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ИЗВЕСТИЯ АКАДЕМИИ НАУК ЭСТОНСКОЙ ССР. ОБЩЕСТВЕННЫЕ НАУКИ
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ECONOMIC ESTIMATION OF DISTANT CONSEQUENCES OF NATURE MANAGEMENT

An adequate economic estimation of research and development programs and large-scale projects requires to forecast and consider consequences of their realization, and particularly the ecological ones. Associated problems of time-discounting under long-term economic-ecological calculations are analyzed in the present paper. With the help of computer simulations with a model of intertemporal-intersectoral relations we justify and interpret the fact that the economic influence of the time factor is complex, i. e. may have different forms. A modification of the method of discounting appropriate to nature-saving economy is developed.

1. Statement of the problem

The foundation of a large industrial complex or water-development works intensively affecting related sectors and environment may cause negative consequences in the distant future, which sometimes may be more substantial than the direct effects. Meanwhile the existing economic conditions of nature management generate an indifference towards their losses and ecological disturbances, since a negative impact of the latter on the level of production and quality of life is not revealed at once but with a shorter or longer time lag. Accordingly, the current economic valuations of costs and inputs depend on past and present activities, but not on their consequences. Increase of costs in a distant future does not provide backward influence on the producer who is responsible for those consequences and therefore they are not taken into account in making engineering decisions. In particular, pollution of environment may damage and thus reduce the stock of resources necessary for future production but it has only a slight influence on the costs in the place of the pollution and at the moment of it.

Economic indifference to distant consequences of present actions accounts in a great part for the character of preference of goods over time: their relative utility diminishes over time at a discount rate. Here, a discount rate is meant to be an index of utility of the fund of time as a sort of a limited resource (the structure, organization and technical level of the system being given). The lost time is balanced by additional production costs. In order to put the compared alternative decisions concerning different moments of time into equal conditions, one should take into account the possibilities of development of the system between these moments. The discount rate serves exactly as the measure of equivalence of an earlier or later supply of exogenous resources or of getting the useful effect (output, profit). Namely, the discount rate is equal to the maximal rate of increase of the volume of profit (in fixed prices) if it is obtained in the year $t+1$ instead of t, i. e. a year later, the amount of resource investment in the initial year t_0 remaining constant (with arbitrary $t=t_0+1$, t_0+2, ...). If the given amount of the resource is supplied *ceteris paribus* a year earlier (in the year

t_0-1), then the rate of the corresponding increase of a shadow price of the resource is also characterized by a discount rate. Both definitions of the discount rate are identical, and as a matter of fact they express the productivity property of a system (every year the output of any good exceeds its input).

The factor $\lambda_{t_0+k}=(1+\delta)^{-k}$ of discounting economic values of the year t_0+k to the year t_0 has a corresponding meaning. Here δ is the discount rate. The discount factor shows (i) the value of a good in the year t_0+k if its value in the year t_0 was \$1, (ii) the costs in the year t_0, which are necessary for obtaining a \$1 output in the year t_0+k.

The conventional discounting methods are oriented on renewable resources under usual terms of turnover of fixed capital (not exceeding 10—15 years), but in practice these methods are mechanically extended to nonrenewable goods and much longer periods of time. This leads to a considerable depreciation of the part of mineral, soil, timber and other natural resources which are planned for exploitation in 25—30 years and later. A transfer of the horizon of socio-economic interests to a more distant future is natural in the modern age. The processes of construction and functioning of territorial-industrial complexes and large water-development works last for decades and cause a profound transformation of nature. Deposits of minerals are developed during a long time.

Lengthening of forecast and planning intervals, scarcity of natural resources, demographic problems, crisis phenomena in ecosystems lead the economy to a revaluation of the time factor role and to qualitative changes in the structure of costs and outputs.

2. Temporal macrostructure of outputs and costs

Intertemporal relations in the economy principally consist in connections between inputs and outputs which are mostly separated in time. Thus, returns to present investments will be obtained from the future output. Such intertemporal flows are reflected in the fundamental proportions of the dynamic balance: one part of output is consumed currently, while another one is accumulated, i. e. used for future production. Respectively, the unit costs of production consist of current and capital costs, the latter being provided by funds which were created and accumulated earlier. This structure of production and costs corresponds to feedforward intertemporal relations in the economy (the past→the present→the future), which were formed in the pre-ecological period of industrial development and are taken as a natural expression of the irreversibility of time.

