WORKING PAPER

ASSESSMENT OF EFFECTIVENESS OF SCIENTIFIC AND TECHNOLOGICAL INNOVATIONS

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VNIISI, Moscow, USSR

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FOREWORD

New manufacturing technologies, such as CIM and FMS, are expected to be one of the major driving forces of the current technological change. CIM and FMS have a lot of cross-impacts between industries and countries. One of the tasks of the IIASA CIM Project is to build up tools to analyze cross-impacts.

For the decision makers it is sometimes a difficult problem to evaluate different investment possibilities and their impacts within one company or within one economy. Y.N. Yvanov's paper presents a method to cope with the problem as a dynamic task of resource allocation. It is an interesting way to analyze these cross-impacts.

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ASSESSMENT OF EFFECTIVENESS OF SCIENTIFIC AND TECHNOLOGICAL INNOVATIONS

Y.N. Ivanov

The most important problem in the innovative process is the selection of innovations to be recommended for adoption on a national scale. In the socialist economy, which is mainly the topic of this presentation, the recommended innovations are included in the State Plan and are implemented in a centralized way. These recommendations may prove helpful for the formulation of national programs in any capitalist economy.

1. Useful and recommended innovations. In an ideal market, economy free market prices may serve as a measure of utility of innovative changes.

When the implementation of innovations does not require capital investments or purchase of licenses, and is limited to the change in raw materials and labor structure, its utility is calculated by the formula of profit: the change is useful when the profits rise, and it is useless when profits fall.

When the utilization of innovations is connected with capital investments, the innovation effect should be calculated with due account of these costs. Second, it should be calculated over a sufficiently long period of time and, third, should not ignore the price forecasts.

It should be emphasized that price forecasting is the most difficult matter in calculating the effectiveness in this way. Its precision is unpredictable. Another problem consists in the extent to which the real prices may be used for measuring the social utility of innovative changes. We do not know how the real prices differ from the ideal prices of the free market.

Let us assume that the abovesaid difficulties are overcome, and we have precise price forecasts reflecting the social utility. In this case each new product may be assessed by its quantitative effect. If it is positive, the innovation is useful, otherwise - it is useless. Thus, all the scientific and technological innovations currently available may be classified as useful and useless.

Among the useful innovations there are such that do not require capital investments for their implementation. Undoubtedly, they must be utilized. These may be new crops in agriculture, for example. The rest require capital investments, and the typical situation here would be like this: the available capital is not sufficient for the implementation of all the suggested innovations to renovate the production. The question is which of them ought to be recommended. Within the approach based on the price forecasts the answer would be: one should recommend the innovations that produce the highest profit per unit of capital investments.

Thus, we may speak of useful or useless innovations, and among the useful ones - of those recommended or rejected. These concepts belong to the approach based on the price forecasts and to another one that will be discussed below. To identify the priorities in the scientific and technological progress means to identify innovation to be recommended for the utilization and to specify the dynamics of this process.

It should be emphasized that not all the innovations can be assessed. This refers in the first place to new consumer goods, new services in the health care system, new methods in education, new environmental activities. In short, all the innovations in the non-production sphere or at the interface of the production and non-production spheres are hard to assess.

2. Dynamic multisectoral model of the national economy. The approach under review is based on the calculations of the national economic model. The dynamic multisectoral models stem from the Leontieff "input-output" model.

The model features the following variables:

- annual volumes of sectoral output;
- average annual basic production assets of industries;
- annual volumes of non-production consumption

and a number of other variables.

The model presents a totality of resources and constraints:

- resources of production and distribution of industries' product;
- limitation of sectoral outputs in conformity with their basic production assets;
- labor resource constraint

and a number of other relationships.

The model has specific sectoral characteristics, such as:

- direct cost factors indicating the amount of output of an industry required for a unit of output of another industry;
- sectoral labor intensities - what labor resources are necessary to manufacture a unit of output in some industry;
- sectoral capital productivity - what amount of basic productivity assets provide or the manufacture of a unit of output

and other specific characteristics.

