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SOCIAL RESOURCES IN THE THEORY OF ECONOMIC GROWTH

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Abstract. Regularities of a production system development are discussed on the basis of the notion that progress in human economic activity is related to advances in the technological use of human effort and energy sources, which are regarded as the most important societal production resources. The concept of substitutive work of equipment P is introduced, which in all respects is equivalent to the efforts of people in production; it can be considered a service of capital, and is regarded as a value-forming factor, along with the traditional production factors. System output (value production) is defined as a function of three variables, two of which are: labour L and substitutive work P, are regarded as active sources of value, which allows us to introduce an energy measure of value, while physical capital K, as a production factor, plays a passive role. Under the assumption that the production system seeks to use all available social resources defined by circumstances external to the system, equations for production factors are formulated; they are also accompanied by equations for the technological characteristics of production equipment. The trajectory of the system development is determined by the characteristics of the system itself and the availability of social resources, which cannot be used completely simultaneously, which leads to a change of modes of development and fluctuations in output, i.e. business cycles. Using the example of the U.S. economy, it is demonstrated that the system of equations is able to describe the observed trajectory of development and output of the production system.

Keywords: Gross Domestic Product, Production Dynamics, Law of Substitution, Principle of Evolution, Value, Econodynamics, Energy.

1. INTRODUCTION

A fundamental problem of the economic growth theory is the development of methods for a consistent interpretation of wealth creation. Both in the Marxian era and at present times, there is no disagreement that labour (in a generalized sense, including the efforts of peasants, workers and employees), L, appears to be the most important source of value, but in an era in which production uses machines, the growth rate of output exceeds the growth rate of labour input, which demonstrates an increase in labour productivity and causes the need to introduce an additional, equipment-related, production factor into the theory. The introduction of physical capital K, as an estimate of the production equipment value, could not properly explain the increase in labour productivity, and it was proposed [1, 13] to use, along with its quantity K, the service of capital as a technological characteristic of installed equipment, so that the output of a production system in value units can be defined as a function of capital K and labour input L with some time-dependent adjustment A(t), taking into account the difference between the production factors used and the services rendered by them in the production of value

$$Y = A(t) f(L, K) \qquad (1)$$

Output Y and capital K are measured in monetary units, and labour input L is usually estimated in man-hours, but in fact we should have in mind the energy expenditures of a human body. We find this simple expression at the beginning of economic growth theories [1].

Considering the role of physical capital in the process of value creation, Joan Robinson [12] pointed out that machines and devices are set up to do certain things, to facilitate certain work, and therefore some characteristic of the fixed capital activity used is necessary. Analysis shows [7, 8] that the universal characteristic of the production process is the work of productive equipment P, which replaces human efforts and, as it is easy to see, can be considered as a service of capital (explanation of the details can be found in my monograph [10]). These considerations lead to a simple schematization in which the production system is seen as a set of equipment (measured by its value K) that obtains its ability to act by using labour L and productive energy P, so that the market value of the products produced is a function of the three production factors

$$Y = Y(K, L, P) \qquad (2)$$

By definition, the substitutive work P is in all respects equivalent to the effort of the workers. However, unlike the active factors L and P, which are the true sources of value, capital K is a passive production factor measured in monetary units of value, like output Y. Labour L and the substitutive work of external energy sources P are measured in energy units.

Later in the paper, the production function (2) will be instantiated (Section 2.2); the equations for the factors of production will be written assuming that the production system seeks to use all available social resources (Section 3.2). The final section (section 3.3) demonstrates, using the example of the US economy, that the established system of equations is capable of describing the observed trajectory of development.

2. PRODUCTION SYSTEM OUTPUT

2.1. Example of a produced value estimate. In the simplest case, the social production system is viewed as a single industry producing the gross domestic product Y, which is the value of all the things and services created by the production system produced per unit time [14]. To illustrate, Fig. 1 shows the GDP of the United States measured in different units of value.