In order to turn the economy to a nature-saving regime, the chain of intertemporal relations should be closed by a feedback (Fig. 1). The first step in this line is the monetary evaluation of losses and ecological expenses caused by preceding activity [1]. To our mind the next step could be the settlement of the compensation fund of these losses.

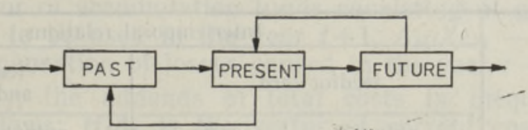

Fig. 1. Scheme of intertemporal relations in nature-saving economy.

Losses of mineral resources in the past as well as the erosion of soil and the reduction of the productivity of agrarian, timber and water resources cause a decrease in the present output. Negative social consequences of ecological disturbances are also equivalent to a certain loss of some goods, including products and services. The remaining losses and damages suffered by a system in the year *t* require an additional output in the same year for their compensation. That part of the production forms a compensation fund. Its volume depends on the intensity of the production in the year $t-k$, which was the cause of the year's *t* losses.

Thus, the remaining losses and damages and a fund of their compensation are generated with a time lag directed opposite to the one which is appropriate to the utilization of the accumulation fund. Indeed, the latter, being produced in the year *t*, is expended on an output of the years $t+1$, $t+2$, etc., i. e. with a forward lag. By the same logic, a compensation of the remaining losses and damages which had caused the need for an additional output may be considered an expense of the production of the year *t* with a backward lag, i. e. on the output of the years $t-1$, $t-2$, etc. Consequently, in case of the remaining losses, not only the goods produced in the past are spent, but also those to be produced in the future: as if the goods were consumed before they are produced. Thus, in nature-saving economy there arises a specific form of intertemporal flows: the profits obtained in the present year from the exploitation of resources are spent on additional future costs which are induced by it. A flow of compensational costs is directed from the future to the present and the past, i. e. opposite to the flow of investments.

Ecological expenses, such as payments for the remaining losses and damages, are accordingly reflected in the structure of costs of the year's *t* production. Subject to payable exploitation of nature, those expenses should be included in production costs of the output which is responsible for the long-term ecological disturbance. If the damage is inflicted in the year *t* but its consequences will affect the economy during the years $t+1$, $t+2$, etc., it becomes a source of future (ecological) costs of the output of the present year *t*. In the same way one could interpret the additional costs in the form of a rise in the price of prospecting, extraction and processing of mineral resource because of a premature transition to worse deposits under the condition that these costs be paid by the producer in the year when he inflicted the losses of a resource. Under the same conditions the costs of environmental recovery activities — purification of the environment, recultivation of soil, reestablishing the variety of flora and fauna, etc. — may be considered as future costs of the present output.

Allocation of output of present period and temporal structure of its costs

Time period	Intertemporal relations			
	feedforward		feedforward and feedback	
	output	costs	output	costs
Past		capital	compensation	capital
Present	consumption	current	consumption	current
Future	accumulation		accumulation	ecological *

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* Payment for the remaining damage.

In an aggregate form the structure of output and costs with respect to their location in time is given in the Table. One can see that in a nature-saving system the output of the present year should cover the current, past and future costs generated by its production. Since intertemporal feedbacks make economic actions dependent on their consequences, the formation of those relations may play an important role in the creation of a new economic mechanism of nature management which would ensure efficient use of resources, preservation and improvement of the environment.

3. The modelling of intertemporal relations

In the previous discussion it was pointed out that a nature-saving economy is essentially characterized by intertemporal feedbacks ensuring a compensation of future costs generated by present economic actions.

For the analysis of intertemporal relations a dynamic model will be used, in which the moments of production and consumption are connected in a way analogous to that of the sectors in the Leontief input-output model. Our model presents a structure of production and costs over time (see the Table). The model is technologically closed: final consumption and exploitation of natural resource are included in the list of the sectors. Both positive and negative consequences of production activities are taken into account. The former consists in the output of goods for final and intermediate consumption, while the latter — in its losses caused by activity in the past. In the model, the losses are represented by additional input required for their compensation. Thus, the damage inflicted to nature is regarded here in terms of corresponding losses in the production system.