The Model:

$$\theta_\nu(t) = \sum_{\nu'=1}^{N} [\alpha_{\nu\nu'}(t)\,\theta_{\nu'}(t) + \beta_{\nu\nu'}(t)\kappa_{\nu'}(t)] + \sigma_\nu(t)\,\Pi(t) +$$

$$\delta_\nu(t)\,\theta_\nu(t) \le \Phi_\nu(t)$$

$$\sum_\nu \lambda_\nu(t)\,\theta_\nu(t) \le \Lambda(t)$$

$$\Phi_\nu(t+1) = \Phi_\nu(t)[1-\omega_\nu(t)] + \sum_{s=o}^{\tau_\nu-1} \rho_\nu(s)\,\Psi_\nu(t-s)$$

$$\kappa_\nu(t) = \sum_{s=o}^{\tau_\nu-1} \xi_\nu(s)\,\Psi_\nu(t-s)$$

where:

N- number of industries;

$\Lambda(t)$- labor resource;

$\theta_\nu(t)$- output of the ν-th industry (in rubles);

$\Phi_\nu(t)$- fixed capital assets in the ν-th industry;

$\Pi(t)$- final consumption;

$\alpha_{\nu\nu'}(t)$- input-output coefficients;

$\beta_{\nu\nu'}(t)$ - technological structure of capital investments;

$\sigma_{\nu}(t)$ - structure of final consumption ($\sum_{\nu=1}^{n} \sigma_{\nu} = 1$);

$\delta_{\nu}(t)$ - capital-output ratio;

$\lambda_{\nu}(t)$ - labor-output ratio;

$\omega_{\nu}(t)$ - discard coefficient;

$\Psi_{\nu}(t)$ - cost of capital assets, started by construction in year **t**;

$\rho_{\nu}(s)$ - coefficient for transformation of capital assets, started by construction in year (t-s), into capital assets in year **t**;

$\xi_{\nu}(s)$ - share of investments in year **t**, connected with capital assets, started by construction in year (t-s)

τ_{ν} - duration of construction in the ν-th industry.

The idea of the so called rough innovation assessment consists in the following. The innovations have a direct impact on the technological specific characteristics. It is important to find out how the change of these technological specific characteristics affects the sectoral specific characteristics and to determine its influence on the aggregate national economic figures by employing the above model. Consequently, the sectoral specific characteristics are an important feature of the said approach and are therefore given special attention.

Such national economic criterion as the amount of non-production consumption may serve as a measure of public production efficiency.

$$J = \sum_{t=1}^{T} \Pi(t)$$

where: T - duration of planning period;

Other criteria, such as the national income, may be used as well. The selection of a criterion is not a formal but necessary procedure. The answers concerning the utility of innovations in this approach would read like this: such and such innovation is useless with respect to such and such national economic criterion, or it is useful as it improves such and such criterion by so many per cent.

Each calculation by the model using a selected criterion permits to formulate effective programs for the development of industries and distribution of sectoral products; in each calculation the best value of the selected national economic criterion is obtained.

3. Impact factors. Each calculation is made with the given sectoral specific characteristics (direct cost coefficient, labor intensity, capital productivity). But an innovation may change sectoral specific characteristics. Consequently, in order to assess the impact of an innovation on the national economic criterion, it is necessary to know its dependence on the sectoral specific characteristics. The impact factors allow one to assess this dependence.

