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New approach to assessing the contribution of science and education to the welfare of countries

Abstract: The issues of the economic effectiveness of educational and research activities are investigated. A simple model of the human capital index is suggested. The contribution of professionals to a country's GDP is shown to grow exponentially with the accumulated years of schooling.

Keywords: investment in education, human capital, intellect, GDP growth, externalities, forecasting.

1. Introduction

As humanity is approaching the "economics of knowledge", the task of developing education and science is becoming more challenging because they are the factors that promote growth of a country's intellectual resources, followed by gross domestic product (GDP) and population welfare growth. However, the quantitative relationship of these factors is still vague.

The current methods of estimating the return on investment in education have several peculiarities. As a rule, they are based on the statistics of developed countries and it is unclear to what extent they can be applied to other economies. Moreover, they are very complex for making estimates to substantiate strategic educational alternatives and forecast the development of countries based on the growth of their intellectual potential. To solve this problem, it is vital to offer an integral index of the intellectual level of countries.

The *objective of this study* is developing a method for determining the contribution of education and science to a country's development. In particular, this concerns the growth of intellectual resources and GDP that would reflect just the key parameters of the phenomenon (order of magnitude values) to obtain a tool convenient for shaping education and science development strategies.

1. Research methods

The study uses research methods applied in economics, marketing, management, knowledge management, and other sciences.

The initial research stage used methods for studying previous research and identifying the specific features of the phenomenon being studied. In so doing, a critical analysis is applied to prior research, in particular, from the system approach viewpoint, and from the standpoint of convenience of using calculation methods in further research. Next, a hypothesis is suggested on the form of mutual relationship of parameters being studied. It is tested preliminarily by using PC-based computational methods.

The body of the study uses quantitative research methods akin to forecasting. In particular, the modelling method is used to search for dependencies of several statistical variables. The sampling method is used to choose a data group for subsequent processing.

To find the weighting factors of the human capital index, the numerical gradient descent method is used to search for the extremum of a multidimensional function, with all relevant computations done in Excel.

Statistical data are compared against forecast ones to validate the adequacy of the solution obtained. Numerical data are visualised graphically, and deviations from the basic regularity are analysed.

To focus on the critical points of the findings, a specific description of the regularity found is suggested.

2. Literature review

Estimates of the economic effectiveness of education have shown that the rate of return on investment in education is 10-15% [1]. This is higher than in many branches of economy. Therefore, in the majority of countries worldwide, the level of coverage with higher education is ever growing. Thus, between 2000 and 2012, the OECD countries have demonstrated a growth of about 10% [2, Table A1.1].

Education and science are the major tools of development of a country's intellectual resources. In turn, intellectual resources are a key factor of development of countries and the growth of their GDP.

The key concept for assessing the role of intellect is human capital (HC). "Modern economic theory understands "human capital" as a set of knowledge, skills and capabilities in each person that he/she can apply for both production and consumption purposes" [3] The following basic approaches to a quantitative assessment of HC are distinguished:

1. An index one based on a variety of natural characteristics of human capital.

2. A cost one based on accounting for HC development-related expenses.

3. A cost one based on accounting for the income HC yields.

4. A cost one based on physical and natural capital being deducted from a country's natural wealth, with the remainder being the human capital value.

However, analysis of the tools developed within the framework of applying these concepts has shown that they are insufficient to face the problems of economic effectiveness of education. This is due to two factors.

First, the existence of "externalities", i.e. benefits external to HC carriers, which other business subjects receive. Employers receive a significant amount, perhaps even a predominant share of externality benefits of education [4]. Besides, skilled professionals play a crucial role in developing and spreading technologies and know-how in a country. Hence, the externality benefits for the country can be much greater than those the company can gain by employing a professional.

Second, several of the developed tools use summation of the system inputs and outputs to be investigated, which is very undesirable. Thus, a known HC assessment method called Human Development Index (HDI) [5] builds on three groups of indicators:

1. Mean life expectancy;

2. Mean years of schooling;

3. GDP per capita at purchasing power parity (PPP), USD.

Here, the second indicator is the system input and the remaining ones are its outputs. If we want to find how the level of intelligence or education affects GDP, using HDI appears ineffective.