Balance relationships for the gross output of the year t (denoted by the column-vector X_t) and its shadow prices (a row-vector H_t) have the following form:

$$X_t \geqslant A_{\mathrm{I}} X_t + A_{\mathrm{II}} X_{t+1} + A_{\mathrm{III}} X_{t-1}, \qquad (1)$$

$$H_t \leqslant H_t A_{\mathrm{I}} + H_{t-1} A_{\mathrm{II}} + H_{t+1} A_{\mathrm{III}}, \qquad (2)$$

where A_{I} is the matrix of direct input-output coefficients, A_{II} — the matrix of investment of durable goods produced in the current year per unit of output of the next year $t+1$, A_{III} — the matrix of inputs for compensation of losses in the current output per unit of the previous $(t-1)$ year's output which is responsible for the losses (for the sake of simplicity we assume that the lag of the impact is equal to one year).

Inequality (1) means that the output in the year t in any sector should not be smaller than the total consumption for different purposes. The addend $A_{\mathrm{I}} X_t$ represents a vector of production used for current inputs, $A_{\mathrm{II}} X_{t+1}$ is the vector of accumulation funds consisting of goods produced during the year t to be used in the year $t+1$, $A_{\mathrm{III}} X_{t-1}$ — the vector of funds for the compensation of losses caused in the year $t-1$.

Correspondingly, the addends of total costs in inequality (2) are interpreted as follows: $H_t A_{\mathrm{I}}$ is the vector of current costs, $H_{t-1} A_{\mathrm{II}}$ — the vector of past costs (i. e. capital costs), $H_{t+1} A_{\mathrm{III}}$ — the vector of future costs (ecological costs), all of them calculated per unit of the output of the year t. According to (2), the shadow price for any good in the year t should not exceed the total costs of its production.

One can see that in the relationships (1) and (2) account is taken of both the flow of production spent with a forward lag and the one spent with a backward lag, as well as of both past and future costs.

4. Positive and negative discount rates

Proceeding from the relationships (1) and (2), we state an optimization model of planning for the interval $[t_0+1, \dots, t_0+n]$. Since the basic problem of dynamic decision-making in the economic-ecological system consists in the alternative between the consumption and saving of natural resources, it is necessary to introduce corresponding exogenous parameters (final demands and inputs of resources) in the relationships (1), (2). For the goals of the present study the following simplest consideration will be sufficient. Fix a year t_0+k within the planning interval and assume that only for that year the vector of final demand for goods Z_{t_0+k} is nonzero. For initial and terminal years of the planning period let there be given nonzero vectors of exogenous costs (i. e. inputs of a resource) per unit — P_{t_0+1}, and P_{t_0+n}, respectively. Then the (primal) problem of the minimization of exogenous costs will be:

$$P_{t_0+1}X_{t_0+1}+P_{t_0+n}X_{t_0+n}\to \min$$

subject to

$$(E-A_{\mathrm{I}})X_{t_0+1}-A_{\mathrm{II}}X_{t_0+2}\geqslant 0,$$

$$(E-A_{\mathrm{I}})X_t-A_{\mathrm{II}}X_{t+1}-A_{\mathrm{III}}X_{t-1}\geqslant \begin{cases} 0 & \text{if} \quad t\neq t_0+k,\\ Z_{t_0+k} & \text{if} \quad t=t_0+k \end{cases} \qquad (3)$$

for $t=t_0+2, \dots, t_0+n-1$,

$$(E-A_{\mathrm{I}})X_{t_0+n}-A_{\mathrm{III}}X_{t_0+n-1}\geqslant 0,$$

$$X_t\geqslant 0.$$

The dual problem of the maximization of final output has the following form:

$$H_{t_0+k}Z_{t_0+k}\to \max$$

subject to

$$H_{t_0+1}(E-A_{\mathrm{I}})-H_{t_0+2}A_{\mathrm{III}}\leqslant P_{t_0+1},$$

$$H_t(E-A_{\mathrm{I}})-H_{t-1}A_{\mathrm{II}}-H_{t+1}A_{\mathrm{III}}\leqslant 0, \qquad (4)$$

