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Ecological Restrictions of Modern Economic Growth

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Abstract—The article analyzes the ecological restrictions on modern economic growth. The conditions and criteria of its transformation into uneconomical (wasteful) growth are determined. The economic damage from human impact on the environment is assessed based on the existing approaches.

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The long-term trend of global economic growth is largely determined by specific competitive advantages and limitations on the development of individual national economies. These changes in the competitive potential lead to the change in leaders in economic activity in the global economy. Economic growth factors change, and new restrictions on the growth of national economies are formed. The saturation of the market with various goods in economically developed countries, long-term depopulation, a significant share of the population at retirement age, and the high level of ensuring basic needs limit the current domestic demand and, consequently, the dynamics and space of growth in developed economies.

The dynamics of the growth of the Gross World Product (GWP) over the past 50 years has slowed down (Fig. 1 built according to [1]). The presently accumulated mass of production facilities in the global economic scale surpasses the current level of total demand. Attempts to stabilize economic growth through monetary factors, which is done by the financial institutions of developed countries, show their groundlessness in the medium-term and long-term outlook and lead to considerable functioning expenses of the financial sector in the global scale.

The fundamental limitation on modern economic growth is the possibility that it will transition into uneconomic growth (wasteful growth), when the marginal costs of economic growth, which are determined by the value of economic damage, begin to exceed its marginal utility. This hypothesis is confirmed by the consequences of the economic policy pursued in the developed countries, which is aimed at increasing the total demand and often results in the inefficient use of natural resources.

The dependence of the amounts of harmful emissions on the scale of economic activity is obvious. In particular, Fig. 2 [2, 3] reflects the relationship between the share of the GDP of individual countries in the GWP and the total amount of the most widespread air pollutant emissions (carbon monoxide, nitrogen oxide, methane and sulfur hexafluoride).

With a certain degree of conditionality, two groups of countries with varying degrees of this dependence can be distinguished among the Big Twenty. The national economies of China, Russia, India, and

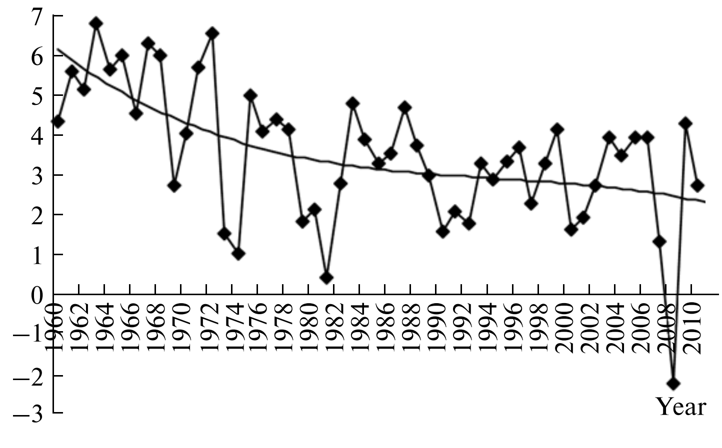

Fig. 1. Growth rate of the GWP (%).

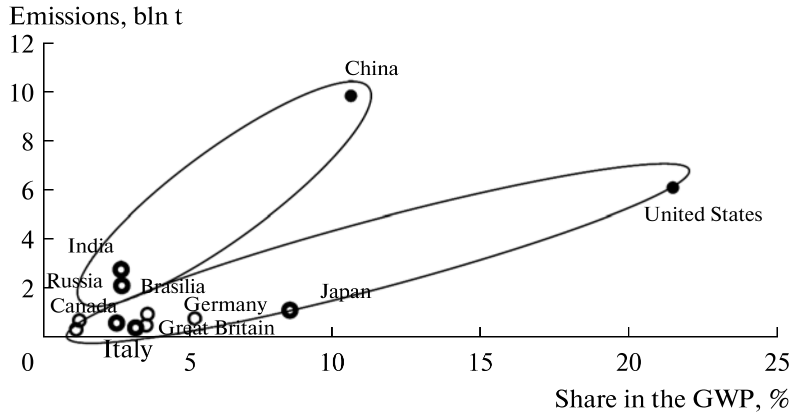

Fig. 2. Share of GDP of individual countries in GWP and total amount of most widespread air pollutant emissions.