2.2. Law of Value Production. In order to write down a concrete expression of the production function, note that the work of equipment P and labour L should be considered as substitutive each other, and the amount of production equipment universally measured by its value K should be considered complementary to the work of production factors L and P. Given that the description should be valid for any starting point of time (universality principle), and assuming also that production is homogeneous, that is, the law of value production does not change depend on the scale of the production,

$$Y = \begin{Bmatrix} \xi K, & \xi > 0 \\ Y_0 \dfrac{L}{L_0}\left(\dfrac{L_0}{L}\dfrac{P}{P_0}\right)^{\alpha}, & 0 < \alpha < 1 \end{Bmatrix} \qquad (4),$$

where L_0 and P_0 are the values of labour and energy inputs in the base year. Relations (4) between the output of the production system and the factors of production are universal, but the values α and ξ are interrelated characteristics of the production system and change when innovations are introduced, that is, the successive replacement of tools, materials, designs, aids and appliances, and other things by more advanced models from one point of view or another.

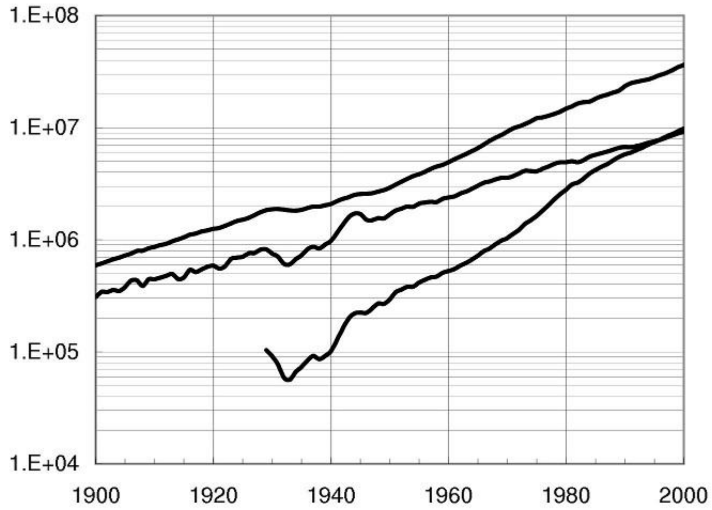

Fig. 1. *Value production in the U.S. economy.*
The short curve represents GDP in millions of current dollars, the middle curve represents growth in real income as measured by constant purchasing power monetary units -- in millions of 1996 dollars. The upper curve represents GDP values in millions of notional energy dollars, each equal to 50,000 joules (see Section 2.3).

The two formulations of the basic economic law (4) define two interpretations of the value production process. The first line of relation (4) relates output to the value of production equipment K (fixed capital), which gives rise to the claim of the productive power of capital, but the true sources of value are interchangeable production factors: labour input L and the work of external energy sources P. Labor input L is measured in man-hours, much effort has been expended to establish methods of estimating labour input that consider the nature of labour (hard or easy), the intensity of work and other factors establishing, after all, that the true measure of labour is work expressed in units of energy. The energy required for a working person can be more than twice the energy required for a resting person [11] and is equal to about $4{,}18\times10^5$ J/hour.

Estimates [2, 8] of the substitutive work P allow us establishing that P is a very small fraction of total energy consumption; for example, in the United States at the beginning of the last century this fraction was about 0.001, but increased to about 0.01 by the end of the century. By comparison, in Russia in 2000, the share of the substitutive work in total energy consumption was less than 0.001 [10, Tables A2 and A3]. The dimensionless ratio of substitutive work to labour effort estimate P/L determines the number of 'mechanical workers' per 'live worker' and can therefore be a significant characteristic of the technological process. For example, this ratio was greater than ten for US production at the end of the last century, while for Russian production it reached two in the late eighties but began to decline rapidly after 1990 [10, Fig. 2.9], indicating not only quantitative, but also technological degradation of Russian social production.

Ratio (4) represents a generalized law of value production: Smith-Marx's theory of labour value is supplemented by the law of substitution, which states that in value production, the work of outside forces of nature through production equipment replaces the efforts of people: labour functions in a complex as labour plus the work of equipment. The factors of production are interchangeable and, in this sense, equivalent, so that labour remains, ultimately, to use Adam Smith's words, "the only universal as well as the only exact measure of value, or the only standard by which we can compare the values of different goods at all times and in all places.

2.3. Energy measure of value. Gross domestic product is valued in monetary units. Money determines the current scale of value, which does not remain constant over time; this creates problems in real life and in theoretical consideration. The thermodynamic interpretation of production processes reveals that the concept of value is akin to the concept of entropy, which allows us to introduce an absolute energy measure of value [3].