Summing up the results of research into the impact of HC on economic growth, A.V. Koritsky comments, "Empirical intercountry studies in the impact of HC on economic growth yield very contradictory results stemming from statistical inadequacy and the huge variance of different, often very problematical indicators used for measuring human capital" [4].

However, some results obtained with these concepts can be useful for solving problems in the economic effectiveness of education. The following comment is worth mentioning: "Economic growth in EU regions is sensitive only to acquiring higher education (the third-level one), whereas variations in the middle education level are statistically insignificant" [6]. "The mentioned above effect of externalities is also critical. It stresses the necessity to outline best the area wherein the effect of the economic effectiveness of education can demonstrate itself, e.g., within country limits" [4].

Fig. 1 shows the functional dependence between mean accumulated years of schooling and the natural logarithm (Ln) of GDP per capita for different countries [7] (for persons 25 years of age and older) at PPP, 2000 intl.$. A certain statistical dependence of these parameters is evident. However, at the same GDP per capita level, the difference in the educational level of countries can exceed two-fold, i.e. the link between these factors is far from being conclusive.

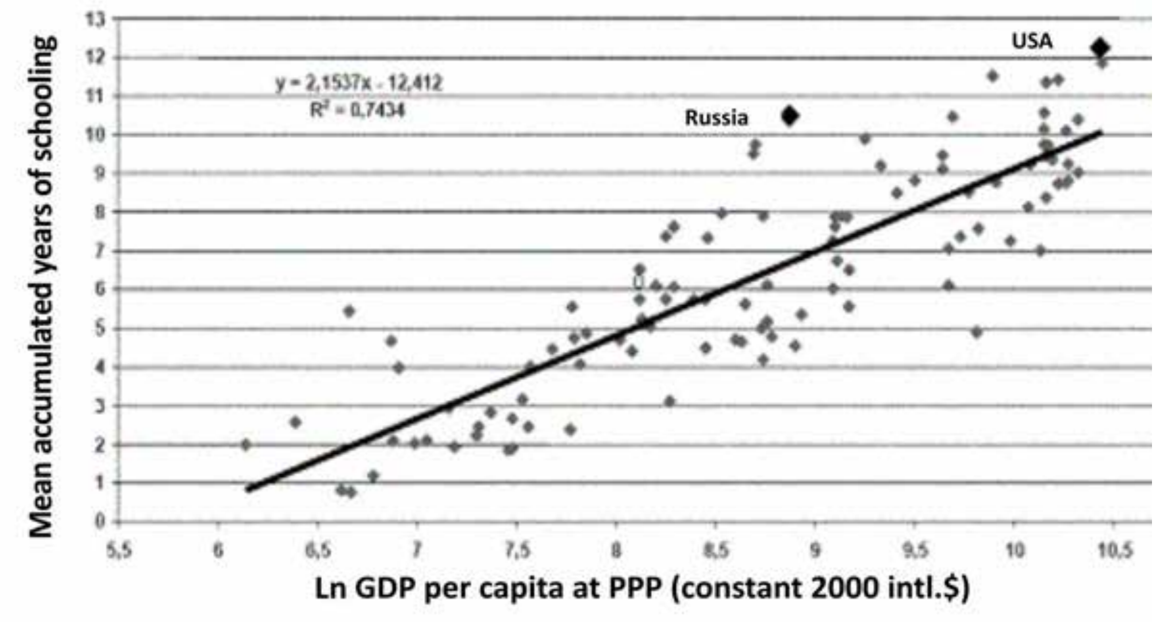

Fig. 1. Years of schooling vs. GDP per capita for different countries

Since the X-axis is the GDP logarithm, this means that the dependence is an exponential one in the linear coordinate system. Hence, with growth of the population's educational level, the GDP of countries grows very quickly. Consequently, the level of education in a country is not an additive value, and it is wrong to estimate it by summation of the accumulated years of schooling for various professionals. Highly educated professionals contribute essentially more to a country's GDP than less educated ones do. Therefore, the contribution of professionals with different skills should be accounted for with a different "weighting".

