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DECISION-THEORETICAL FOUNDATIONS OF THE VALIDITIES OF TECHNOLOGY FORECASTING METHODS

BY

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Among others the extrapolation method and the Delphi method are the most frequently utilized for the technology forecastings for the reason that these are the simplest. At the same time, precisely for this very reason, they are blamed as having no reasonable foundation of their validities. This paper shows that the reasonable models for the real decision-making behaviour imply (i) the extrapolation method reflects the decision environment which works as the pressure to the decision maker in the competitive situation, (ii) the Delphi method, if properly designed, reflects the organizational decision process and works as the "pre-simulation" of the real decision making and hence provides a new pressure to the decision maker. This paper also shows that these models imply the science/technology outputs and performances are distributed among countries and institutes in peculiar ways, leading to the peculiar distributions which are quite different from the well-known and frequently applied statistical distributions on some practically critical aspects.

The scope and the limit of the rationatities of these models are also examined.

1. Problem, Scope and Method

Various methods are now available for technology forecastings. Among these methods the extrapolation method and the Delphi method are applied most frequently. Its reason is mainly due to the fact that they are the simplest in their structure and procedure. Precisely for this very reason they are often blamed as being too simple to have reasonable foundation fro their validities. The purpose of this paper is to provide their theoretical foundation from the view point of decision analysis.

The decision in technology development may be expected to be lawful. The analysis of this lawfulness is expected to lead to the examination of the validities of the forecasting methods in question.

2. Extrapolation and Delphi Methods

The procedure of the extrapolation consists basically in projecting the past trend to the future. To be practicable, its procedure is more sophisticated in that the trend of the fundamental factors is taken instead of that of the output factors for the purpose of basing the forecasting upon the causality, or in that the envelope curve of each of the trends is taken to enscope the long range. The sophistication of the first type is seen in forecasting the future transportation demand by extrapolating GDP first and then calculating the future demand thereupon instead of extrapolating the transportation demand itself. The underlying idea of this is that the economic activity level represented in terms of GDP determines the transportation demand.

The sophistication of the second type is seen in forecasting the speed of the aircrafts in several decades [1]. The underlying idea of this is that the fequent switch between the rapid and the slow growth in speed is merely local in the long range context and can be considered to lie on a single curve from a macroscopic point of view. The forecasting operation may be expressed as follows.

$$O_1 : P \rightarrow F \qquad (2.1)$$

where P and F denote the spaces of the past trend and of the future forecastings respectively.

The procedure of the Delphi method is to collect the vague or fuzzy forecastings of the experts and to make them converge to a kind of consensus by repeating the process in a proper way. Here the experts are mostly the leading scientists, the experienced analysts in forecastings, and the technology managers. As they are, in their careers, well-trained to conform their ideas or opinions to other people, the converge is very often attained in the past Delphi surveys. Once the consensus is attained, it is often easily accepted as a kind of the "authorized" forecasting [3]. Now the Delphi forecasting operation may be expressed as follows.

$$O_2 : F \rightarrow F \qquad (2.2)$$

where the first occurence of F denotes the space of the vague forecastings of the individual experts and the second one denotes the space of the "authorized" or "confirmed" forecastings respectively. When the first and the second occurence of F are denoted by F_1 and F_2 respectively, the realtion (2.2) is rewritten as follows.

$$O_2' : F_1 \rightarrow F_2 \qquad (2.2')$$

3. General Characters of Decisions in Science and Technology

The decision in technology development is classified into the individual and the institutional decisions. Here the individual decision denotes the decision made by each scientist or engineer as to his own scientific activity, and the institutional decision denotes the decision made by managers or leaders as to the scientific activity of the institutions they manage or lead.

The individual decision is governed by the science information distribution market and the scientists labour market. Each scientist chooses his research topic in reviewing the science information which is distributed him by the science information market. This market which invisibly exists among scientists is controlled by the institution because they monopolize the science information, and each scientist merely chooses information among the circulated ones. His freedom of this choice is quite restricted because he must accord himself to the scientists labour market. This market is again controlled by the institutions because only the institutions provide them the job opportunities. Hence the individual decision is governed by the institutional decision and may be expressed by the following relation.

$$D_1 : I \times J \to S \qquad (3.1)$$

where I, J and S denote the spaces of the science information, of the job opportunities and of the individual decisions respectively.

The institutional decision makers are the managers in research institutes, professors in universities, the leaders in research projects and the government officials in national planning. In reality their decisions are very often dependent on the advices of their staffs.

However, as the staffs can be considered unseparable from the decision makers, they can be ignored or included in the decision makers. Hence, for the purpose of simplicity, they will altogether be called the decision makers hereafter. Now it deserves recalling that the experts who are qualified for the Delphi survey belong to the class of the decision makers defined just above.

The institutional decision is made in the midst of the pressure from the managerial environment E which constraints the decision making. E consists of the scientists labour market, the science information market and so on. The scientists labour market constrains the targets of scientific productivity, the science information market constraints the target of scientific activity fields and the target date of the accomplishment and so on. In this way E constraints the managerial targets.

