the examined phenomenon
	The scientific group creates obervations that describe certain instances of the phenomenon. Obviously, the created observations obey the "logical law" established in the previous step
Existing statistical observations are used for estimating the functions of the theoretical model	By using the created observations we estimate the function f that fits them
The quantitative model is imposed to proper statistical/econometric tests. They aim at testing the ability of the estimated model for describing the real world phenomenon. Suitable corrections are undertaken. They aim at establishing the best possible quantitative law for the examined phenomenon	The function f is tested against existing actual observations. Suitable corrections are undertaken

It should be added that the proposed methodology is not in contrast with the traditional statistical/econometric one, even not in the domain of physical-technical phenomena. Rather, it is a complementary one. Specifically, the proposed methodology applies when observations, which would otherwise permit the use of a more rigorous statistical/econometric methodology, are not available.

An indispensable prerequisite for applying our proposed methodology is the existence of a considerable high level of expert knowledge for the phenomenon studied. Then, although this knowledge may not suffice to quantify directly the phenomenon studied, it can create artificial observations describing particular random instances of the phenomenon. The mathematical representation of the phenomenon can be defined by processing statistically the created observations.

Clearly, the methodology proposed here might lead to some imprecise formal representation of the phenomenon examined because of the imprecision hidden in the data created. In some cases, this imprecision can be avoided by collecting or creating data by experiments and then the rigorous statistical/econometrical methodology can be applied. However, often the process of obtaining real data may be costly or time consuming so that then there is some kind of trade-off between the application of these two methodologies.

5. AN EXAMPLE

This section will describe the application of the proposed methodology in a Greek region. The aim is to model the environmental-economic system of the Olympia Region in the western part of the Peloponnesus. In this case we aim to apply the proposed methodology, because neither the necessary data exist nor experiments can be performed to generate them; collection of new data from future measurements might be possible for some individual causal relationships, but this would be costly and time consuming. Thus, this situation seems to be ideal for the use of the proposed methodology. It should be noted that this section aims at elaborating and illustrating the properties of the proposed methodology and not to go deeply into the case study itself.

The interdisciplinary group of experts in our case study consisted of nine independent environmental scientists working in the region. The whole model describing the economic-environmental structure of this area consists of seventy individual causal relationships between the elements of the environmental-economic system; thus the model consists of seventy equations.

In this context, we will present here the modeling procedure for only one individual phenomenon/relationship, namely concerning the water quality of the Alfios River. The interdisciplinary group has taken for granted that the river water quality (Rq) is determined by the population size in the relevant watershed (Pop), the activities of the plant creating electricity from coal (El) and the total amount of the arable cultivation in the zone around the river (Arpsm). The relevant (abstract) function f has the following general form:

$$\mathrm{Rq}_t = f(\mathrm{Pop}_t, \mathrm{El}_t, \mathrm{Arpsm}_{t-1}) \tag{2}$$

We will briefly discuss here the effect of each independent variable on the river water quality. Population influences water quality via the sewage system, which has some given technical characteristics. The activities of the electricity generating plant influence the river mainly via the disposal of ashes; the relevant technical characteristics of the disposal system are considered as given, so that the total activity of the plant is the determinant variable. This activity is measured in tons of coal. Finally, the arable production influences water quality in the next time unit (year), as the pesticides and fertilizers flow into the river during the rain period. Since the density of arable cultivations in the region is homogeneous and standard, total cultivations are important.

The river water quality is measured by an index from zero (worst) to 100 (best). For this interaction of effects we have actually only three reliable real-world statistical observations, given in Table 2. They stem from random past measurements taken place on an irregular basis.

Obviously, these observations do not suffice to estimate the function f in (2). Therefore, the interdisciplinary group had to create a set of artificial observations; a part of which is presented in Table 3 for the sake of illustration.

The problem then is to estimate the function f of (2) by using the set of the newly created observations; note that at this stage we deliberately do not make use of any of the real observations from Table 2 in the process of estimating f, so that they can be used afterwards for testing the model. For the mathematical fitting we have examined sixty-six candidate functional specifications; they are all linear compositions of the logarithmic, linear, exponential, and rational mathematical expressions for three independent variables. All these functional specifications are presented in Annex 1. In strict statistical terms, the set of all these candidate specifications may be seen as superfluous, since a few simple specifications may already lead to a statistically acceptable model. However, the inclusion of more specifications creates an interesting mathematical experiment, especially when physical/technical deterministic phenomena are under investigation.

By using the regression methodology based on the ordinary least squares criterion, we were able to estimate the coefficients A, B, and C for each one of the sixty-six candidate functions. Then the function that gives the most favorable minimum square error is selected as the one which fits better the given data set (the data in Table 1 have been given a suitable scaling before being processed).

Candidate function 14 appears to give the lowest least squares sum, and therefore this function is chosen. The numerical specification of the relevant functional relationship appears to be as follows:

$$Rq = (-1) + (-1.1E1) + (116.2/Pop) - [0.1 * 10^{-10} * \exp(Arpsm)] \qquad (3)$$

The statistical estimations for the function (3) are given in Table 4.

