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The Approach to Measuring and Assessing the Intensity of Innovation Activity at the Macro Level

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Abstract— The approach to measuring and assessing the intensity of innovation activity is based on the ratio of investment efforts and indicators of labor productivity dynamics caused by them. Two methods based on this approach are proposed. In one of them the innovation activity intensity is measured via decomposition of the labor productivity increase into the factors that generate it - the dynamics of capital productivity ratio and capital-labor ratio (in logarithms). Another methodical approach closely connected with the previous one is based on the special parameter, characterizing investment potential growth, the demand for the net investments to increase unit intensity productivity.

Calculations made on US statistics since the early 1960s give an idea of the innovation factor role in certain quantitative assessments. It turned out that in general for the period 1961-2014 about 3/4 of the productivity increase is due to the capital-labor ratio growth, and only ¼ to the capital productivity ratio growth. In 1981-2000 about half of the productivity increase was already obtained due to the innovation factor; investment, which provided breakthrough technologies. At the same time, a reduction in the relative demand for investment from the beginning of the 1980s made it possible with almost the same accumulation rate to stop the threatening tendency towards reducing of the labor productivity growth rates.

Keywords: innovation activity, labor productivity, investment, technology, research and development, macro-level, USA

1. INTRODUCTION

This article attempts to "separate" the measurements associated with technological progress and innovation, and at the same time establish a link between them. The approach to measuring and assessing the intensity of innovation activity is based on the correlation of investment efforts and the resulting indicators of the dynamics of labor productivity. The better this ratio gets the higher is innovative activity, i.e. the less investment is required to increase the unit intensity productivity.

The need to replace obsolescent productive facilities, to form a new technological basis, accompanied by an increase in labor productivity, imposes higher demands on quality, technical parameters of the natural and material composition of investments, assumes, in principle, an increase in the unit investment costs. Innovative activity that reduces the relative need for investment by creating more intelligent and advanced technologies, which can, thus, slow down or even overcome the "propensity" to increase capital intensity can counter this objective tendency.

The condition for stabilizing or even reducing the capital intensity is the increasing effectiveness in the highly intellectual sphere of research and development that precedes the investment activity itself. The increase in efficiency in this sphere is based on the results of fundamental science, the identification and use of increasingly deeper and subtle laws of nature, the "rent of knowledge" [1–7]. Ratios linking key macroeconomic parameters at the model level are investigated, in particular, in the classic works of R. Solow [8–10].

In the present work, an attempt is made to link the productivity of labor dynamics to investment factors (in particular, to the index of capital-labor ratio) and on this basis to choose the key to assess the innovative component of productivity growth; simultaneously, at a qualitative level, to study the dependence of productivity growth rates on the introduced parameter characterizing the relative need for investment.

There is a literature that covers this subject. In these studies, the difference in labor productivity in countries around the world, already at the level of models and calculations based on production functions, is explained by the capital-labor ratio and the level of technology, the so-called level of multifactor productivity (MFP). Elements of MFP are identified on the basis of ―residual” principle: ―as the gap in labor productivity between countries, *not explained* by differences in the capital-labor ratio and the quality of human capital” [11].

The detailed review, that includes around 50 papers on this subject, is presented in paper [12], in Russian language, by A. Zaitsev (2016). Papers [13-24] that cover different countries, different approaches and specific methods for assessing the relationship between economic growth and the factors of production are also focused on capability analysis and assessment of causes of differences between countries [13-24]. In addition we present some new studies [25, 26].

Investments in fixed assets, while ensuring the transition of the national economy to an increasingly higher technological level, measured by the assessment of productivity, are

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simultaneously represent the price that society pays for achieving this level.

The ratio of investment costs and results helps to asses the level of "innovativeness" of the project of modernization of the productive facilities.

Let's consider two methodical approaches that are based on this idea and that concern the evaluation of the intensity of innovation activity, already at the operational level. They are based on one and the same principle of the ratio of investment costs and results - the growth of labor productivity.

In the first of them, the intensity of innovation activity is measured by decomposing the growth of labor productivity into the factors that generate it: the dynamics of capital productivity ratio and capital-labor ratio. Accordingly, the assessment of the intensity of innovation activity is part of the productivity increase that is due to dynamics of capital productivity ratio. The more the productivity growth surpasses the dynamics of the capital-labor ratio, ensuring a positive value of the growth rate of capital productivity ratio, the higher the level (scales) of innovation activity, the role and significance of the innovation factor.

As you probably know, the labor productivity index can be represented as multiplication of capital-labor ratio and capital productivity ratio:

$$I_{lp.} = I_{cl} \cdot I_{ra}, \ (1)$$

where $I_{lp.}$ – labor productivity index, I_{cl} – capital-labor ratio index and I_{ra} – capital productivity index.

In discrete time, the task of distinguishing the role of each of these factors (attributes) in the performance gain does not have a unique solution: there are at least three ways to present the productivity gain as the sum of two parts corresponding to the increment due to the change in the capital-labor ratio and due to the change in the capital productivity ratio[1].

It is more appropriate to consider the case of continuous time.[2] In this case, the logarithm of the growth rate is the increment rate. When we take a logarithm of the equation (1), we get the following result:

$$\ln I_{lp.} = \ln I_{cl} + \ln I_{ra} \ (2)$$

This way, the productivity index is represented (in continuous time) as the sum of indices of the capital-labor ratio and the capital productivity ratio.

On the basis of ratio (2), we can single out[3] a part of the increment rate associated with a change in the capital productivity ratio:

$$\alpha_{innov} = \frac{\ln I_{ra}}{\ln I_{lp}}.$$

Hereafter let's assume that parameter α_{innov} is assessment of the intensity of innovation activity.

