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A Generalized Model of Science Development at Normal and Crisis Status of the Country

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Science can be regarded most generally as a specific sphere of human behaviour, directed towards obtaining new knowledge about nature, society and intellectual activity. The development of science as a priority social institution for each civilized country attracts the attention of many leaders and researchers.

The laws of science functioning and development have been studied and the interaction of science with other institutions and society spheres as well. An important place in this activity is occupied by the analytical approach, within the frames of which different mathematical models of science development are designed.

A model for science rapid development has become popular in the last time according to which science grows as rapidly as the population, and it develops proportionally to the amount of the last generation. Science advances proportionally to the mass of knowledge, inherited by the preceding generation.

From the upper confirmation the following simple differential equation follows [1, 2]:

(1) $$dI/dt = kI,\ I(t_0)= I_0,\ t > t_0=0,$$

with a solution

(2) $$I(t)= I_0\, e^{kt};$$

where I is the informative parameter, characterizing science, k is a constant.

Usually the number of discoveries, patents, printed materials, staff employed in science, the volume of investments in science, the economic efficiency of the research work, citations in significant editions and specialized electronic data bases, etc., are used as informative parameters. Very often some indirect indicators for science development such as number of publications and citations (science-metric approach) are applied.

The exponential character of alterations of a number of informative parameters in science is established by statistical analysis. D. Price mentions that "if a more or less satisfactory way is found to measure a sufficiently big segment in science, then this segment grows exponentially under normal conditions. The law for exponential growth can be considered as a basic law for each analysis of science" [1, 2]. A satisfactory statement and investigation of models (1) and (2) is given in [2, 6].

It should be noted that even under the most favorable conditions for science development the exponential relation cannot be reserved too long. Some constraints appear in the material and personnel resources, or such of ecologic, ethic or other character. Besides this the coefficient k is too critical in model (1) and (2). Many authors do not express the structure of this coefficient or give it ambiguous interpretations such as: averaged constant, characterizing the reflection of a publication in one or another area of knowledge, proportionality coefficient, typical for given science and for the concrete conditions of development, etc.

Many of the authors assume that the coefficient k is constant and non-negative and note that it has no universal value and is different for the different countries and historical periods, depending directly on the economic level.

Some examples are known in history, when the growth rates of science and some of its directions decrease rapidly. This happens frequently during war periods and after them, in a social and economic crisis. No mechanism accounting these essential changes is included in model (1) and (2).

This problem is actual now for almost all the East-european countries, in which a large social-political and economic transition is realized with alteration of the property system and way of economy control – from a centralized towards a market one. This is accompanied by considerable suppress of the economic development, decrease of the finances for fundamental and applied science and education, large decrease in the number of the working in science young and qualified specialists, due to emigration abroad or passing to some commercial structures in their own country.

The present paper offers a method which can account the changes already mentioned in models for science development in East European countries, usually called countries in transition.

Some statistic data for the science in the Russian Federation (RF) will be used. It should be noted that the situation in the other East European countries is not very different in many aspects.

It is known that a sector for production of information resources – an information sector of economy, is created within the frames of the sector for goods and services. The functioning of the first sector is described by the famous model of expanded reproduction [3, 4, 5], consisting of three relations: balance equation, equation for dynamics of the main funds and production function. For the information sector the notion basic funds F is also introduced, which is directly connected with the investments in it. The relation of the speed for production of the information resources with the basic funds and the human potential in the information sector is given by a specific production function.

In the so called two-sector model the part of the final product, produced in the first sector, is used for expansion of the basic funds in the second sector. On its hand the information resources are used to increase the productivity of the first sector. Unlike the material product and energy, the information resources are not exhausted during consumption. Simultaneously with this, it is assumed that they possess the property of quick moral and material ageing.

On the basis of the two-sector model described, a model for science development can be defined in which:

– the information resources are adequate to the information parameter I;

– the basic funds of the information sector, characterizing the volume of investments in it, should be considered as an independent control parameter.

Then the model for science development in transition countries can be represented by the following differential equation:

(3) $$dI/dt = kI + C,\ I(t_0) = I_0,$$

with a solution

(4) $$I(t) = I_0\, e^{kt} - (C/k)(1 - e^{kt}),$$

where $k = k_1 F^{\alpha} L^{\beta} - \lambda$, L is the number of people occupied in science; λ – parameter, characterizing knowledge ageing; C – external system parameter, accounting the intensity of the information exchanged with the external environment; k_1 , α, β – model parameters.

In case $C>0$, knowledge inflow is realized, i.e., information resources from outside are applied. If $C<0$, the inverse process of information resources outflow is implemented – "brain outflow", know-how, decrease in scientists number.

Table 1 gives the number of emigrants from RF, working in "science and scientific services" branch.

Table 1

Year	1980	1990	1991	1992	1993	1994	1995	1996	1997
Emmigration (thous. people)	0.1	2.1	1.8	2.1	2.3	2.1	2.2	1.9	1.2

The analysis of these data leads to the inference that the external "brain outflow" in the last years is about 2000 persons per year. The main decrease of scientists and researchers is connected with internal migration to other, mainly commercial structures. It is almost two orders greater than the external emigration.

The model suggested (3) can be regarded as a generalization of the model for exponential development of science (1). The last one is a partial case of (3) for $C=0$ and $\lambda=0$

(5) $$dI/dt = kI,\ k = k_1 F^{\alpha} L^{\beta}$$

at which the parameter k is structured.