3. Research results

3.1. Human capital index

To solve the problem being considered, we will use the so-called index approach. In our study, as distinct to the example shown in Fig. 1, where the index is the mean accumulated years of schooling, we will choose an index with a more differentiated focus on the intellectual component, namely, the number of professionals with a higher education degree and the number of R&D employees (researchers). Let us call this parameter "Human capital index" (IEC or I_{HC}).

Note that we intend to assess the amount of implicit knowledge of professionals in different countries. However, since it is challenging to measure the amount of implicit knowledge directly, we will assess its scope through the educational characteristics of people who have acquired such knowledge.

As a natural indicator of the intellectual level, we will introduce the measurement unit "intellectual capacities of an average person with higher education at an ISCE 5A level" and designate this unit as "hcu". As mentioned above, an educational level lower than higher contributes relatively less to economic growth. Therefore, we will account for only four levels of professional education: higher professional (level 5A), middle professional (5B), R&D professionals and a level lower than the tertiary one (as per UNESCO classification). We will not account for education level 6 in this approximation to exclude duplication with R&D professionals. Let us introduce the human capital index:

$$\mathbf{I_{HC} = \Sigma\, K_i \cdot N_i}\,. \qquad (1)$$

where $\mathbf{N_i}$ is number of professionals with education level i, $\mathbf{K_i}$ is weighting factor of the given educational level. Note that data on the educational level are given, as a rule, as a share of able-bodied population (T = 25-64 years old) with such education ($\mathbf{D_i} = \mathbf{N_i / N_T}$). Usually, the share of able-bodied professionals is roughly 50% of the entire country's population ($\mathbf{N_C}$). Therefore, formula (1) can be transformed approximately to (2):

$$\mathbf{I_{HC} = 0.5 \cdot N_C \cdot [K_1 \cdot (1 - D_{5B} - D_{5A}) + K_{5B} \cdot D_{5B} + K_{5A} \cdot D_{5A}] + K_S \cdot N_S}. \qquad (2)$$

This is a gross approximation, but we will refer the error to that of determining factors $\mathbf{K_i}$ in application to concrete countries. Here, $\mathbf{K_1}$, $\mathbf{K_{5B}}$, $\mathbf{K_{5A}}$, $\mathbf{K_S}$ are weighting factors for employees without higher education – with tertiary education levels 5B and 5A, and for researchers, respectively.

3.2. Relationship between GDP and human capital index I_{HC}

Let us find the relation between $\mathbf{I_{HC}}$ for different countries and their GDP. In this connection, we will introduce the "human capital multiplier" notion

$$\mathbf{M_{HC} = GDP / I_{HC}} \quad (3)$$

To find weighting factors K_i, we will use the following procedure. Let us find M_{HC} values for each country in the base group. Next, we will find the relative standard deviation (A_{ja}) of M_{HC} for the given group. Then we will vary the values of K_i and find their set, for which A_{ja} achieves a minimum.

When choosing the base group, one should take into account the statement made by Simon Kuznets that, among the factors defining the successful application of the accumulated experience of developed countries, the foremost one is the adequacy of the initial accumulated human capital [8]. Therefore, we will limit ourselves only to the biggest countries that have accumulated a significant intellectual potential.

These countries will not include those where $M_{\mathbf{HC}}$ differs significantly from $M_{\mathbf{HC}}$ in the base group because in this case the standard deviation will be big *a priori*, and an attempt to find K_i by minimising it will be abortive. The three biggest economies (the USA, the European Union and China) show a small spread of M_{HC} values and they, in principal, are sufficient to find three K_i factors (here the EU is considered an integrated economy). However, with such a selection of the base group, the relative standard deviation will be little for the given group and big for another set of countries. Therefore, an attempt to extend the base group composition is desirable.

Preliminary estimates have shown that Russia and Japan exhibit significant deviations of $M_{\mathbf{HC}}$ from those of the three biggest economies, with this difference for Russia being greater. Note also that reliable data on the education level are absent for India. Using any other separate country, for instance, Brazil as a fourth "reference point" would be hardly correct because its GDP is significantly lesser than that of the leading big three economies. Due to the factors stated, the following group of countries was included in the other base group: Japan, Brazil, Mexico, Turkey, and Indonesia.