for $t=t_0+2, \dots, t_0+n-1$,

$$H_{t_0+n}(E-A_{\mathrm{I}})-H_{t_0+n-1}A_{\mathrm{II}}\leqslant P_{t_0+n},$$

$$H_t\geqslant 0.$$

The principal distinction between the models (3), (4) and the conventional ones is that the matrix of corresponding optimization problems has not a block-triangle structure, but there are nonzero blocks on both sides of the diagonal (Fig. 2).[1] Owing to this fact it is possible to get various types of dynamics of variables in solutions corresponding to different objective functions and, respectively, to describe a variety of preferences of goods over time. For comparison, notice that in conventional models only one of the two types of dynamics (growth or extinction) is possible, being determined by a technological matrix. But in the present model with intertemporal feedback a combination of both tendencies may be present, since the process of the depletion of resources is taken into account along with the process of capital accumulation.

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[1] A dynamic Leontief model is presented in [2, p. 59], where along with forward-directed intertemporal relations also the backward ones are present: the expectation of the future output is based on the past actual changes in the output. This model differs essentially by its sense and properties from the one considered in [3] and in the present paper.

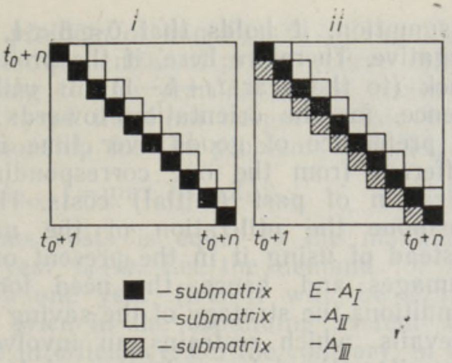

Fig. 2. Structure of the matrix of intertemporal relations: i — with feedforwards only, ii — with both feedforwards and feedbacks.

A corresponding growth rate of the model is related to each of the above-mentioned processes. The rate related to accumulation is greater than unity, while the other one is smaller than unity. In order to determine these rates, let us study the dynamics of variables of the model with different objective functions.

First of all, let us examine the special case of the problems (3), (4) where the future costs are not taken into account, i. e. $P_{t_0+n}=0$, so that the initial exogenous costs (requirements of the resource) $P_{t_0+1}X_{t_0+1}$ are to be minimized. It may be called a model of accumulation. That statement of the model can be regarded as a usual lagged dynamic problem (in the interval $[t_0+1, \dots, t_0+k]$) of achievement of the required terminal output with a minimal initial input. It has a balanced solution, growing at the maximal rate $\bar{\alpha}$ (see, e. g., [4]). The corresponding dual variables (shadow prices) are diminishing at the same rate. If the system is productive, then $\bar{\alpha}>1$. The value $\bar{\alpha}-1$ is interpreted as a discount rate. Being a sort of a measure of the utility of the time resource, in this case it shows how much the required initial exogenous input (i. e., the minimized objective function) would decrease relatively if, *ceteris paribus*, it were put into action a year earlier, i. e. in the year t_0 instead of t_0+1. From the dual point of view the discount rate expresses the increase rate of the utility of the final output (i. e. the maximized objective function of the dual problem) if it were obtained in the year t_0+k-1 instead of t_0+k.

Thus, in the case when only the initial exogenous costs are minimized while the future ones are not taken into account, we get a situation typical of the conventional approach: the discount rate is positive and hence the goods are more preferable in the year t than in the year $t+1$. A measure of preference is given by the diminishing sequence of vectors of shadow prices which discount respective goods produced at different moments of time. The diminishing of prices reflects a stimulation of the earliest possible utilization of resources since in a productive system to delay it would mean to lose the corresponding annual returns.