The managerial tasks to achieve the targets are also constrained by the resources. Now the institutional decision may be expressed as the target achieving behaviour to follow.

$$D_2 : R \times T \to M \tag{3.2}$$

where R, T and M denote the spaces of the resources, of the targets and of the institutional decisions respectively. To have a precise idea of the relation (3.2), it suffices to consider the goal programming formulation for the decision D_2 wherein the goals or targets T appear as the essential terms for the resource allocation problem (for the general description of the goal programming, see, for example, [2]).

The institutional decisions enscope I and J in (3.1) as was stated earlier, and R is constrained by S because the individual decisions determine the supply of the scientific manpower which is the most important resource. These causalities or feedback may be expressed as follows.

$$C_1 : M \to I \times J \tag{3.3}$$

$$C_2 : S \to R \tag{3.4}$$

In the market-based technology system as well as the planned technology system, the causality (3.3) tends to dominate the causality (3.4). In fact the successive applications of the relations (3.3) and (3.1) yields the following important causality.

$$C_3 : M \to S \tag{3.5}$$

The causality (3.5) leads to the following proposition.

Proposition 3.1 For the purpose of technology forecasting, it is the decisive factor to forecast the institutional decision.

The relations (3.4) and (3.5) together imply the following causality:

$$C_4 : M \to R \tag{3.6}$$

4. Decision Behaviour in Rapid Innovation Age

When technology is growing, the managerial environment or the market expects that it continues to grow. This expectation forces the decision maker to keep it growing. If he fails in it, He will lose his customers who expect it growing and he will lose the support of the capital market which expects it growing. In such a situation he will lose his position in the competition on the decision makers labour market. Hence he is forced to keep it growing by any means.

Suppose the operation speed of the computer has been improving for many years. In such a situation the new manager of computer development who took office from his predecessor is forced to keep it improving by any means. Suppose the speed-up was made by the improvement in electronics component in the days of his successor and the improvement in this field is already saturated. Then he is forced to find another means which contributes to the speed-up. This attempt may lead to the development, say, in design technology or software technology. Finally he may succeed in continuing the speed-up. This story explains that the past trend provides the pressure for the manager to extend this trend to the future, leading to the targets setting. This relation may be expressed as follows.

$$D_3 : R \times P \rightarrow T \qquad (4.1)$$

The relation (4.1) implies that the past trend contributes to the target setting. The relations (3.2) and (4.1) together yield the following relation.

$$D_4 : R \times P \rightarrow M \qquad (4.2)$$

Recalling the dependence of R on M by the relation (3.6), the relation (4.2) yields the fundamental causality:

$$C_5 : P \rightarrow M \qquad (4.3)$$

The relations (2.1) and (4.3) together with Proposition 3.1 yield the validity of the extrapolation method.

Proposition 4.1 The extrapolation of the past trend is the decisive factor of the technology development.

5. Decision Behaviour in Organized Technology Age

When large scale technology is dominant, the whole technology system is governed by the large scale institutes which are controlled by the decision makers. In short the whole technology system is dependent largely on their decisions. At first each decision maker has some vague or fuzzy forecastings about his targets though he is too inconfident of them to express them as his targets in a definite way. He may not consciously base his plan upon these forecastings but may tend to do so. Hence, instead of the relation (4.2), the following relation is obtained.

$$D_5 : R \times F \to T \tag{5.1}$$

The relations (3.2) and (5.1) together yield the following relation.

$$D_6 : R \times F \to M \tag{5.2}$$

The relation (5.1) and hence the relation (5.2) represents some aspect of the relation (2.2). It deserves recalling here that the experts participating in the Delphi survey belongs to the class of the decision makers. In other words,

$$H(O_2) \subset H(D_6) \tag{5.3}$$

where $H(X)$ denotes the class of the subjects who execute the operation or decision X.

In an analogous way to the relation (4.3), the relation (5.2) yields another fundamental causality:

$$C_6 : F \to M \tag{5.4}$$

The relations (2.2), (5.3) and (5.4) together with Proposition 3.1 yield the validity of the Delphi method.

Proposition 5.1 The consensus in the Delphi is the decisive factor of the technology development.

6. Decision Behaviour in Competition Age

In industrial and military technology competitions a certain level of technology is required as a threshold. If this level is not attained and the technology level remains much behind the competitors level, the whole effort made so far ends in waste. Therefore the optimal decision is of the yes-no type to achieve the threshold or to do nothing from the beginning for avoiding the waste. This decision is expected to cause the extremization on one hand and the clusterization on the other hand. Here the extremization denotes the bi-modal distribution separated on either side of the threshold and the clusterization denotes the concentrated distribution around the mode on each side. In fact the sharp bi-modal or milti-modal distribution is seen in the international or intercorporate distribution of technology. This signifies the international or intercorporate gap in technology which is deeper than the gap in economic wealth. Its mathematical expression whose dynamics explains an aspect of the causality of such a deep gap will be presented elsewhere [3].

7. Conclusion

The extrapolation and the Delphi methods which are the most prevalent in technology forecastings and which have not been theoretically justified are given the theoretical validities herein from the view point of the decision analysis. This analysis is rational in the ages of exploding and organized technology but may fail to be valid in another situation. Each situation may demand its proper methods. In our age, however, these two methods are shown highly valid. Another effect of decisions on the unequitable technology development is discussed in terms of its dynamics and statistical distributions.

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