Table 2. Existing Real-World Observations

Rq	Pop	E1 (ton)	Arpsm (kgr)
92	9,000	20,000	1,000,000
85	9,300	22,000	800,000
80	9,500	30,000	1,150,000

Table 3. Part of the Created Observations

Rq	Pop	E1 (ton)	Arpsm (kgr)
45	10,200	60,000	1,150,000
30	10,000	70,000	1,200,000
18	11,000	80,000	1,200,000
48	12,000	50,000	1,500,000
45	11,500	50,000	2,000,000
55	13,000	30,000	1,900,000
57	13,500	30,000	1,300,000
60	14,000	25,000	1,500,000
48	12,000	35,000	2,500,000
56	13,000	25,000	1,500,000
68	13,000	20,000	1,500,000
47	10,000	60,000	1,100,000

Table 4. Statistical Estimation for Function (3)

Variable	Coefficient	Std. Error	*t*-Statistic
C	3.5	1.46	2.41
EL	–0.94	0.11	–8.03
1/POP	65.27	22.31	2.92
EXP (ARPSM)	–1.22E-11	5.61E-12	–2.18

Note: *R*-squared = 0.94; Adjusted *R*-squared = 0.92; *F*-statistic = 43.94

Since it may happen that during the runs of the whole model, under some scenarios, the variable Arpsm may take a relatively high value (probably higher than the existing values in the relevant data set, so that the relevant exponential expression will be extremely high), we have decided that when Arpsm > 20 (scaled value), then the second best candidate will be used. The second best candidate is twelfth (Annex 1); thus, when Arpsm > 20 the relevant numerical specification is the following:

$$\mathrm{Rq} = (-1) + (-1.1\ \mathrm{El}) + (100.8/\mathrm{Pop}) + (16.3/\mathrm{Arpsm}) \tag{4}$$

Once we have obtained the function f, we should test whether it fits suitably the real statistical observations we have obtained for the phenomenon at hand (Table 1) and therefore constitutes a formal representation of the real world relationship at hand. By applying candidate function 14 to the existing three observations, we respectively estimate the following values for Rq:

- for the first observation, function f estimates that Rq = 89, while the real value is 92;
- for the second observation function f estimates that Rq = 84, while the real value is 85; and
- finally, for the third observation f gives Rq = 81, while the real value is 80.

We apply the Chow's forecast and breakpoint test which validates that the function (3) fits statistically sufficient the three real world observations [8, 9]. This permits us to accept function (14) as a reliable approximation of the law underlying the phenomenon in investigation.

Note that if we want to examine the influence of the independent variables under different conditions (for example, when a better ash disposal system is adopted by the electricity plant or when an advanced sewage processing system is introduced by the relevant municipalities), then we should create another set of observations that takes into account the new technical conditions.

6. EPILOGUE

The article gives in detail the theoretical basis of a methodology which leads to modeling an environmental-economic system when there is a considerable lack of statistical data and of scientific insight as well. The methodology is based on the assumed scientific knowledge of scientists/experts. Particularly, this knowledge is used for creating artificial observations which substitute for the lack of actual observations. The proposed methodology may be applied for modeling original physical phenomena or physical interactions involved in social phenomena. In this context, the proposed methodology is not a contrast with standard statistical/econometric ones; rather, it is complementary since the proposed methodology applies, under certain conditions, when the statistical/econometric one cannot be applied because of lack of statistical data. This methodology is illustrated in the present article by a simple example concerning the modeling procedure for an environmental-economic water quality system in Greece where no other coherent method could be used.

It appears that methodology designed in the study may constitute a useful scientific instrument for those cases where neither the scientific knowledge nor the statistical data suffice for establishing a formal environmental-economic model. Therefore, it may be a useful tool for environmental policy designing and monitoring. In this framework, this methodology may also be proven to be useful for environmental impact assessment under similar conditions as those described above.

On the other hand, it is clear that various aspects of this methodology still require further research and elaboration so that some rather restrictive conditions may be removed or at least relaxed. Specifically, these restrictions mainly refer to the creation of artificial data. It seems that the use of a range of values instead of unique values may be proven more helpful. In the same process, the use of "consensus" observations appears to be rather restrictive and therefore a more pluralistic approach based on statistical methods could be useful.