To find optimal values of factors K_i, we calculated the values of $\mathbf{I_{HC}}$, M_{HC} and Δ_j with variation of K_i. In so doing, data on the level of education for 2005 [9, 10] were used and presented in the Table (GDP at PPP and 2011 dollars).

Data for optimising weighting factors K_i

	D_{5A}, %	D_{5B}, %	N_S, mln	N_C, mln	GDP, trillion dollars/annually
USA	30.0	9.0	1.4	319	15.5
European Union	17.0	7.0	1.6	503	15.4
China	3.5	6.4	1.3	1,369	13.5
Indonesia	2.8	6.6	0.02	253	2.1
Japan	18	22	0.66	127	4.4
Brazil	0.7	10.1	0.14	203	2.8
Turkey	0	10	0.072	77	1.3
Mexico	1.0	14	0.05	120	1.9

The difference in six years between the date of registering the education level and GDP is introduced to embed intellectual level growth into GDP growth. Next, the gradient descent method was used to find the values of K_i, for which the relative standard deviation (Δ_j) was minimal.

Estimates have shown that minimum Δ_j is achieved at $K_1 \approx 0.015$ and $K_{5B} \approx 0.25$. The optimal value of these parameters depends weakly on the base group of countries and K_S. Fig. 2 shows Δ_j vs. parameter K_S plotted for three and eight base countries (Δ_3 and Δ_8).

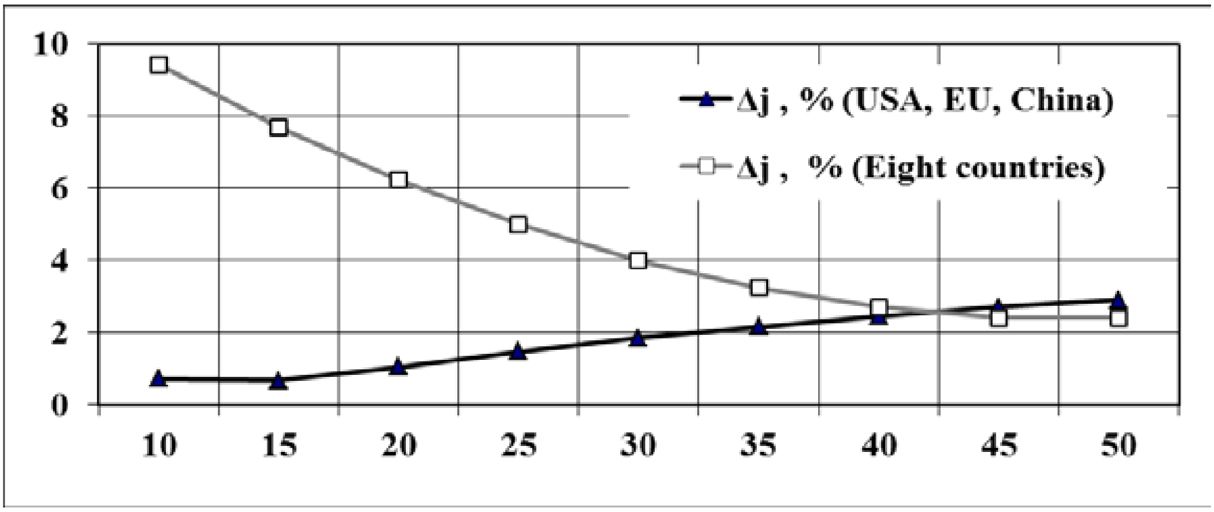

Fig. 2. Relative standard deviation of $M_{HC}(K_S)$

If we take eight countries, minimum Δ_j is achieved at the values of factors (4). In this case, $\Delta_3 \approx 2.8\%$ and $\Delta_8 \approx 2.4\%$; $M_{HC} \approx 125\ 200$ dollars/annually•hcu.

$$K_1 \approx 0.014,\ K_{5B} \approx 0.25,\ K_{5A} \approx 1.0,\ K_S \approx 48 \quad (4)$$

If one minimises Δ_j by taking the three biggest economies, the optimal values will be those in (5). In this case, Δ_3 = 0.04% and $\Delta_8 \approx$ 9.4%; $M_{HC} \approx$ 221 400 dollars/annually•hcu.