The impact factor of some specific characteristic in a certain year indicates by how many per cent the national economic criterion has increased if, beginning with this year and onward till the end of the planning period, this specific characteristic improves by one unit.

$$\kappa^{\alpha}_{\nu\nu'} = \frac{\alpha_{\nu\nu'}}{J} \cdot \frac{\partial J}{\partial \alpha_{\nu\nu'}}$$

$$\kappa^{\lambda}_{\gamma} = \frac{\lambda_{\nu}}{J} \cdot \frac{\partial J}{\partial \lambda_{\nu}}$$

$$\kappa^{\delta}_{\nu} = \frac{\delta_{\nu}}{J} \cdot \frac{\partial J}{\partial \delta_{\nu}}$$

The impact factor reflects the degree of sensitivity of public production to the change of sectoral specific characteristics. The larger is the scale of the industry it refers to, the higher is the factor. It is not equal to zero, if the industry it refers to is on a critical path of the economic development.

Impact factors serve as price analogues in the process of innovations assessment.

4. Evaluations. Impact factors are obtained as a result of model calculations. They present only part of the data required for the innovation assessment. The data concerning the changes in the sectoral specific characteristics resulting from the innovation utilization are required too.

Each innovation is usually accompanied by the following information: volume of capital investment, change in the labor-intensity and capital productivity after the innovation is implemented, difference in the specific costs of certain products in comparison with the previous (competing) mode of production used. These data are presented in the form of detailed product specifications, while impact factors are referred to the sectoral product specifications. In other words, each innovation influences some part of the given industry, and the task is to find out how it would affect the industry as a whole.

The change in the sectoral specific characteristics turn out to be so many times less than the changes in the specific characteristics of the technological level as the innovated product is less than that of the branch to which this product belongs.

$$\Delta\alpha_{\nu\nu'} = \frac{vi}{\theta_\nu} \Delta a_{ii'}$$

$$\Delta\lambda_\nu = \frac{vi}{\theta_\nu} \Delta \ell_i$$

$$\Delta\delta_\nu = \frac{vi}{\theta_\nu} \Delta d_i$$

where: $\Delta a_{ii'}$, $\Delta \ell_i$, Δd_i - **increment of direct row material,** labor, capital requirements, which are connected with the i-th product, produced with the new technology;

v_i - output of the i-th product;

i - belongs to ν

5. Effect formula. An innovation gives rise to changes in the technological specific characteristics which are translated into the changes of the sectoral specific characteristics. The innovation effect is determined by means of impact factor with the help of the effect formula that reads as follows: one should multiply the change of the sectoral specific characteristics by their impact factor, then sum up these products with a proper sign, then subtract from the total sum the capital investments for the innovation implementation multiplied by their impact factors.

$$\Delta J = \sum_{\nu\nu'} \kappa^{\alpha}_{\nu\nu'} \Delta\alpha_{\nu\nu'} + \sum_{\nu} \kappa_{\gamma}^{\lambda} \Delta\lambda_\nu + \sum_{\nu} \kappa_\nu^{\delta} \Delta\delta_\nu +$$

$$+ \sum_{\nu\, N^\rho} \kappa_\nu^{\xi} (t_r) \Delta\kappa_\nu (t_r)$$

where: $\Delta\kappa(t_r)$ - capital investment in year of reconstruction t_r;

κ_ν^{ξ} - dual variables, which correspond to capital-forming industries N^ρ.

The impact factors depend on the year in the planning period, therefore the calculated effect also depends on the same. One should carefully choose the moment (the year) for the innovation to be introduced so as to obtain the maximum effect

6. The "range" approach. This presentation deals with the theoretical aspect of innovation assessment method, as well as with some other matters concerning the real impact factors. The first theme is closed with the effect formula and now we pass to the model itself.

Soviet statistics operate with a 18-sector product mix: electric power engineering, oil and gas industry, coal industry, agriculture and forestry, construction, transport, communication, etc. Within this framework there are statistical data on intersectoral deliveries, sectoral production assets, labor consumption and other figures. The period under review is the past 20 years.

The above data make it possible to define the coefficients of sectoral direct costs, capital productivity and labor intensity (for the past period). The traditional forecasting technique is to guess the most likely behavior of these specific characteristics in the future. Since the model intends to identify the preferable courses of the technological change, i.e. the preferable changes in the sectoral specific characteristics, it is impossible to try and predict the results of this identification before it is done. Thus, the traditional forecasting technique is not acceptable in this case. Instead, the so called range approach should be employed.