The statement of the labour theory of value, that labour alone is the source of all created wealth and the absolute measure of value, is true for the early development of production (about the beginning of the second millennium AD), when the involvement of energy in production was insignificant [10, chapter 12]. In the general case, when the effect of substitution is taken into account, one would expect that an estimate of work, which includes the properly accounted work of those employed in production and the true work of the production equipment, would prove to be an absolute measure of value. To verify the validity of this assertion, Bodro and the author [3] compared the total work to produce value per unit time L+ P, measured in energy units, with the output Y. The ratio (L+ P)/Y determines the work required to produce a thing or service worth one unit of money or, in other words, the 'energy content' of a unit of money. Fig. 2 shows estimates of this value for the United States and the Russian Federation. The average 'energy content' of the 1996 dollar in the last years of the century (1960-2000) equals $1{,}4\times10^{5}$ Joules per dollar, while the average 'energy content' of the 2000 rouble in the same years (1960-2000) equals $0{,}12\times10^{5}$ Joules per rouble. The average 'energy content' of one dollar is 14 times greater than the 'energy content' of the rouble, which must correspond to the greater purchasing power of the dollar as compared to the rouble. The purchasing power parity of the rouble is approximately two times less than the official exchange rate, which was equal in those years to approximately 30 roubles per dollar, so comparing the calculated 'energy content' of the dollar and the rouble confirms the validity of introducing a universal energy unit of value.

The absolute measure of value can be set as some energy scale ς_{ref}. In order to establish the values of output in energy units, the values of total net work L + P in the corresponding years should be divided by the value of the conventional energy unit. Taking $\varsigma_{ref} = 50000$ Joules per dollar, we find the values of U.S. GDP in energy units shown in Fig. 1. Let us note the differences between the calculated dependence and the dependence of GDP in monetary units of constant purchasing power.

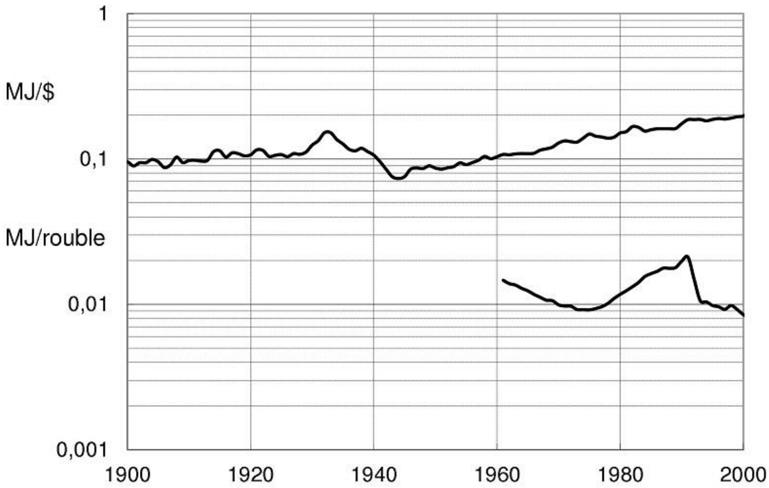

Fig. 2. *The 'energy content' of monetary units. The curves show the amount of work required to create a product worth one dollar in 1996 (upper curve) and one rouble in 2000 (lower curve) in different years. (According to the work of Bodro and the author [3] with clarification of values for Russia)*

3. SOCIAL PRODUCTION DYNAMICS

3.1. Social resources. The development of the production system and the increase in output is linked to the ability to use labour and productive energy in production, which are the most important social resources and the true sources of wealth. The natural environment as a source of raw materials for industry and the production infrastructure are also important social resources.

3.1.1 Participants in production processes. When considering economic phenomena, all the available population is taken into account, but economic theory nevertheless distinguishes a group of people who can actively participate in production, i.e. economically active people. Their number is usually about half of the entire population, or a little more for developed countries. The aggregate labour input of these people L is the most important production factor, the role of which has been thoroughly investigated in political economy and neoclassical economics. Labour input L is measured in man-hours, but adjustments corresponding to the nature of labour (heavy or light), the intensity of work, and other factors are taken into account, so that the true measure of labour should be the work (in units of energy) performed by those employed in the production process.

3.1.2 Energy in production processes. The production system plays the role of a mechanism that draws energy from a variety of sources; there are the remnants of former biospheres among them: forest, coal, oil; direct and indirect solar energy in the form of air and water flows; and the energy of nuclear fission and fusion. This energy, through various adaptations, is used to transform substances of the natural environment into objects of the artificial environment creating useful complexity for people [4, 5]. Of the total amount of primary energy, we can single out the small part that is used to actuate various devices allowing labour efforts to replace by the work of production equipment.