Model (3) provides the possibility to obtain more trajectories of science development depending on the parameters F, L, λ, C.

Linear rise of the information parameter I is possible through inflow of new resources ($k=0$; $C>0$). At $k=0$ and $C=0$ there appears a stationary mode, when knowledge reproduction is compensated by its ageing and lack of information exchange with the outer world. A third case is also possible for knowledge decrease with the help of the relations: linear ($k=0$; $C<0$) and exponential ($k<0$; $C>0$).

The above inferences are made under the assumption that L and F are constant. In reality for a longer period of time the number of scientists in the world and the common expenses for science increase exponentially, i.e.

$$L(t) = L_0\, e^{ft} \text{ and } F(t) = F_0\, e^{rt}.$$

Then (3) obtains the following form:

$$dI/dt = k(t)\, I + C,$$

where

(6) $$k\ (t) = k_1 F_0 L_0^{(\alpha f - \beta r)\ t} - \lambda.$$

In the last decade there is an inverse tendency in RF for rapid decrease of the people employed in the scientific sphere, as well as of state support for science.

Table 2 gives data for alteration in the staff number, occupied in the research sector of RF.

Table 2

Staff		1989	1990	1991	1992	1993	1994	1995	1996	1997
General	Real	2215.8	1943.4	1677.8	1532.6	1315.0	1106.3	1061.0	990.7	934.6
	Decrease		272.4	265.6	145.2	217.6	208.7	45.3	70.3	56.1
Investigators	Real	1118.8	992.6	878.5	804.0	644.9	525.3	518.7	484.8	455.1
	Decrease		126.2	114.1	74.5	159.1	119.6	6.6	33.9	29.7

The data from the table show that from 1989 until 1996 the number of the people employed in science area has decreased more than in half. These data can be represented by diminishing exponents in first approximation

(7) $$L(t)=L_0 e^{-ft}, \quad F(t)=F_0 e^{-rt}$$

at that (6) is written by

(8) $$k\,(t)=k_1 F_0 L_0^{-(\alpha f+\beta r)\,t}-\lambda.$$

The presence of the exponential part in the above relation speeds the decrease of $K(t)$ and influences negatively the character of behaviour of $I(t)$. This may be demonstrated on a partial case of model (3). Let $\lambda=0$, $C=0$, i.e., there is no knowledge ageing and the external connections of the system are blocked. Then

(9) $$I(t)=I'_0\, e^{(-a/z)\,e^{-zt}},$$

where

(10) $$I'_0=I'_0\, e^{a/z}\,;\ a=k_1F_0L_0;z=\alpha f+\beta r.$$

The knowledge volume in this system is restricted and it tends towards

(11) $$\lim_{t\to\infty} I(t)=I_0\ e^{a/z}.$$

For comparison, when the values L and F are constant, the knowledge volume increases unlimitedly.

The crisis status, in which the sectors economy and scientific service of more of the countries in transition are found, influences actively the research results. Unfortunately, there are not available any detail and exact statistic data of these processes. But even the available ones are enough to illustrate the powerful tendency for science restriction as a whole and especially its applied part.

The models from (3) upto (11) suggested in the present paper for the transition countries do not contest in any way the classic model for rapid development of science (1) and (2). This exponential growth of science is valid for normal conditions in society. As a rule the periods of crisis, connected with social-economic cataclysms lead to a breaking in the exponential growth of science. For many countries the period during and immediately after the Second world war is such, such is the last decade for many of the transition countries. Usually when the reason for the crisis is removed, the situation is normalized and the exponential growth of science could be reestablished. But this requires certain material resources and human potential. The providing of these resources is not possible for the state and it depends directly on its policy in the area of science, on its strategic purposes and tasks, set for the integral development of the country.

If during or after the crisis the state wishes to return or at least to approach the level of great science, this will require considerable attempts and expenses. Otherwise the country will accept "science, which does not fit its possibilities" and then more modest means will be necessary than in the first case.

Models (3)–(11) suggested in the present paper for science development allow the estimation and prognosis of this development in normal and extremal state of society – wars, social-economic cataclysms, etc.

Conclusion

The results obtained in the present paper could be reduced to the following:

1. A number of characteristics of the countries performing transition from centralized towards market economy are described, the crisis making impossible the exponential growth of science.

2. On the basis of economic and informative indicators a generalized model for science development is suggested which can be used in normal development of the country – with exponential growth of science, as well as when it is in a crisis and passing to market economy.

3. It is shown that this model can be used to prognose science development depending on the strategy for economy development used by the state and its scientific insurance.

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Обобщенная модель развития науки при нормальном и кризисном состоянии страны

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(Р е з ю м е)

В работе выявлено ряд особеностей стран в переходе от централизованной к рыночной экономике, кризисное состояние которых делает невозможным осуществления экспоненциального роста науки.

На основе экономических и информационных показателей предложена обобщенная модель развития науки, которая может применяться как для нормального развития страны – с экспоненциальным ростом науки, так и для такого ее состояния, когда она находится в кризисе и осуществляет трудный переход к рыночном экономике.

Показано что эта модель может быть использованной для прогнозирования развития науки в зависимости от применяемой государством стратегии развития экономики и ее научного обеспечения.