This method implies identification of the range where the special characteristics changed in the past. Their future behavior is considered to be uncertain but it will occur within the ranges where the middles are the same as in the past, and they are as wide as before. The model calculations are now made for several sets of characteristics covering the ranges, not for one set only. As to innovation assessment, when the range approach is employed, their useful-useless character is determined in the context of the future. If the innovation is determined as useful throughout the whole period, it is classified as useful (and vice versa). If it is useful for some part of this period and useless for the rest of it, no definite judgment is made as to its utility.

The approach in question is more reliable though more labor-consuming than the traditional one. The ranges where the characteristics change were determined historically. They include structural changes, foreign trade policies, restructuring of production by means of new technology, etc. When past changes are extrapolated into the future, it is supposed that the abovesaid change factors will work to the same extent in the future. This is the main hypothesis of the range approach.

The results treated in the next section are represented by two values: one of them refers to all the lower limits of the ranges of the specific characteristics, the other - to all the upper ones.

7. <u>Real impact factors</u>. The impact factors obtained as a result of model calculation allow one to make substantive

conclusions.

If all the sectoral specific characteristics are improved by 1 per cent, the national economic criterion will improve by 3 to 4 per cent. The first figure refers to the lower line of the sectoral specific characteristics (optimistic ones), the second one - to the upper line (pessimistic ones). These figures correspond with the improvement made in the first year of the planning period and maintained throughout it.

How will the effect change with the improvement of the specific characteristics if these improvements are manifest later than the first year of the planning period? In other words, what are the losses from lagging? The dynamics of such losses turns out to be close to a linear one: the improvements started at the last moment of the planning period, naturally, yield a zero effect, whereas the improvements started in the middle of the planning period yield the effect approximately half the effect of those started in the first year of the planning period. Thus, the losses caused by a delayed introduction of innovations are linear in time.

The second point concerns the essential and non-essential specific characteristics. There are 432 specific characteristics in the 18-sector model. On the average, each of them improves the criterion by some 0.007 to 0.01 per cent. The most essential specific characteristic is labor intensity of agricultural production which, if reduced by 1 per cent, improves the criterion by 0.18 to 0.22 per cent, and that makes 4 to 7 per cent of the total effect provided for by the 1 per cent improvement in all the specific characteristics.

In ranking the specific characteristics the first place will go to the labor intensity of agricultural production since its impact factor is the largest; other places will be occupied by the rest of them in the order of their impact factor diminution. The specific characteristics in the first 30 to 50 places possess the impact factors ten times smaller than the labor intensity of agricultural production. The first ten characteristics account for 30 to 45 per cent of cumulative effect; the first twenty - from 51 to 62 per cent; the first fifty - 78 to 82 per cent. In order to achieve 99 per cent, it is necessary to maintain 220 or 215 characteristics.

These figures indicate that not more than half the sectoral specific characteristics may be qualified as essential. In other words, in order to improve the national criterion it is sufficient to focus on the improvement of half the sectoral characteristics. This is the first conclusion, and it may be interpreted as follows: one should no distribute the resources equally between all sciences. Each economy in any given moment has most preferable directions of the technologic progress, and they should be actively tackled.

The second conclusion is of a different character. Lately, opinions appeared in the literature dealing with forecasting that can be best presented in a formula form: The technological progress = biotechnology + computerization + robotization or the technological progress + flexible manufacturing systems + new materials + computerization.

In other words, the authors of these ideas want to convince the public that only 2, 3 or 4 directions of development can be essential. The rest are either insignificant or not significant enough. It is a wrong idea. Dozens of directions can be equally essential.

The last conclusions concerned trends of science i.e. future innovations which are not yet formalized as specific suggestions. The conclusions are obtained with the help of impact factors. The same impact factors may serve as tools of assessing the utility of the exiting innovations.