The bases for proposing the use of energy for production purposes lie in a “storehouse of knowledge”, which seems useless until it is used in routine production processes. Just as the supply of labour can be related to the population, which can be seen as the reservoir from which labour emerges, the supply of substitutive work P can be related to the knowledge archive, which plays the role of the pool (reservoir) from which energy use proposals emerge. Indeed, one can find a large number of brilliant examples of the 'conversion' of knowledge into ways of using energy in the history of technology. As an example, we can point to the invention of steam engine or internal combustion engine.

As a production factor, substitutive work P gets a special price. The use of energy sources around us is related to the designing and use of production equipment. The amount of equipment used, which is needed to support the substitutive work P, must be estimated as μK (μ is retirement rate), so that the price of the substitutive work, as a production factor, is determined by the expression

$$p = \frac{\mu K}{P} \qquad (5)$$

This value is different from the price of energy carriers as ordinary intermediate or final products.

3.1.3. Artificial and natural environment. From a philistine perspective, the process of production is the process of transforming the natural materials, which humans find in the natural environment, into finished and unfinished objects. Indeed, under such an approach, the products created (housing, food, clothing, buildings, machines, vehicles, sanitation, household appliances, and other consumer items) can be seen as a result of converting 'wild' natural forms of substances into 'useful' forms.

In addition to the natural environment as a source of 'wild' substances and energy necessary for production, humans are surrounded by artificial things created by humans themselves over many centuries (structures, various machines, works of art, principles of organization, results of scientific research, and many others) which, in one way or another, prove useful to humans.

Particular attention in economic theory is paid to production equipment, which represents the material realization of technology; it was invented and installed to perform various operations. The value of production equipment K is defined as fixed production capital. Production equipment is passive in itself: its function is to involve in production the various means of employing labour L and substitutive work P, which are the true sources of value. A characteristic of this ability of capital is the amount of labour and substitutive work per unit (at cost) of production equipment set up

$$\lambda = \frac{\Delta L}{\Delta K}, \quad \varepsilon = \frac{\Delta P}{\Delta K} \qquad (6)$$

An increase in basic productive capital leads to an increase in output, as shown in the first line of relations (4), and this has given rise to the myth of the productive power of capital in a broad sense. If you have productive stocks, then you get dividends; if you have money lying in the bank, you get interest. Stocks and money are the capital in broader sense. But money and stocks are only symbols producing nothing without the tremendous work on producing value within the capitalist organization of the national economy. The mystical power of capital to bring profit follows from the rules of distribution of the social product created by people in work and substitutive work. Only the efforts of people (given the law of substitution) lead, as we discussed in section 2.2, to an increase in value, that is, to the creation of wealth**.**

3.2. Dynamics of production factors.

3.2.1. Balance relationship. The amount of production equipment or fixed production assets universally assessed by their value K satisfies the known balance relation

$$\frac{dK}{dt} = I - \mu K \qquad (7)$$

Where *I* is productive investment, i.e. the part of gross domestic product that is accumulated in the tangible form of productive equipment, while the other part of gross product goes to consumption and non-productive strategic accumulation in tangible and intangible form, which is also necessary for the functioning of the social system. The second summand in the right-hand side of equation (7) describes the reduction of capital due to retirement from service with a disposal or depreciation coefficient μ. Note that investment is not only and not so much about money. Investments must ultimately be tangible: they are constructions, new equipment, and new technology.

Expansion of production characterized by changes in production assets (accumulated value) requires additional labour and substitutive work of equipment, and the current state of technology determines how much labour L and work of external sources (wind, water, coal, oil, and other) P is to be attracted to make the installed equipment working. Dynamics of production factors is written down [6] as a pair of balance equations

$$\frac{dL}{dt} = \lambda I - \mu L, \quad \frac{dP}{dt} = \varepsilon I - \mu P \qquad (8)$$

The first terms in the right-hand side of these relations describe the necessary increase in consumption of factors of production when investment I is introduced, which manifests itself as a driving force of development. The second terms in the right-hand sides of equations (8) reflect the reduction of production factors when some equipment is removed or worn out. The reduction in the amount of production equipment (capital) is characterized by the retirement rate μ.