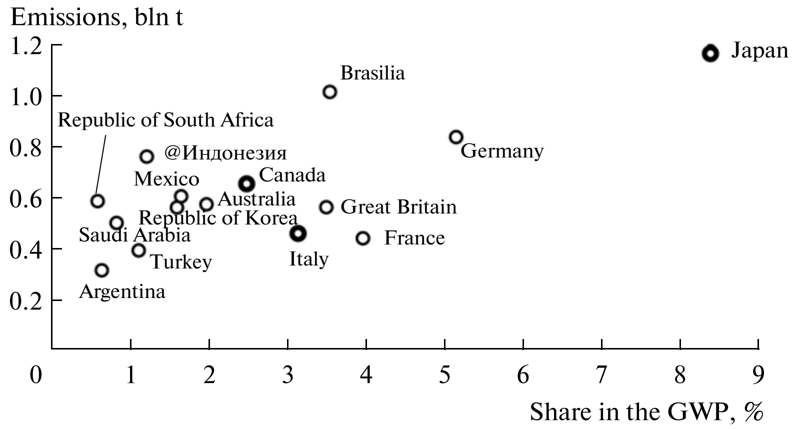

Fig. 3. Share of the GDP of the Big Twenty countries in GWP and total amount of most widespread air pollutant emissions.

Indonesia, unlike other members of the union, show the more significant dependence of the amount of pollutant emissions on the scale of economic activity (Fig. 3) [2, 3].

There is no common approach to assessing the amount and dynamics of human impact on the environment in the process of economic growth. Most researchers argue that the strength of this impact is gradually increasing. The question about the rate of this increase remains debatable.

The factorial similarities between the models of economic growth and human impact on the environment have been reflected in using the similar analytic tools for modeling these phenomena. Some of these analogous approaches are shown in Table 1.

The *IPAT* model that characterizes the increasing growth rate of human impact on the environment in proportion to the growth in the GWP is the most illustrative. This dependence follows from the quality of the technological growth in the course of which, first, nonrenewable natural resources are depleted; second, renewable resources are excessively exploited at a rate that exceeds the capacity of their recovery; and, third, pollutant emissions surpass the assimilation capacity of the environment.

As applied to the *IPAT* model, the growth rate of the impact is determined according to the following formula of the differential function with several variables:

$$\frac{dI}{I} = \frac{\partial I}{\partial P}\frac{dP}{I} + \frac{\partial I}{\partial A}\frac{dA}{I} + \frac{\partial I}{\partial T}\frac{dT}{I}. \quad (1)$$

For example, we estimate the rate of the environmental impact of lead emissions in car exhaust from 1946 to 1967 with allowance for the fact that the population during this period increased by 41%, the consumption of transport services measured as a vehicle traffic mile per man grew by a factor of two, and lead emissions per traffic mile increased by 83%. The cumulative growth rate of the impact of lead emissions (1.41 × 2.0 × 1.83) was 516% [5, p. 369]. In other words, the growth rate of the environmental impact proved to be multifold compared to the growth rate of each of the influencing factors. This example demonstrates that the effect of growth on the environmental

Table 1. Modeling economic growth and human impact on the environment

Economic growth models	Models of human impact on the environment
1. Cobb-Douglas production function [4]: $Y = AK^{\alpha}L^{1-\alpha}$, where Y is the calculated index of growth in output; α is the parameter determined based on statistical data; parameter A (Total Factor Productivity) is the coefficient that reflects the level of total technological productivity	1. Formula of the physical human impact on the *IPAT* environment [5, p. 367]: $I = PAT$, where I is the impact, P is the population, A is affluence, well-being, and T is the technology.*
2. R. Solow model [6]: $Y = F(K, L) = K^{\alpha}L^{1-\alpha}$, where Y – is the total output that depends on two factors: K (capital) and L – (labor).	2. Strength of the impact on the environment (I) depends on the assembly of interrelated factors: the level of per capita consumption (C); technologies used to produce goods and services (T), and population (P). This dependence is described by the formula [7] $I = CTP$
3. The model of M. Kremer [8], who is a follower of the neoclassical tradition of using the production function: $GWP = AP^{\alpha}N^{1-\alpha}$, where A is the level of technology, P is the number of employees, and N is the land resources used.	3. Level of human impact on the environment is caused by the area of a biologically productive land used by an individual. This dependence is described by the term "environmental footprint" [9].