Now, consider the contrary special case: the problem of minimizing terminal exogenous costs $P_{t_0+n}X_{t_0+n}$, assuming that $P_{t_0+1}=0$. In this case, (3) is a model of depletion with outputs diminishing and shadow prices growing over time. The corresponding optimal balanced solution is the one with the minimal rate of growth β.[2] Under the productivity

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[2] It is noteworthy that the notion of minimal balanced growth arises due to the introduction of intertemporal feedback into the model. Indeed, in a conventional one, i. e. with $A_{III}=0$, minimal solution is zero.

assumption, it holds that $0<\beta<1$, so that the discount rate $\beta-1$ is negative. Therefore here, if the production of the final output is shifted back (to the year t_0+k-1), its utility will decrease at the rate $\beta-1$. Hence, for the orientation towards minimizing future costs, the type of preference of goods over time is appropriate, which is principally different from the one corresponding to the conditions of the minimization of past (initial) costs. Here, it proves to be preferable to postpone the utilization of the natural resource to the next year instead of using it in the present one, because it delays corresponding damages and, hence, the need for their compensation. Under these conditions the strategy of the saving and efficient utilization of resources prevails, which restrains an involvement in the processing of new deposits, stimulates reduction of losses and development of a technology adapted to natural circulations of energy and substance.

Thus, contrary to the positive discount rate which characterizes the limited nature of the time-resource proceeding from the goal of expansion of the techno-economic system, the negative discount rate corresponds to the purpose of slowing down the depletion of the resource-ecological system. Notice that the depletion may be well compatible with the productivity of the system — to this end the output should exceed the input, including the compensation of losses caused by preceding activities.

5. Dynamics of shadow prices in the case of the joint minimization of initial and terminal costs

It was pointed out that in the nature-saving economy different items of production costs are discounted in time with the help of two different rates — positive and negative ones. The first one is applied to current and capital (i. e. past) costs, while the second one — to compensational (future) costs.

The dynamics of the discount factor of the total sum of all the three items of costs in the year t to the initial year t_0 *ceteris paribus*, depends on the ratios of positive and negative discount rates (by modulus) and on initial levels of accumulation and compensation funds. All possible trajectories of the aggregate discount factor can be obtained by varying the exogenous data in the problem (3) of minimizing the sum of initial (past) and terminal (future) exogenous costs.

In optimal plans two shadow prices are related to every product in the year t (Fig. 3). One of them is declining over time (curve *1*), which corresponds to the problem of min $P_{t_0+1}X_{t_0+1}$, while the other one, corresponding to the problem of min $P_{t_0+n}X_{t_0+n}$ is growing (curve *2*).

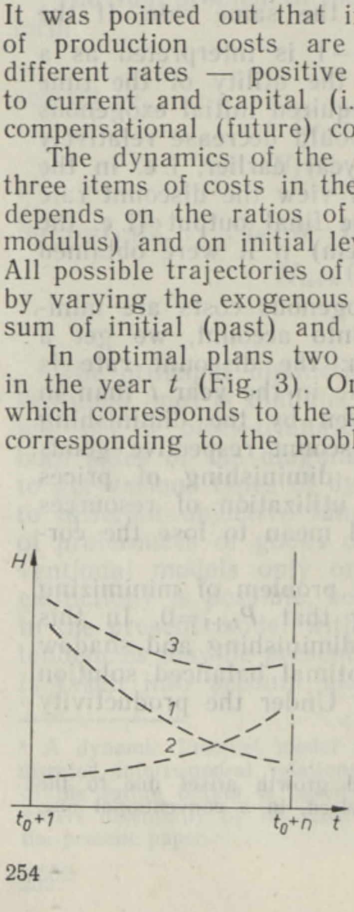

Fig. 3. Trajectories of shadow prices in the problems of minimization: *1* — of past costs, *2* — of future costs, *3* — of the sum of past and future costs.

The values of shadow prices in the problem of min $P_{t_0+1}X_{t_0+1}+P_{t_0+n}X_{t_0+n}$ are equal to the sums of the two above-mentioned prices (curve *3*). In the point of this curve corresponding to the year t_0+k, the vector of prices expresses the maximum utility of the final output of this year, as it follows from the duality relationship for the problems (3), (4):

$$\min(P_{t_0+1}X_{t_0+1}+P_{t_0+n}X_{t_0+n})=\max H_{t_0+k}Z_{t_0+k}, \tag{5}$$

i. e. the minimum sum of exogenous costs is equal to the maximum utility of the final output in the year t_0+k. Let the demand for the final output be shifted forward by one year (i. e. it will be Z_{t_0+k+1} instead of Z_{t_0+k}), then its shadow price in the expanding system will reduce, corresponding to an increase in efficiency. On the contrary, in the exhausting system, such a shift will result in a rise of the shadow price of the final output (reduction of efficiency). Those effects will cause a change, at a certain rate, in the vector of the aggregate shadow prices in the given year. At the beginning of the planning period their dynamics depends more on the past costs, while at the end — on the future ones. Differently directed influences are equalized at the minimum point of the curve (Fig. 3, curve *3*).