3.2.2. Dynamics of technological coefficients. In equations (8) there are technological characteristics of production equipment, which are convenient to use in dimensionless form

$$\bar{\lambda}(t) = \frac{K}{L}\lambda, \quad \bar{\varepsilon}(t) = \frac{K}{P}\varepsilon \qquad (9)$$

The technological coefficients determine the necessary quantities of labour and productive energy inputs per unit of the introduced equipment (in value terms), respectively. If quantities (9) turn out to be less than unity, this means that labour- and energy-saving technologies are introduced at that point in time**.**

Note that the combination of the technological coefficients

$$\alpha = \frac{1-\bar{\lambda}}{\bar{\varepsilon}-\bar{\lambda}} \qquad (10)$$

determines the relationship between the growth rate of production factors, which can be convinced by excluding the dimensionless investment $\frac{I}{K}$ and the retirement rate μ from equations (7) and (8). More significantly, the combination (10) is nothing but an index α in the production function (4), which can be seen by differentiating relations (2) by time and using equations (4), (7), and (8). The index α is directly expressed through the technological characteristics and is therefore called the technological index, which can be evaluated independently.

It is assumed that the technological coefficients change in such a way that the available social resources are used in the fullest possible way. This determines the relaxation equations for the dimensionless technology coefficients

$$\frac{d\bar{\lambda}}{dt} = -\frac{1}{\tau}\left(\bar{\lambda} - \frac{\tilde{\nu}+\mu}{\tilde{\delta}+\mu}\right), \qquad \frac{d\bar{\varepsilon}}{dt} = -\frac{1}{\tau}\left(\bar{\varepsilon} - \frac{\tilde{\eta}+\mu}{\tilde{\delta}+\mu}\right), \qquad (11)$$

where τ is the time of putting production equipment into operation, i.e., the time of transition from one technological situation to another. The symbols $\tilde{\delta}$**,** $\tilde{\nu}$ and $\tilde{\eta}$ denote the possible (potential) growth rates of production factors: capital K, labour L, and productive energy P, respectively. In other words, the rate of growth of social resources is introduced into consideration: $\tilde{\nu}$ is the rate of growth of labour, $\tilde{\delta}$ is evaluated as the available production possibilities, $\tilde{\eta}$ represents the possibilities of using productive energy determined by technological developments**.**

3.2.3. Investment and the three development modes. Equations (7) and (8) include investment I, upon the assignment of which we should take into account the constraints imposed by internal (shortage of available production and ensuring the necessary level of consumption) and external (availability of labour and energy) reasons. Investments implemented, I, are obviously determined by the competition between the capabilities of the production system on the one hand and the availability of labour and energy on the other. In the case where the production system seeks to use all available social resources, we should write for investment

$$I = (\delta+\mu)K = \min\begin{Bmatrix} (\tilde{\delta}+\mu)K \\ (\bar{\nu}+\mu)K/\bar{\lambda} \\ (\bar{\eta}+\mu)K/\bar{\varepsilon} \end{Bmatrix} \qquad (12)$$

Obviously, the rates of real growth of production factors, i.e. δ, ν and η, do not exceed the rates of potential growth $\tilde{\delta}$, $\tilde{\nu}$ and $\tilde{\eta}$ of the corresponding factors and differ from them. According to the three possibilities written in equations (12), there are three modes of economic development. The first line of equations applies to the case of scarcity of production possibilities and abundance of labour force L, available energy P, and raw materials. The second line describes the situation in the case of scarcity of labour, abundance of production possibilities, energy and raw materials. The last line of equations applies to the case of shortage of energy and abundance of production possibilities, labour, and raw materials.

When studying the functioning of the national economy, cycles of different duration have been found; short business cycles in social production are associated with the existence of alternative modes of production system functioning [9]. In the US, the second and third modes are realized alternately in terms of relation (12) with a period of about four years [10, sections 5.4.2 and 6.6.2]. Apparently, the first mode is also realized in Russia, indicating a lack of production possibilities. In order to build a mathematical model of the phenomenon and to analyze the problem, it is necessary to consider together the dynamics of production and money circulation.