* The model distributes the level of ecological responsibility of the countries, which differ in the level of development. The developing countries with high population growth rates are responsible for the population restriction measures. The societies of affluence must control an irrational (excessive) growth in consumption. Industrial countries with a transformed economy are responsible for the high concentration of environmental pollutant emissions generated by resource-intensive technologies T.

impact in proportion to the increase in the scale of economic activity.[1]

The multiplicative impact of the population growth on the environment can also be substantiated by the following method. The key parameter in determining the level of human impact on the environment in the *IPAT* model is the population. The output of goods and developed technologies are derivatives of the population's needs. If the impact parameter is understood as the negative consequences of technological disasters generated by human activity (e.g., pollution level), then the *IPAT* model can be represented as follows:

$$\begin{aligned} Pollution\ Level &= P\frac{GWP}{Capita}\frac{Pollution\ Emission}{GWP} \\ &= P\frac{Pollution\ Emission}{Capita}. \end{aligned} \quad (2)$$

[1] The author's assertion about the growing impact on the environment in proportion to the growth in the scale of economic activity can be viewed as controversial because the data on the increase in the global GDP and amount of emissions since 1960 show that a 1% increase in the GDP accounts for about 0.75% of the increase in carbon emissions. In other words, emissions grow at a slower rate. At the same time, as the data in the last decade show, the growth rate of emissions also decrease much slower than the growth in GDP (actually, 1% of the slowdown in GDP growth accounts for about 0.5% of emission reduction; see, e.g., http://ecoportal.su/news.php?id=65459). Thus, even in a period of stagnation or recession of the world economy, the growth in emissions can continue creating additional long-term threats (editors' note).

The population can be expressed by the function $P(t)$ by the argument of the time factor t. Then, expression (2) is given as follows:

$$\begin{aligned} &Pollution\ Level \\ &= P(t)\ Pollution\ Emission\ Per\ Capita\ (P(t)). \end{aligned} \quad (3)$$

Functional dependence (3) is nonlinear. The impact on the ecosystem also increases both with the increase in the population ($P(t)$) and growth in pollution emissions per capita ($P(t)$) or in case of the excess of the growth rate for one of the variables over the decrease rate for another.

In order to assess the dynamics of the population, we use the Verhulst logistic equation [10]

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right), \quad (4)$$

where P is the population, t is the time factor, r is the annual population growth rate (%), and K is the maximum possible population.

The equation is solved by the logistic S-shaped function

$$P(t) = KP_0e^{rt}/(K + P_0(e^{rt} - 1)), \quad (5)$$

where P_0 is the population at the beginning of the period and

$$\lim_{t\to\infty} P(t) = K.$$

Using (5) to assess the population dynamics yields good results, which is illustrated by Fig. 4 and built according to the data [11] at K equal to 10 bln people as of the end of 2200 [12] and the calculated parameters P_0 = 222.86 mln people (1867) and r = 0.032 (3.2%).

To transform the indicator "the level of a man-made disaster impact" into the assessment of the economic damage from environmental pollution (ED), we introduce a constant coefficient that characterizes the annual economic damage from man-made disasters generated by the activity of one person (in dollars).

$$ED(t) = \mu[KP_0e^{rt}/(K + P_0(e^{rt} - 1))]. \qquad (6)$$

The neoclassical economic theory explains why the marginal costs related to the growth in the GWP can exceed its marginal benefits. In accordance with the law of the diminishing marginal utility, the total value of economic growth increases more and more slowly. The law of increasing marginal costs explains the progressive rate of increase ~~in the latter,~~ in proportion to the growth in economic activity. Thus, the global economy faces the need to compensate for the economic losses from disasters and catastrophes, spending more and more resources to overcome their consequences and a decreasing share of resources to reproduce material values and improve the quality of life [13].

The trends revealed based on the graphical analysis of the data on damage as a result of large technological accidents and natural disasters [14] and the dynamics of the GWP [15] confirm the theoretical conclusions regarding the decreasing growth rate of the total utility of economic growth and increasing growth rates of marginal costs (Fig. 5). In 10 years (2000–2009), the economic damage from man-made accidents and natural disasters totaled 1.05 tln USD, and it has reached the value of 0.904 tln USD for only 4 years of the new decade (2010–2013) [14]. This rate dynamics of damage from industrial accidents and natural disasters can be defined as an exponential dynamics.