ANNEX 1.
The Candidate Functional Specifications

1 : $y = K + A \exp x_1 + B \exp x_2 + C \exp x_3$
2 : $y = K + A \exp x_1 + B \exp x_2 + C \exp x_3$
3 : $y = K + A \exp x_1 + B x_2 + C\ 1/X_3$
4 : $y = K + A \exp x_1 + B\ 1/X_2 + C\ 1/X_3$
5 : $y = K + A \exp x_1 + B x_2 + C x_3$
6 : $y = K + A\ 1/X_1 + B\ 1/X_2 + C\ 1/X_3$

7 : $y = K + A\ 1/X_1 + B \exp x_2 + C x_3$
8 : $y = K + A\ 1/X_1 + B x_2 + C x_3$
9 : $y = K + A\ 1/X_1 + B x_2 + C \exp x_3$
10: $y = K + A x_1 + B x_2 + C x_3$
11: $y = K + A x_1 + B \exp x_2 + C \exp x_3$
12: $y = K + A x_1 + B\ 1/X_2 + C\ 1/X_3$
13: $y = K + A x_1 + B \exp x_2 + C\ 1/X_3$
14: $y = K + A x_1 + B\ 1/X_2 + C \exp x$
15: $y = K + A\ 1/X_1 + B \exp x + C x_3$
16: $y = K + A\ 1/X_1 + B \exp x_2 + C \exp x_3$
17: $y = K + A x_1 + B x_2 + C \exp x_3$
18: $y = K + A x_1 + B x_2 + C\ 1/X_3$
19: $y = K + A x_1 + B \exp x_2 + C x_3$
20: $y = K + A x_1 + B\ 1/X_2 + C x_3$
21: $y = K + A\ 1/X_1 + B\ 1/X_2 + C \exp x_3$
22: $y = K + A\ 1/X_1 + B \exp x_2 + C\ 1/X_3$
23: $y = K + A\ 1/X_1 + B x_2 + C\ 1/X_3$
24: $y = K + A \exp x_1 + B \exp x_2 + C x_3$
25: $y = K + A \exp x_1 + B x_2 + C \exp x_3$
26: $y = K + A \exp x_1 + B\ 1/X_2 + C \exp x_3$
27: $y = K + A \exp x_1 + B\ e1/X2 + C \log x_3$
28: $y = K + A \exp x_1 + B \log x + C\ 1/X_3$
29: $y = K + A \exp x_1 + B \log x_2 + C \log x_3$
30: $y = K + A\ 1/X_1 + B \exp x_2 + C \log x_3$
31: $y = K + A\ 1/X_1 + B \log x_2 + C \log x_3$
32: $y = K + A\ 1/X_1 + B \log x_2 + C \exp x_3$
33: $y = K + A \log x_1 + B \log x_2 + C \log x_3$
34: $y = K + A \log x_1 + B \exp x_2 + C \exp x_3$
35: $y = K + A \log x_1 + B\ 1/X_2 + C\ 1/X_3$
36: $y = K + A \log x_1 + B \exp x_2 + C\ 1/X_3$
37: $y = K + A \log x_1 + B\ 1/X_2 + C \exp x_3$
38: $y = K + A\ 1/X_1 + B \exp x_2 + C \log x_3$
39: $y = K + A \log x_1 + B \log x_2 + C \exp x_3$
40: $y = K + A \log x_1 + B \log x_2 + C\ 1/X_3$
41: $y = K + A \log x_1 + B \exp x_2 + C \log x_3$
42: $y = K + A \log x_1 + B\ 1/X_2 + C \log x_3$
43: $y = K + A\ 1/X_1 + B\ 1/X_2 + C \log x_3$
44: $y = K + A\ 1/X_1 + B \log x + C\ 1/Xx_3$
45: $y = K + A \exp x_1 + B \exp x_2 + C \log x_3$
46: $y = K + A \exp x_1 + B \log x_2 + C \exp x_3$

47: $y = K + A \exp x_1 + B \log x_2 + C x_3$
48: $y = K + A \exp x_1 + B x_2 + C \log x_3$
49: $y = K + A \log x_1 + B \exp x_2 + C x_3$
50: $y = K + A \log x_1 + B x_2 + C x_3$
51: $y = K + A \log x_1 + B x_2 + C \exp x_3$
52: $y = K + A x_1 + B \log x_2 + C \exp x_3$
53: $y = K + A \log x_1 + B \exp x_2 + C x_3$
54: $y = K + A x_1 + B x_2 + C \log x_3$
55: $y = K + A x_1 + B \log x_2 + C x_3$
56: $y = K + A \log x_1 + B \log x_2 + C x_3$
57: $y = K + A \log x_1 + B x_2 + C \log x_3$
58: $y = K + A \log x_1 + B\ 1/X_2 + C x_3$
59: $y = K + A \log x_1 + B x_2 + C\ 1/X_3$
60: $y = K + A\ 1/X_1 + B \log x_2 + C x_3$
61: $y = K + A\ 1/X_2 + B x_2 + C \log x_3$
62: $y = K + A x_1 + B \log x_2 + C\ 1/X_3$
63: $y = K + A x_1 + B\ 1/X_2 + C \log x_3$
64: $y = K + A\ 1/X_1 + B\ 1/X_2 + C x_3$
65: $y = K + A x_1 + B \log x_2 + C \log x_3$
66: $y = K + A x_1 + B \exp x_2 + C \log x_3$

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