3.3. Trajectories of development.

3.3.1 System of equations for a production system evolution. The relations (7), (8), (11), and (12), written in the previous sections, form a system of equations that describes changes of production factors K, L, P together with evolution of characteristics $\bar{\lambda}$, $\bar{\varepsilon}$, α of a production system, which is here considered in the most rough approximation as a single branch of production. Given the potential growth rates of social resources: production equipment $\tilde{\delta}$, labour $\tilde{\nu}$**,** and productive energy $\tilde{\eta}$, as well as the time of transition from one technological situation to another and the depreciation coefficient μ, the system allows us to determine the trajectory of evolution of a production system (production factors and technological coefficients), after which it is not very difficult to calculate by formulas (4) the time dependence of value production**.**

3.3.2. Example of a development trajectory. Next, we turn to the case of the development of the United States economy considered earlier [7], for which we take the values of the fixed capital retirement rate μ to be known ($\mu \approx 0{,}02$ before 1925 increasing to 0.068 for 1925 - 1999), the time of technological transition is assumed to be $\tau = 1$ (one year). The rate of potential growth of labour costs $\tilde{\nu}$ is actually the growth rate of the labour force; the values $\tilde{\delta}$ and $\tilde{\eta}$ are not directly estimated, but they were set somewhat higher than the real rate of development, so that the obtained dependencies of production factors correspond to the empirical ones. In fact, this procedure reconstructs the values of social resources for the U.S. production system.

Fig. 3 shows the values of the production factors K, L, P and the technological index α calculated with the specified values of the system parameters and given rates of potential growth of capital, labour costs, and substitutive work.

The calculated values of production factors differ from the estimates of social resources, and correspond to empirical estimates, while also determining the technological coefficients $\bar{\lambda}$, $\bar{\varepsilon}$, and the technological index α.

The study reveals the pulsation of technological coefficients and the change of development modes associating with the existence of alternative types of production system functioning. In the period under consideration, there is a change of types of development in U.S. production during a time period of about four years. Production processes proceed with an abundance of investment and raw materials, but with a shortage of labour, when $\frac{d\bar{\lambda}}{dt} < 0$, or with a shortage of substitutive work, when $\frac{d\bar{\lambda}}{dt} > 0$; the period with the marginal use of labour is replaced by a period with the marginal use of productive energy, when small cycles of development take place. The change of modes causes the rate of real growth of productive factors to be less than the given rate of growth of social resources.

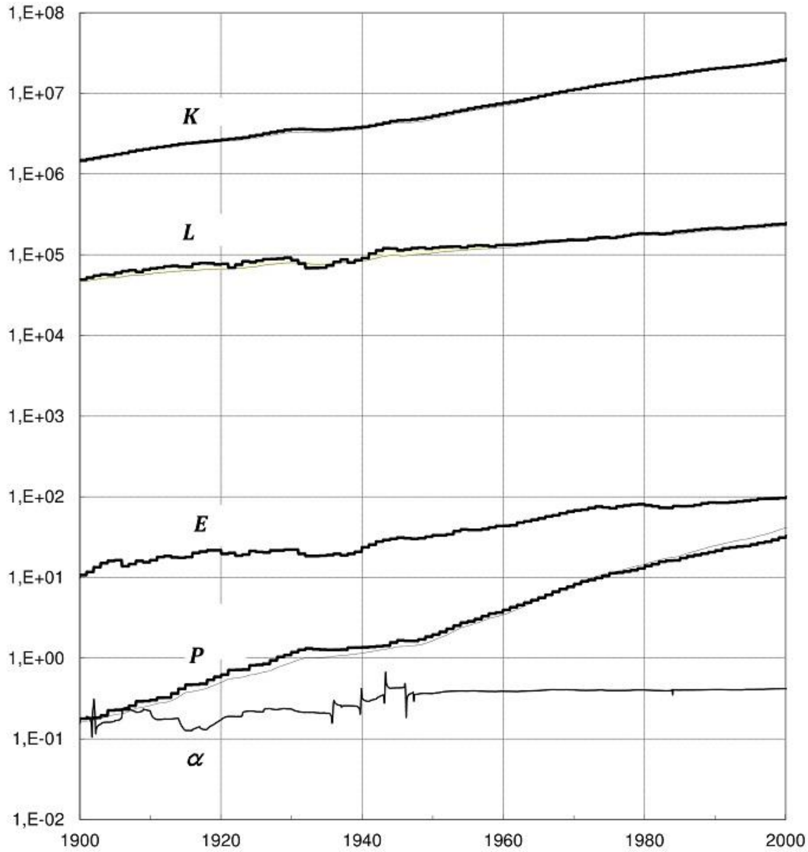

Fig. 3. *Production factors in the U.S. economy. Value of basic production equipment (fixed capital) K in millions of 1996 dollars; labour input L in millions of man-hours per year; primary energy E, substitutive work P in* 10^{18} *joules per year, and the dimensionless technology index α. Bold lines represent empirical values, while weak lines show the results of calculations K, L, P, α; primary energy values are shown for illustration purposes.*

Now, after we have calculated the production factors and the technological index, we turn to the law of value production (4), and find the dependence of output on time, depicted in Fig. 4 with a thin line compared to the empirical values of GDP depicted with a thicker line. We can see that the calculated trajectory virtually coincides with the actual dependence of GDP depicted earlier in Fig. 1. This result indicates the validity of the value production law (4) and the consistency of its system of equations.