This conclusion is also confirmed by the data from the Information Analytical Carbon Dioxide Center at the Environmental Science Department of the National Laboratory (Tennessee, the United States) on the global carbon dioxide emissions[2] (Fig. 6 built according to [15]), as well as by the similar statistics on separate national economies, in particular on Russia's economy (Fig. 7).

The growth rate of production and consumption waste in Russia in 2002–2012, which was calculated based on the data of Table 2 [16, 17], was 245.7 %, while the growth rate of the physical volume of GDP for the same period was 157.1%. The share of used and neutralized production and consumption waste in the

[2] Emissions from production of electricity and fuel, liquid and solid fuel, processing industry, construction, transport, sphere of commercial and public services and housing are meant.

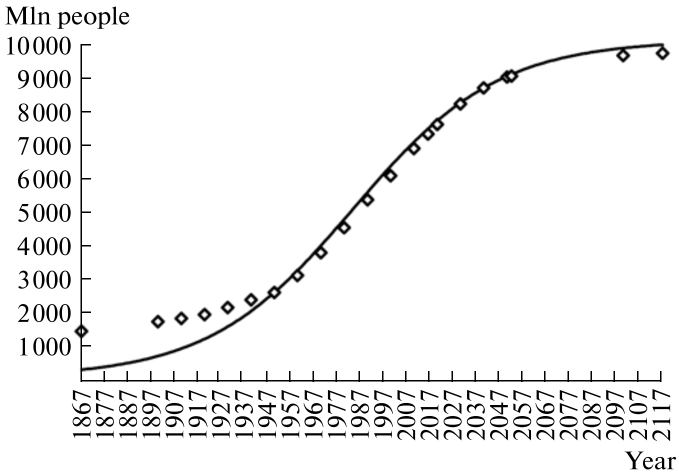

Fig. 4. Modeling world population according to Verhulst equation (—); (–◇–) Forecast of the world population accouding to the U.N.O. data.

total waste was about 50% almost during the entire study period.

Even with allowance for the decrease in the index in 2008–2009, the exponential trend for the growth rate of production and consumption waste (see Fig. 7 built according to [16–18]) can be fixed. The waste indices, which remain after deducing the amounts of used and neutralized waste from the amounts of production and consumption waste, also shows a steady growth.

When forecasting the environmental constraints to the growth of the domestic economy, it must be taken into account that the Russian natural climatic and spatial geographical features will always determine the differences in the industrial and technological structure of the Russian economy from the analogous parameters of, for example, the European countries. Even if the most modern technologies are used, the economic growth in Russia will have a specificity of using larger volumes of mass resources (energy, metal, building materials, etc.) and, hence, making a more intense impact on the environment.

Naturally, a gradual slowdown in the growth rate of the world's population will limit the negative impact of human activities on the environment. However, calculations show that, if the increasing growth rate of economic damage from environmental pollution (ED) and the decreasing growth rate of the GWP persist, the absolute values of these parameters can equal in prospect. Thus, the economic growth, which sharpens the social and environmental problems of economic inequality and poverty, as well as environmental pollution, is inwardly unstable and, in the absence of technological improvements, can transform into uneconomic growth. In accordance with the marginalist 1
theory, we can state that economic growth is efficient

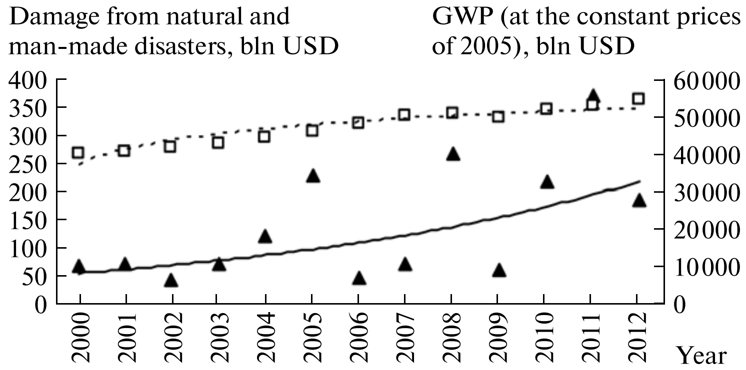

Fig. 5. Trends of GWP dynamics (right scale) and economic damage from natural and man-made disasters: — exponential; - - - logarithmic GWP.

until its marginal utility equals the marginal cost of economic damage.