$$K_1 \approx 0.015,\ K_{5B} \approx 0.27,\ K_{5A} \approx 1.0,\ K_S \approx 12 \quad (5)$$

Since for forecasting purposes it suffices for the relative standard deviation to be about 3%, indices (4) or close ones of type (6) are more preferable.

$$K_1 \approx 0.015,\ K_{5B} \approx 0.25,\ K_{5A} \approx 1.0,\ K_S \approx 35 \quad (6)$$

Fig. 3 shows GDP values for several biggest world economies obtained by using formula (3) and indices (6) (here, $M_{HC} \approx$ 147 000 dollars/annually•hcu). Obviously, the forecasted GDP values as a whole are a sufficiently close fit to actual ones for the majority of chosen countries.

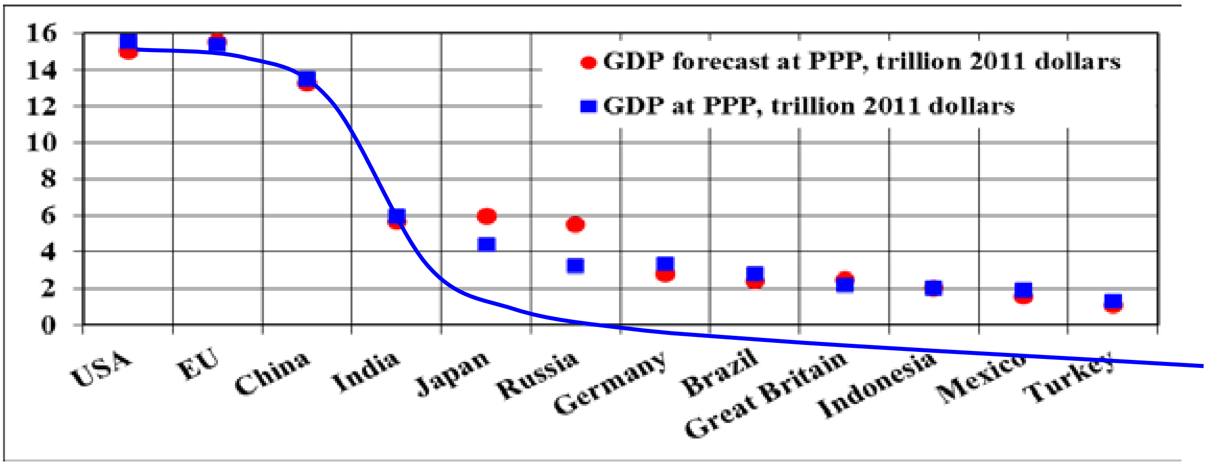

Fig. 3. Forecasted and real GDP in the biggest economies

3.3. Variation of multiplier M_{HC} value

Note that for Russia multiplier M_{HC} is significantly less than the mean value and equals $M_{HC} \approx$ 86 000 dollars/annually•hcu. Presumably, this is due to the substandard quality of education in Russia. However, the quality of the level of education in many developing countries [14], in which the effect of decreasing M_{HC} is absent, is yet lower. On the other hand, there are other countries that exhibit a substantial decreasing deviation of multiplier M_{HC} from the mean value, for instance, Japan. However, there is no doubt in the quality of education in these countries, though the share of these countries as per GDP in the world is relatively small.

3.4. Contribution of professionals with different education to a country's GDP

To interpret the obtained data for the coefficients of contribution to I_{HC} (4) and (5), let us exploit the fact that for the system of indices (4) with the multiplier M_{HC} = 125 200 dollars/annually•hcu (at PPP 2011) one person with higher education (K_{5A} = 1 hcu) contributes 125 200 dollars to a country's GDP annually. In this case, this person's schooling term is approximately 16 years. A specialist with no higher education is educated for about eight years and contributes to the GDP pro rata to one's K_1 = 0.014. A scientist advances in skills after gaining a higher education degree for about six more years and his/her contribution to the GDP is about 6 million dollars annually. The data for the three and eight economies are shown in Fig. 4 in the logarithmic system of coordinates.