If, at the beginning of a planning period, the future costs compose an insignificant part of the total costs and the positive and negative discount rates are close to each other in absolute values (as this is in Fig. 3), then for a sufficiently long period the factor of discounting values to the initial year is a convex function of time. For example, it implies that the discount factor for monetary estimation of deposits of a mineral resource may be on the average close to unity for a period of its exploitation.

In any case, an account of long-term ecological consequences of production activity will essentially increase the value of the discount factor compared to the one obtained in the conventional way.

In the problem (3), the trajectory of gross outputs has a form of a beak: they grow exponentially at a rate $\bar{\alpha}>1$ until the year t_0+k, declining after that at a rate $\bar{\beta}<1$. This is a response of the production system to the external load provided by the final demand in the year t_0+k. It consists of the phases of pre-action and post-action. In the former phase, during the period $t_0+1, \ldots, t_0+k-1$, the production is increased up to the level needed for meeting the final demand Z_{t_0+k}. The post-action consists in the compensation of the remaining damage in a system during the period, $t_0+k+1, \ldots, t_0+n$.

6. Conclusions

The above discussion allows us to conclude that the effect of the time factor (represented by the sign of the discount rate) depends on how an objective of the system is oriented on the time axis.

In modern economy, goals of the most efficient utilization of labour and material resources available at the moment of decision-making are dominating. This orientation corresponds to the decline of discount factors over time, i. e. the positive discount rate. Accordingly, accumulated goods are preferred to the future ones, and an urgent intensive exploitation of natural resources is stimulated. This results in a rise in the productivity and development of the technosphere, but this is achieved at the expense of a degradation of ecosystems at even a greater speed.

In case when minimization of future costs is the prevailing goal, the discount rate is negative (discount factors grow over time). Consequently, the saving of natural resources and the prevention of the losses of nonrenewable materials will become preferable.

Thus, the minimization of past costs corresponds to a process of accumulation, while that of the future ones — to a process of depletion. In the economic-ecological system with intertemporal feedback those processes co-exist and interact.

The conventional methods of discounting entirely oriented on a minimization of the past costs are unacceptable for economic-ecological calculations with a distant forecast horizon. In such calculations it is appropriate to use two discount rates — the positive and the negative ones, and in the long-run perspective, to take into account a tendency for a rise in the utility of goods over time.

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LOODUSKASUTUSE PIKAAJALISTE TAGAJÄRGEDE MAJANDUSLIK HINNANG

Teaduslik-tehniliste programmide ja suuremahuliste projektide adekvaatseks rahvamajanduslikuks hindamiseks on vaja prognoosida ja arvestada nende realiseerimise pikaajalisi, eeskätt ökoloogilisi tagajärgi. Artiklis analüüsitakse sellega seotud eriaegsete suuruste võrdlemise probleemi ökoloogilis-majanduslikes arvutustes kaugeks perspektiiviks. Ajateguri majandusliku mõju mitmesust on interpreteeritud ja põhjendatud aegadevahelisel mudelil imitatsioonarvutustega. On välja töötatud kulude diskonteerimise meetod loodussäästliku majanduse jaoks.

Eesti NSV Teaduste Akadeemia
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Toimetusse saabunud
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Илья КАГАНОВИЧ

ЭКОНОМИЧЕСКАЯ ОЦЕНКА ОТДАЛЕННЫХ ПОСЛЕДСТВИЙ ПРИРОДОПОЛЬЗОВАНИЯ

Для адекватной народнохозяйственной оценки научно-технических программ и проектов большого масштаба необходимо прогнозировать и учитывать отдаленные последствия их реализации, прежде всего экологические. В статье анализируются связанные с этим проблемы соизмерения разновременных величин при экономико-экологических расчетах на дальнюю перспективу. Неоднозначность экономического влияния фактора времени обоснована и интерпретирована с помощью имитационных расчетов на модели межвременных-межотраслевых связей. Выведена модификация метода дисконтирования затрат для природосберегающей экономики.

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