In accordance with the international data, the vulnerability of objects that is related to the material damage from accidents of various nature grows every year on the average by 10% [19]. More than the 10% of the annual growth in economic damage is typical, in particular for the U.S. economy, where the total damage from the largest disasters has increased by a factor of eight [13] over the past 20 years. Figure 8 graphs the forecast scenario of the 10% annual growth in the ED and growth in the GWP, which was built based on the data [20, 21]. Under the assigned conditions, the maximum effect of economic growth falls to the 2040s. In the future, the volumes of economic damage will begin to grow rapidly and, by the end of the 2060s, they will become equal to the volume of the GWP. Naturally, this is just one of the possible scenarios based on the hypothesis of an uneconomic growth. In particular, if the total productivity of the production factors grows, the forecast will be more optimistic.

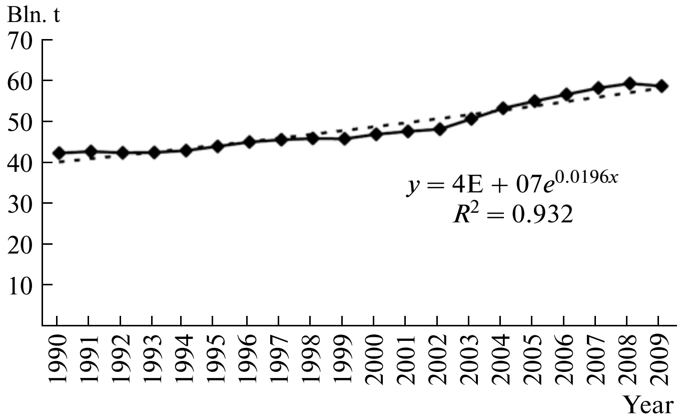

Fig. 6. Total world amounts of emissions: –◆– CO_2; - - - exponential.

The impact of economic damage from environmental pollution on the quantitative estimate of an economic growth rate is not confined to only the valuation of the negative consequences of harmful emissions. The calculation is more complicated here. It includes the cost of inputs for the elimination and prevention of man-made damage to the environment, implementation of pollution charges, the formation of an incentive system for encouraging nature protection activities and expenses for restoring people.

The format of studying the nature of an uneconomic growth implies an analysis of the dynamics of its constituent economic activities. In our opinion, the ratio of waste from the production and consumption of economic goods to the amount of their production for a particular kind of economic activity (hereinafter, the index "waste/economic benefits") is one of the most indicative criteria of this growth. If the value of this index becomes greater than ~~unity~~ 1, then economic growth transforms into an uneconomical growth, i.e., wasteful growth when growth costs begin to exceed growth benefits.

The results from analyzing the statistical data on the most significant type of economic activity in Russia (production of fuel and energy minerals) visually demonstrate the uneconomic nature of growth in this type of activity (Fig. 9, built according to [16, 22]).

In a deficit economy, it was important to produce more goods, and the GDP index actually was a defining measure of the economic well-being of society. Currently, the countries of relative affluence, which often have unacceptable costs related to economic growth, defeat the purpose of using this index as the main criterion of the level of national welfare. The economic growth rates gradually lose this function in the traditional meaning. Of course, the economy continues to be a material platform for livelihood and public progress, but already along with other spheres of human activity. In this context, the theoretical paradigm of economic growth that makes it necessary to

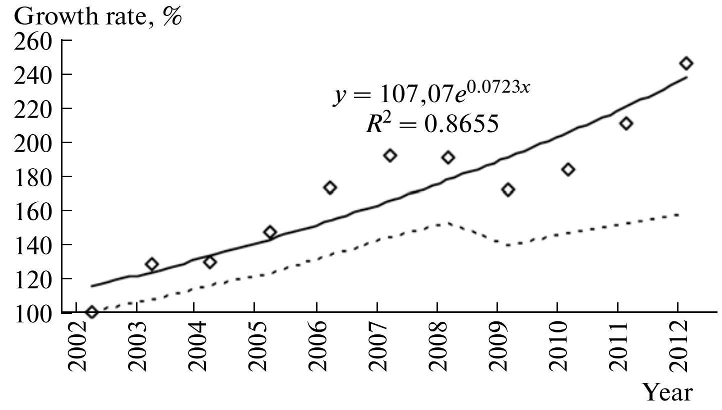

Fig. 7. Growth rates (by 2002): production and consumption waste (◇); physical volume of GDP (- - -) in Russia.