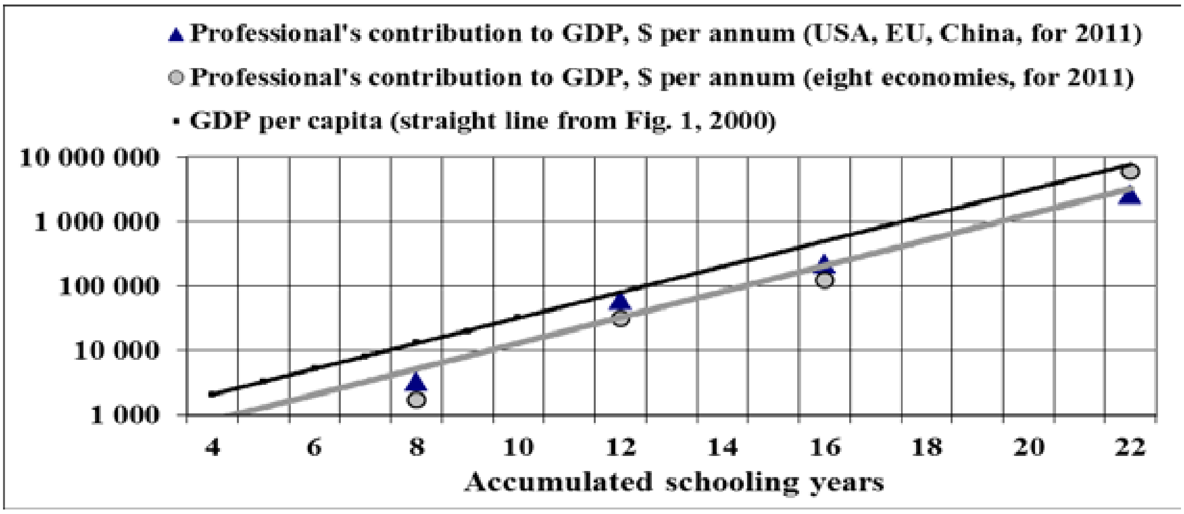

Fig. 4. GDP per capita vs. education of professionals

The values of the coefficients of contribution to GDP can be approximated with a straight line in the logarithmic system of coordinates. This means that the respective relationship is close to an exponential one. Its approximate formula (intl.$ 2011, at PPP) has the form

$$G_E = 125 \cdot 10^{E/5}. \quad (7)$$

Here E is the accumulated years of schooling; G_E is the annual contribution of a professional to the country's GDP. For example, with E = 16 years, $G_E = 125 \cdot 10^{3.2}$ = 198 100 dollars/annually. This relationship shows that each five years of schooling increase a professional's contribution to a country's GDP by approximately ten-fold, with an annual increase of 58%. Further, let us call this regularity the "law of educational exponent" or simply "educational exponent".

Recall that a professional's wages grow significantly slower (about by 10% per year of schooling [13]) than his/her contribution to the country's GDP. This is because the residual effect of GDP growth is realised outside the company that employs the professional (the externalities effect) owing to diffusion of innovation technologies and know-how.

The educational exponent is similar in essence to the graph in Fig. 1 (it is moved to Fig. 4 – the squares). Evidently, the data obtained by independent methods are indicative of a fact close in essence: *the contribution of a professional to a country's GDP grows exponentially with his/her qualification*.

4. Discussion of results

Note that the points in Fig. 5 can be used to plot a straight line in many ways and that the values of factors (4-7) have to be refined at a later stage. However, this does not alter the essence of the regularity found.

The human capital of countries is assessed in the study by summation of the scientific and education contribution with account of such factors as financing R&D, and so forth. A more detailed test of the validity of such summation and its impact on the GDP estimate error is required.

The fact that the contribution of professionals with higher education to the country's GDP exceeds that of less qualified workers many-fold indicates that for developing countries it would probably be more profitable to invest in higher education and R&D, than in the education of a lower level. It is advisable to validate this result against historical cases.

The effectiveness of training a big number of technicians in vocational schools or colleges is also doubtful. For instance, this is the case in Russia. However, even this result has to be validated by more focused research.

Conclusions

A simple method has been suggested for assessing the human capital of countries. The human capital index has been shown to help forecast countries' GDP with an acceptable error.

The contribution of a professional to a country's GDP has been found to grow exponentially with additional years of schooling.

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