The positive rates of growth in capital productivity and capital-labor ratio make it possible to "naturally" decompose the increase in labor productivity by factors explaining it in full. Negative rates of growth in capital productivity that signal about preemptive rates of growth of capital-labor ratio compared to labor productivity dynamics bring the value of α_{innov} to be less than zero.

It is important to note that the negative value of α_{innov} does not specifically mean the lack of innovation activities. Apparently, the following statement is valid: the positive value of α_{innov} parameter is sufficient, but it is not a necessary condition for innovation activities to be present.

Another procedure, closely related to this one, and which was mentioned earlier, relates to absolute scale of (net) investments that lead to increase of productivity. We are talking about the calculation of the unit (per one employee) net investments in terms of the productivity increment of unit intensity $E^{1,T}$.

$$E^{1,T} = \frac{I^{1,T}}{\sum_{\tau=1}^{T} L^{\tau} / T} : \ \Pr^{T} - \Pr^{0}$$

where $E^{1,T}$ – unit costs (per one employee) of net investment per unit of productivity increment over the period $1,T$; $I^{1,T}$ – net investments per period $1,T$ (fixed capital in year T minus fixed capital in base year at constant prices); $\Pr^{T}$ - labor productivity in the year T; $\Pr^{0}$ - labor productivity in base year; L^{τ} - number of employees in the year τ.

Parameter $E^{1,T}$ shows the investment potential of growth, the need for investment for the growth of productivity of a unit intensity; answers the question: how much dollars of net investment is required during a certain period to equip one workplace, more precisely, per one mid-annual worker, to increase its labor productivity by one dollar. If, for example, the value of $E^{1,T}$ parameter is decreasing, i.e. productivity growth requires relatively smaller (intellectually capacious) investments, then in this case it is natural to talk about improving the ratio of investment costs and results due to the higher quality of the natural material composition of investments (~~–b~~etter less, but of higher quality"); about presence (or increase in scale) of innovation activities.

The changes of $E^{1,T}$ parameter, determining the ratio of investment costs and results (productivity growth) in dynamics, reflect, at certain conditions to a certain extent, the presence and intensity of innovation activity. Hereafter, to

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1 Such variants are provided in the classic textbooks on statistics. For example, see [27].

2 Proposed by E.A. Shiltsin.

3 Such a transfer of a fraction from a continuous decomposition into a discrete one does not lack sense. According to US statistics (as discussed below), the difference between a discrete and a continuous decomposition is no more than 3%.

make is shorter let's call $E^{1,T}$ parameter – ―investment costs".

Let's illustrate the above approach using the US economy due to its well-known technological leadership. We consider longer than half a century time period from a point of view of the innovation factor influence on economic growth. This period is divided, with a certain degree of conventionality, into three long time periods: 1961-1980, 1981-2000, and 2001-2014.

Let's present the data characterizing the intensity of innovation activity in accordance with the proposed approach (Table 1).

Table 1. Share in the overall increment in productivity due to the increase in the capital productivity ratio (assessment of innovation activity intensity) per each period, %

Base year	1960			1980		2000
Period	1961-1980	1961-2000	1961-2014	1981-2000	1981-2014	2001-2014
Value of α_{innov}	16	33	26	50	32	3

Reference [28-30]

The data presented in the table above provides us some insight into the nature of the reproduction process in the United States, and the role of innovation factor in certain quantitative assessments already. It turned out, for example, that in general for the period of 1961-2014, about 3/4 of the increase in productivity was due to investments based on routine research, 1/4 - on fundamental research and development, which ensure a predominant growth in productivity relative to the capital-labor ratio. Also, it can be definitely stated that there was a special twenty-year period that spanned the eighties and nineties of the last century and had a decisive influence on the picture of the reproduction process for more than half a century. This time period is characterized by the important role of investments, based on fundamental research, due to which it became possible to gain a significant advantage in the growth of labor productivity relative to the capital-labor ratio indices. In 1981-2000s almost half of the increase in productivity was gained due to investments that provided breakthrough technologies.

We'd like to remind, that another way to assess innovation activity is related to the comparison of specific investments and productivity growth. Let's look at the connection between the dynamics of productivity and investment costs. The mid-1960s are characterized by the highest ***cumulative*** average annual growth rate of labor productivity throughout the whole time period under review; in this sense, it is zone of historical (global) extremum, which formed a distinctive "hump" of cumulative dynamics. At the same time, special attention should be paid to the fact that on a segment of a prolonged falling trend the slowdown in productivity growth does not differ in monotony. In particular, approximately since the mid-1970s the steep descent was replaced by a smoother trajectory of decline, and since the beginning of the 1980s it was stabilized.

Until the early 1980s, the curve of cumulative labor productivity was accompanied in many ways by the mirror dynamics of investment costs. The zone of the global cumulative maximum of productivity in the mid-1960s corresponds exactly with the zone of cumulative minimum of costs. And as a result, up until the beginning of the 1980s, the following asymmetry can be seen: the fall in cumulative productivity growth rates is accompanied (proportionally) by an increase in the trend of investment costs.

Until the end of 2000s the cumulative rates of productivity growth remained constant with a slightly reduced investment costs. In the most recent years, the characteristic asymmetry is revived again.

CONCLUSION

Two methods of measuring the intensity of innovation activity were applied within the framework of the proposed approach and yielded consistent results. It turned out that for the past 50 years productivity growth in the US was provided to a decisive degree (by about 3/4) by the increase of the capital-labor ratio. The innovative component of technological progress was most clearly manifested during the last two decades of the 20th century. Simultaneously, the relationship between the performance dynamics and the parameter characterizing the relative need for investment has been established at a qualitative level.

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