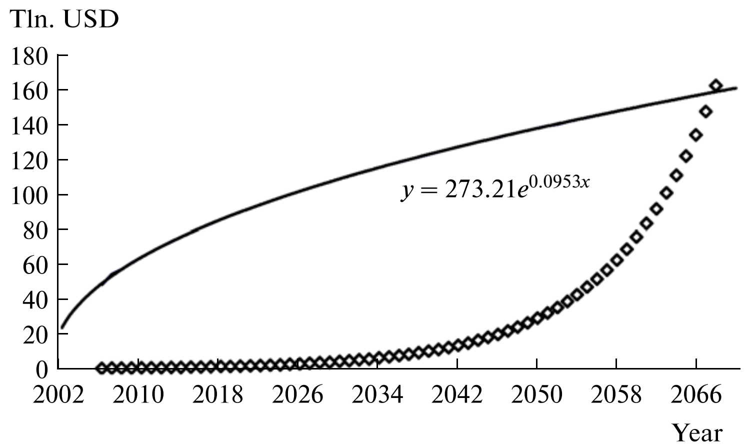

Fig. 8. Modeling hypothesis of uneconomical growth: – GWP; ◇ economical damage (ED).

expand the subject, and the method of studying the indicator of modern economic growth also changes.

The GDP index directly ~~changes~~ the result of economic activity; meanwhile, it is important to take account of the socioeconomic well-being, i.e., characteristics such as life expectancy, infant mortality, educational achievements, etc. Thus, the task of assessing the quality of economic growth becomes urgent. It can be solved to some extent by using a number of indices, such as the Human Development Index (HDI), the Genuine Progress Indicator (GPI) or the Index of Sustainable Economic Welfare (ISEW), and the Happy Planet Index (HPI). Thus, the American research organization Redefining Progress calculates the GPI index that estimates the growth in national welfare with allowance for the negative consequences of economic activity. It is estimated by decreasing the amount of GDP by the value of social and environmental costs.

Thus, sustained economic growth is possible if the paradigm of economic necessity is replaced by a new paradigm that motivates the economy to meet a higher level of needs. High rates of economic growth are not identical to the increase in its quality. They may be

Table 2. Production and consumption waste in Russia

Index	2002	2004	2006	2007	2008	2009	2010	2011	2012
Production and consumption waste, mln t.	**2038**	**2635**	**3519.4**	3899	3877	3505.0	3734.7	4303.3	5007.9
Share of used and neutralized production and consumption waste in the total waste, %	**60**	**43**	**40**	58	51	47	47	46	47

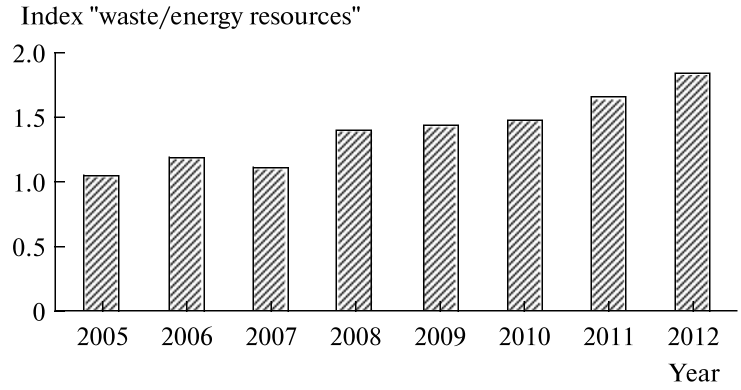

Fig. 9. Dynamics of index “waste/fuel-energy resources.”

accompanied by the strengthening of social inequality, the deepening of the global finance crisis, and growth in the negative human impact on the environment. In this situation, any theory of economic growth that ignores the valuable aspects of environmental, social, and human character may not be regarded as meeting the realities of today’s socioeconomic development.

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SPELL: 1. marginalist