The described system of evolution equations allows us to analyze the past and current functioning of the production system, but the ability to apply these equations to forecast output is limited. In order to make real predictions, it is obviously necessary to have an idea of the future availability of production factors and anticipated technological changes, which determines the possible scenarios for the development of the production system. However, methods for directly calculating and predicting the rate of potential growth of production factors have not been developed enough to offer them for use in applications. In order to promptly overcome this kind of difficulties, simpler methods for constructing development scenarios based on a simpler reduced system of evolutionary equations have been developed and are used [10, chapter 6].

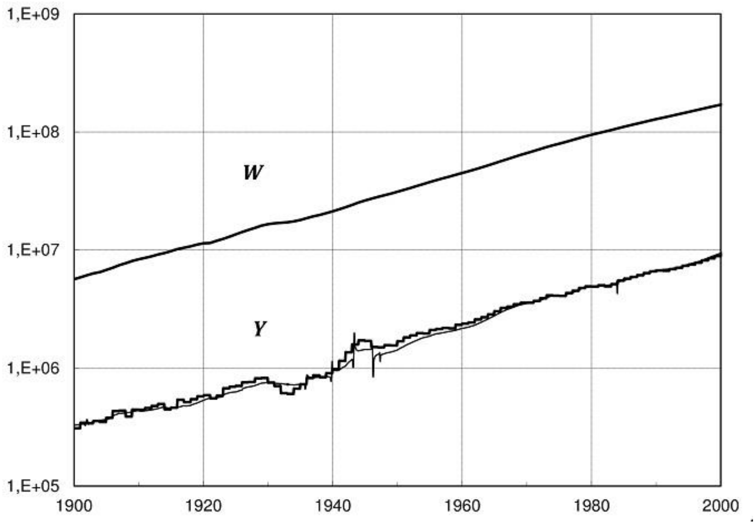

Fig. 4. *GDP and National Wealth of the United States. Total National Wealth (top curve) and Gross Domestic Product (bottom: bold curve - empirical values, thin curve calculated from Equations 4). All values are in millions of 1996 dollars. Нет ссылки на этот рис!*

4. CONCLUSION

Our reasoning (see also monograph [10, Chapter 6]) establishes that the evolution of the production system is determined, after all, by the ability to attract additional resources, which are determined by the position of the human population in the natural environment. The ability to use energy flows has a decisive influence on the functioning and development of the population. The trajectory of the production system is determined by the desire of the system to use all available resources. This behavior of the system is the result of summating the efforts of many entrepreneurs striving to obtain the greatest profit. Human effort is, of course, the main driving force, but, provided that $\bar{\lambda} < 1$, the efforts of the workers are partially replaced by the work of machines driven by third-party energy sources, resulting in increased productivity. In this case, the leading principles of economy of live labour remain as follows: those who have substituted the labour input with a greater value of the work of machines win. However, the law of saving energy does not exist; at least it remains in the shadow of the law of saving live labour.

The theory allows us to develop methods for analyzing and constructing realistic development scenarios while taking into account technological capabilities and the availability of production factors. The output of a production system is universally related to the factors of production L and P and the technological index α; these values, in turn, are determined by investment and the technological capabilities of production equipment. In contrast to theories based on the notion of the productive power of capital [1], the formalism under discussion does not contain any arbitrary fitting quantities.

Econodynamics continues the tradition of considering the human population as a natural phenomenon accessible to natural-scientific analysis, a feature of which is the establishment of causal relations of phenomena. Before the differentiation of sciences, this was the natural method of consideration, which was followed by Malthus as one of the founders of this tradition in demography, and by Marx as one of the founders of the modern science about society. The natural-scientific approach rests on empirical justification and therefore the theory is based on the basic economic law in the form of (4), the justice of which was confirmed when considering the production system development in the United States.

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